Benefitting from Biodiversity-Based Innovation

Edwin Arvey Cristancho-Pinilla

Doctor of Philosophy

SPRU – Science and Technology Policy Research

University of Sussex

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I hereby declare that this thesis has not been and will not be, submitted in whole or in part to another University for the award of any other degree.

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UNIVERSITY OF SUSSEX

Edwin Arvey Cristancho-Pinilla

Doctor of Philosophy in Science and Technology Policy

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ABSTRACT

This thesis argues for the need for a more comprehensive discussion of biodiversity use in relation to enhancing benefits of this use for biodiverse countries and promoting more equitable sharing of these benefits. The findings from this doctoral research reveal that biodiversity-based innovation is a social shaping process that has resulted in large benefits. The cumulative capability to use species from biodiversity gives meanings that contribute to the species shaping process, with organisations and institutional changes providing direction and increasing the rate of the shaping process. In showing how innovation takes place and how the appropriation of benefits occurs, this research contributes to studies on science policy and innovation in relation, especially, to biodiversity-based innovation.

The thesis introduces the Convention of Biological Diversity (CBD) and the Nagoya Protocol as representing change to the governance of biodiversity. The theoretical approach draws on evolutionary and institutional economics, both of which inform and extend a question that is central in the sociology of technology: That is how are technology (innovation understood as an output) and social practices shaped collectively? Three cases are used to trace what occurs in the shaping process of species from biodiversity: (i) The Jersey cow is a breed within the species *Bos Taurus* or modern taurine cattle. The isolated character of Jersey delimited the scope of the breed at a point in time when it was being bred locally and allow us to identify its shaping as a 'technology', and the broader diffusion of its use. The Jersey cow is used to introduce the theoretical framework and the analysis. (ii) Maca, originally from Peru, is a root crop with nutritional and, allegedly, fertility enhancing properties. It was domesticated in Peru and only a few world regions have conditions favouring its production. Maca is commercialised as flour and used as a raw material. (iii) Quinua has great potential as a staple food crop. The Food and Agriculture Organization (FAO) declared 2013 to be the International Year of Quinoa on the basis of its unique and nutritious character. Three Andean countries (Bolivia, Ecuador and Peru) report exports of quinua grain, although dozens of countries around the world are engaged in performing agronomic testing for its commercial production. A comparative analysis of the three cases helps to identify the science and technology policy issues related to implementation of the CBD and the Nagoya Protocol. The case studies demonstrate the innovation process of species from biodiversity. Benefits arise from the diffusion of the use of the species (via commercialisation), which accrued to individuals or groups. The characterisation of the innovation process highlights how the voices and agency of actors and organisations affected the shaping process. The governance over the goods that emerged from the use of the species defined the appropriation of benefits.

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‘Just that,’ said the fox. ‘To me, you are still nothing more than a little boy who is just like a hundred thousand other little boys. And I have no need of you. And you, on your part, have no need of me. To you, I am nothing more than a fox like a hundred thousand other foxes. But if you tame me, then we shall need each other. To me, you will be unique in all the world. To you, I shall be unique in all the world . . .’

‘I am beginning to understand,’ said the little prince. ‘There is a flower . . . I think that she has tamed me . . .’

The little prince, by Antoine de Saint-Exupéry

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Acronym List

Acronym	Name
ABS	access and benefits sharing
ETC Group	Action Group on Erosion, Technology, and Concentration
SPS Agreement	Agreement on the Application of Sanitary and Phytosanitary Measures
TRIPS	Agreement on Trade-Related Aspects of Intellectual Property Rights
BADEA	Arab Bank for Economic Development in Africa
BCRP	Banco Central de Reserva del Perú / Central Reserve Bank of Peru
BI	Biodiversity International
IDRC	Canadian International Development Research Centre
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza / Tropical Agronomic Centre on Research and Training
CIAT	Centro Internacional de Agricultura Tropical / International Center for Tropical Agriculture
CIP	Centro Internacional de la Papa / International Potato Centre
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo / International Maize and Wheat Improvement Center
NSISI	Chinese National Standard Information Sharing Infrastucture
CNB	Comisión Nacional contra la Biopiratería / Peruvian National Comission again Biopiracy
CNA	competent national authority
CA	Comunidad Andina / Andean Community
CONPES	Consejo Nacional de Política Económica y Social / Colombian Council of the National Economic and Social Policy
CNT	Consejo Nacional Técnico / Peruvian National Technical Council
CGIAR	Consortium of International Agricultural Research Centers, formely Consultative Group for International Agricultural Research
CBD	Convention of Biological Diversity
DANIDA	Danish International Development Agency
DNA	deoxyribonucleic acid
DAD-IS	Domestic Animal Diversity Information System
ENAV	Escuela Nacional de Agricultura y Veterinaria / Peruvian National School of Agriculture and Veterinary
FAO	Food and Agriculture Organization
FOSS	Free/Open Source Software
PROINPA	Fundación para la Promoción e Investigación de Productos Andinos, Fundación PROINPA / Bolivian Foundation for the Promotion and Research of Andean Products, Proinpa Foundation
IBCE	Instituto Boliviano de Comercio Exterior / Bolivian Institute of External Trade

Acronym	Name
IBNORCA	Instituto Boliviano de Normalización y Calidad / Bolivian Institute of Normalisation and Quality
ICONTEC	Instituto Colombiano de Normas Técnicas y Certificación / Colombian Institute of Technical Standards and Certification
INIAP	Instituto Nacional Autónomo de Investigaciones Agropecuarias / Ecuadorian National Institute of Agro-Livestock Research
INDECOPI	Instituto Nacional de Defensa de la Competencia y de la Protección de la Propiedad Intelectual / Peruvian National Institute of Competence Defense and Protection of Intellectual Property
INEI	Instituto Nacional de Estadística e Informática / Peruvian National Institute of Statistics and Informatics
INIA	Instituto Nacional de Innovacion Agraria / Peruvian National Agricultural Innovation Institute
INIAF	Instituto Nacional de Innovación Agropecuaria y Forestal / Bolivian National Agricultural, Livestock and Forestry Institute
IICA	Inter-American Institute for Cooperation on Agriculture / Instituto Inter-Americano de Cooperación para la Agricultura (formely Instituto Inter-Americano de Ciencias Agrícolas)
IAASC	International Association for the Study of the Commons
IBPGR	International Board for Plant Genetic Resources (today Biodiversity International)
ICBA	International Center for Biosaline Agriculture
ICN	International Code of Nomenclature for algae, fungi, and plants
ICNCP	International Code of Nomenclature for Cultivated Plants
ICZN	International Code of Zoological Nomenclature
ILO	International Labour Office
IPPC	International Plant Protection Convention
ISF	International Seed Federation
ISTA	International Seed Testing Association
IYQ	International Year of Quinoa
IsDB	Islamic Development Bank
LMOs	living modified organisms
m.a.s.l.	metres above sea leavel
mm	millimetres
MINAG	Ministerio de Agricultura y Riego / Peruvian Ministry of Agriculture
MAT	mutually agreed terms
NASA	National Aeronautics and Space Administration
NBER	National Bureau of Economic Research
NGO	non-governmental organisation
NSI	National System of Innovation
NTP	Norma Técnica Peruana / Peruvian Technical Norm
OSSI	Open Source Seed Initiative
OECD	Organisation for Economic Co-operation and Development
OAS	Organization of American States

Acronym	Name
PBR	plant breeder's rights
PGRFA	plant genetic resources for food and agriculture
PIC	prior informed consent
R&D	research and development
RJA&HS	Royal Jersey Agricultural & Horticultural Society
INEN	Servicio Nacional de Normalizacion / Ecuadorian National Service of Normalisation
SENASA	Servicio Nacional de Sanidad Agraria / Peruvian National Service of Agrarian Health
SCOT	social construction of technology
SDC	Swiss Agency for Development and Cooperation
UPOV	Union Internationale pour la Protection des Obtentions Végétales / International Union for the Protection of New Varieties of Plants
USSR	Union of Soviet Socialist Republics
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme
FIDA	United Nations International Fund for Agricultural Development
USAID	United States Agency for International Development
NRC	United States National Research Council
USA	United States of America
USPTO	United States Patent and Trademark Office
UNALM	Universidad Nacional Agraria La Molina / National Agrarian University - La Molina
WB	World Bank
WHO	World Health Organization
WIPO	World Intellectual Property Organization
WTO	World Trade Organization

1 Introduction: Evidence for biodiversity-based innovation

This thesis provides evidence, a background and a theoretical approach to contribute to the formulation of policies[1] related to the exploitation (or in general 'use') of biodiversity[2] from biodiverse developing countries (see Ch. 5 Section 5.1). It proposes a framework of analysis for examine the biodiversity-based innovation process (see Ch. 4 Section 4.1), applied to selected food sector case studies. The thesis reflects discussions accompanying the implementation of an international agreement on the use of biodiversity - the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity (hereafter, the Nagoya Protocol). These discussions centred around the motivations, logic and concepts encompassed by this change in the institutional arrangement governing the exchange of plants and animals, and how the protocol's principal aim of biodiverse countries gaining greater benefit from their resources, might be achieved. This opening chapter concludes by formulating the research questions (examined in chapter 3 and rearticulated in chapter 4) guiding the empirical examination of the case studies.

1.1 Need for evidence-based policy-making

The 12 October 2014 saw the coming into force of the Nagoya Protocol, an international agreement aimed at enabling providers and users to share the benefits arising from fair and equitable utilisation of genetic resources (CBD, 2011 art. 5). This

[1] Evidence-based policy-making is a legitimate approach informed by 'scientific facts' or at least more reliable knowledge about 'what works', which moves away from developing policies based fundamentally on political ideologies (see Sanderson, 2002; Behague *et al.*, 2009).

[2] This thesis maintains what stated by the Convention of Biological Diversity (CBD), for the term '"Biological diversity" (which) means the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems'. The term '"Biological resources" includes genetic resources, organisms or parts thereof, populations, or any other biotic component of ecosystems with actual or potential use or value for humanity' (Article 2) (CBD, 1992). Thus, the use of biodiversity includes the use of resources (e.g., species, varieties or breeds) from such biodiversity, and its commercial exploitation.

agreement, which so far has been signed by 94 countries,[3] formalises the trend towards less 'free and open access' to biodiversity among countries, by 'reaffirming the sovereign rights of States over their natural resources' (Preamble). It is claimed that the Nagoya Protocol 'will create greater legal certainty and transparency for both providers and users of genetic resources by [establishing] more predictable conditions for access' to the resources offered by biodiversity (CBD, 2017a). The protocol sets out the governing principles for developing the third objective[4] of the 1992 United Nations Conference on Environment and Development (UNCED)[5] Convention of Biological Diversity (CBD). So far, 196 countries around the world are parties to the CBD (CBD, 2017b).

According to some scholars, the CBD provides a 'flexible framework for accommodating developed and developing countries' concerns and capacities' (McGraw, 2002 table 2; Morgera and Tsioumani, 2011 p. 3). This is important because, prior to the 1950s, the resources from biodiversity, in many cases, were managed as public goods based on the concept of an endless 'common heritage of mankind' (FAO, 1983; Baslar, 1998). However, the claim that developing countries should have sovereignty over such resources coexists with the fact that the technology 'to utilise and tap the potential of these resources' belongs largely to the developed countries (Stellina, 2015). Claims relating to 'common heritage' imply 'common ownership', which is 'opposite [to the] principles of international law governing access to or control or dominion over assets or properties, particularly natural resources which fall within the jurisdiction of a recognized state'. Thus, states have sovereign control over their own biodiversity (Mgbeoji, 2003 p. 826).[6] In this understanding of sovereignty over biodiversity, under the CBD countries

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[3] A country becomes party to the Nagoya Protocol through ratification, accession, acceptance, approval or succession. Portugal and Qatar fulfilled these conditions and become parties to the protocol on 10th July 2017 and 25th April 2017 respectively, becoming the 95th and 96th parties to the protocol (see CBD, 2017c).

[4] The CBD objectives (Article 1) to be considered 'in accordance with its relevant provisions are (1) the conservation of biological diversity, (2) the sustainable use of its components and (3) the fair and equitable sharing of the benefits arising out of the utilization of genetic resources, including by appropriate access to genetic resources and by an appropriate transfer of relevant technologies, taking into account all rights over those resources and to technologies, and by appropriate funding' (CBD, 1992).

[5] Also referred to as the Rio 'Earth Summit'.

[6] 'Common heritage has only attained juridical mention within the ambit of claims of communal rights on areas or resources which lie outside the limits of state jurisdictional authority: A sort of *res communis humanitatis*. In other words, it is a term and concept applied to the so-called global commons. These include the ocean floor, outer space, the Moon and Antarctica' (Mgbeoji, 2003 p. 826).

agreed to exchange particular resources under conditions such as mutually agreed terms (MAT) between providers and users (CBD, 1992 art. 15-4) (see Annex section A.5).

Historically, cooperation and exchange have created an unequal distribution of the benefits appropriated from use of biodiversity; for some scholars, this suggests unfairness.[7] This situation has been studied by several authors,[8] including Jack Kloppenburg. Kloppenburg (1988) explains that biodiversity resources flow easily out of the periphery (as he refers to developing countries), contributing to the economy of developed countries, and being dispossessed (seized) at little cost and with no direct remuneration to developing countries.

Fairness depends on the actor's perspective and it is not the purpose of this thesis to explore actor's perspectives on this issue. Instead, this thesis focusses on standards of fairness with a forward-looking CBD approach in order to contribute to future studies and policies. According to Kloppenburg's argument, the seed industry in developed countries has reached out to global markets, selling 'new plant varieties', which incorporate some of the genetic resources from the biodiversity originating from developing countries. As a result of this process of innovation, 'new plant varieties' are no longer free goods, but have become commodities (Kloppenburg, 2004 p. 15). Kloppenburg's 'expropriation' type argument is problematic from a developed country perspective for two reasons: First, in an exchange relationship, fairness needs to consider the investment in other means of production (e.g., capital or accumulated knowledge) (Ten Kate and Laird, 2000 p. 263) and the contributions made to biodiversity-derived resources by agro-industrial methods in inputs (e.g., designer seed to create 'new plant varieties') and outputs (e.g.,

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[7] A detailed explanation of the understanding of fairness and justice regarding the CBD is given by De Jonge. (2011). Also, Martin *et al.* (2013 p. 126) consider the Nagoya Protocol as providing a framework that balances 'the access to genetic resources […] with the fair and equitable sharing of benefits', and that "seeks to limit potential distributional injustice arising from the disproportionate flows of benefits from genetic resources from South to North".

[8] Lightbourne (2013) recalls that 'in the 1970s, the balance of benefits deriving from the so-called 'Columbian Exchange' was the subject of acrimonious debates'. Fowler refers to the 'Columbian Exchange' as the 'flow of crops between newly discovered territories in America […] and colonies in Africa and Asia, and to the constitution of germplasm collections by colonial powers'. In discussing that exchange, he asks, 'have […] the "grain rich" countries benefited disproportionately from the acquisition of genetic resources from the "gene rich" countries?' (Cited in Lightbourne, 2013 p. 7). In the 1990s, the 'Report of the Ad hoc Working Group on the Work of its Second Session in Preparation for a Legal Instrument on Biological Diversity of the Planet' held in Geneva, 19-23 February 1990, gives an interesting revision of the main issues regarding the differences and perspectives of developed and developing countries about the conservation of biological diversity (see UNEP, 1990).

processing or purification) (Ten Kate and Laird, 2005 p. 23). Second, fairness implies a search for distributive justice based on historical accountability, liability, [9] or compensation[10] which could be unrealisable and might be an impediment to forward-looking arrangements.[11] This thesis does not analyse fairness in the distribution of benefits, but provides an understanding of the institutional arrangements surrounding cooperation and exchange and explaining unequal distribution which prevails today. Its conclusions will relate to how the principal aim of the CBD and the protocol that biodiverse countries should obtain greater benefit from their resources, might be achieved in the future. Therefore, the scope of the discussion will be limited on how "fairness" can be achieved by having more equal benefits for biodiverse countries versus non-biodiverse countries.

The implementation of the CBD is based on mechanisms put in place by each country (i.e., party). For example, the Andean countries (i.e., Bolivia, Colombia, Ecuador, Peru),[12] which are rich in biodiversity, share some of their ecosystems and, therefore, their biological resources, under the Common Regime on Access to Genetic Resources agreement,[13] known also as Decision 391 of the Andean Community of 1996: This was pioneering regulation for the implementation of the CBD. Access to genetic resources in the territories of any of the parties should adhere to the following conditions:

(i) the designation of a competent national authority (CNA) to represent each state;
(ii) rules and procedures to implement prior informed consent (PIC) and MAT between the providers and users of the resources from biodiversity in the form of an access contract; and
(iii) a link between access and benefits sharing (ABS) (CA, 1996 Ch. III).

[9] Several regional (European Union scope) and international negotiations and agreements have centred on liability and redress in relation to environmental issues, but few are in force. Shibata (2014) presents a review of these negotiations and how The Nagoya-Kuala Lumpur Supplementary Protocol on Liability and Redress to the Cartagena Protocol on Biosafety constitutes a new attempt in this direction (see Shibata, 2014).

[10] Dedeurwaerdere (2005) suggests that it is possible to go further of the traditional property regimes. He proposes 'use (of resources) is authorised without any permit from the rights holders, without however conferring free usage — (but) *ex post* compensation is still required' (Dedeurwaerdere, 2005 p. 487).

[11] E.g., an agro-industrial company from a relatively non-biodiverse region is unlikely to invest in a biodiverse region if this might result in a claim on this company's profits or assets. This might result from the assertion of historical accountability or liability in the biodiverse region's sovereign territory.

[12] Chile (between 1969 and 1976) and Venezuela (between 1973 and 2011) were parties of the Andean Community (CA for its Spanish name *Comunidad Andina*) (see CA, 2010).

[13] The relationship between biodiversity and the objective of Decision 391 around the concept of genetic resources, is explained by the objectives of the CBD and the terms used. See fn. 4.

The conditions, which are derived from the CBD, provide a framework for deliberation and action by bioprospectors operating both currently and in the future. Bioprospecting, the use of biodiversity and 'traditional knowledge', leads to the development of commercially exploitable new products (innovations); this is often, but not exclusively the aim of the pharmaceutical and seed industries (Macilwain, 1998). This framework tries to balance conservation and sustainable use of biodiversity (Morgera and Tsioumani, 2011). Before the CBD, conservation was of interest to those involved in intense use (and possible destruction) of the resources from biodiversity, but there were no institutional arrangements governing the outcome of that use (e.g., preventing loss of biodiversity or reparation).[14] The benefits arising from the use of biodiversity might provide benefits that are positive for conservation. Thus, if a bioprospector successfully commercialises a new product in adherence to the CBD-Nagoya protocol framework, some benefits should be redirected to biodiversity conservation (Buck and Hamilton, 2011), which would increase the chances of sustainable future use of biodiversity.

On the implementation of the CBD and, particularly, Decision 391, Ruiz Muller highlighted the lack of evidence and how it affected the intent to use biodiversity.

> During the development of Decision 391, limited hard data and information were available on global genetic resources and products derived from them, their trade flows and the nature of their markets. Experts had to contend with a lack of verifiable information on the origins, sources, uses, and nature of genetic resources.
>
> This resulted in overestimation of the potential benefits from [future] bioprospecting, which became a key driving force for conservation and sustainable use of biodiversity in the region, and a source of potential monetary benefits for countries. (Ruiz Muller, 2004 p. 243)

Following a critical analysis, Ruiz concluded that Decision 391 'offers limited possibilities for partnerships and cooperative efforts. The problem is not so much that a regional access framework exists, but how this regime is structured and designed' (Ruiz Muller, 2004 p. 257). According to the Colombian Government (CONPES and Colombia,

[14] Biodiversity has often been greater than that part of which is taken up and standardised for commercial purposes. Commercial standardisation may create a risk if, for example, in the case of plants, the commercial 'new' varieties displace native varieties and lead to their extinction. This can be quite insidious since cross-pollination between extensively grown 'standardised' crops and 'native' species may contribute to the extinction process. Until now, 'native' biodiversity has been preserved in ways such as the provision of 'natural reserves' (i.e., National Parks) and the prohibition of certain types of cultivation or activities in these preserved areas.

2011 p. 14), the potential for using biodiversity is hampered by regulations, including Decision 391, since the implementation of norms results in high transaction costs and uncertainty for private investors engaged in biodiversity-based innovation.

Implementation of the CBD varies. There are some successful cases of access to previously unexploited resources from biodiversity and the commercialisation of derivative new products. For example, biotechnology-based enzymes and microorganisms, plant oils for plastics formations and coatings, hybrids from scientific breeding, and plant extracts. Some companies have reduced or halted research and development (R&D) activities using resources from biodiversity (e.g., from the biotech industry) given the negative perceptions of the CBD (Laird *et al.*, 2008 pp. 13-14).

In the context of the Nagoya Protocol, a study by Kamau *et al.* (2010), recognises that 'there is no specified obligation of user states to ensure benefit sharing. As before (with the CBD), the enforcement of benefit-sharing duties is left to contractual means, with all the difficulties of forum, litigation costs, and prosecution of titles' (Kamau *et al.*, 2010).[15] This is disappointing from the perspective of the provider of genetic resources, which generally have lower capabilities (i.e., actors from developing countries) compared to users (i.e., actors from developed countries) (Kamau and Winter, 2013). Also, it is difficult to implement, since contracts can be agreed between actors governed by different legislation and, therefore, different rationales about 'how damages are determined for violations of material and immaterial property', in the case of the resources from biodiversity (Godt, 2009 p. 419).[16]

Although the above discussion provides an important motivation and background to this thesis, the aim of this doctoral research is to examine the processes involved in

[15] Mongera *et al.* (2014) give a detailed revision of the protocol and identifies the development provided by article 6 on 'the rights and obligations of parties in regulating access to genetic resources, aiming to address the enforcement challenges resulting from the transnational component of the ABS transactions' (Morgera *et al.*, 2014 p. 137). However, as Kamau *et al.* (2010) indicate, it is not accompanied by similar precision in terms of benefit-sharing. This results in difficulties related to the enforcement of benefit sharing, especially if this enforcement involves different jurisdictions (Kamau *et al.*, 2010 p. 257).

[16] Godt (2009) evaluates how enforcement of benefit-sharing takes place in the context of 'benefits [that] are generated in industrialized countries (so-called user states) on the basis of genetic resources or traditional knowledge accessed in other countries (commonly called "provider states")'. She disagrees with the decision implicit in the CBD that benefit sharing concerns the provider state rather than both providers and users and, for that reason, she evaluates enforcement in user states (Godt, 2009).

the broader use (diffusion) and commercialisation[17] of certain crops and livestock which are taken as cases to investigate the processes of innovation from biodiversity. A better understanding of these processes would provide evidence and be informative for the policy-makers. The present situation is one of gridlock and impediments to the skills that might be learned and the routines that might be controlled, replicated or imitated (Nelson and Winter, 1982) in the context of use for crops and livestock. This is because the protocol generates uncertainty and the potential for extensive liability for those who would seek to use the resources from biodiversity.

The Nagoya Protocol underlines that biodiversity is no (longer)[18] understood as *a* 'common-pool resource'. In Ostrom's (1990 p. 30) view, this kind of good can be used by everyone,[19] while the protocol considers biodiversity as subject to the sovereign control of the country of origin, similar to the case of non-renewable resources (i.e., gold, silver, oil). However, in contrast to non-renewable resources, a *technological attribute* of the resources from biodiversity is that they are reproducible from the transfer of small amounts of seed or small numbers of living specimens. This transfer could have been occurring over a long period prior to the Nagoya Protocol and, following this transfer, improvements to (or more generally shaping of (Bijker and Law, 1992 p. 3)) these resources in the processes towards commercialisation (or 'diffusion of use' more generally) may have occurred, which further complicate the questions of ownership and sovereign control. For thousands of years, the principal source of benefits from biodiversity were cultivation/husbandry of biological resources, where open access to resources capable of reproduction (i.e., seeds, livestock) was customary (at least under certain circumstances or among members of the same communities). However, in the most recent decades, new techniques and forms of appropriation of benefits have been

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[17] Commercialisation is a relatively new practice compared to the diffusion of use of biodiversity. Commercialisation can increase the rate of diffusion of biodiversity use. This thesis emphasises commercialisation, despite both practices allowing appropriation of benefits.

[18] Mgbeoji (2003) considers that plant genetic resources 'have always been subject to various national jurisdictions', rather than being subject to the 'common heritage of mankind' principle (Mgbeoji, 2003).

[19] Ostrom (1990) recognises that systems of biodiversity can be sufficiently extensive that it becomes costly (but not impossible) to exclude users their use. These systems are the stocks that can produce flows without harming the original stocks (Ostrom, 1990 p. 30). Although in the past biodiversity was considered an endless resource, appropriate for use by everyone (and, therefore, a public good), resources from biodiversity now are treated as 'common-pool resource' which some actors are able to exploit and to reduce their stock to harmful levels.

developed (Section 1.4 and Annex A). A clearer understanding of the process involved towards the commercialisation of new products (or diffusion of the use of resources from biodiversity), might provide a more workable set of institutional arrangements and might also encourage greater benefit for biodiverse countries and, therefore, more equitable sharing of the benefits from use of biodiversity.

It is assumed in this thesis that the use of biodiversity includes innovation activities that support the introduction of new products (goods or services) to the market (i.e., to be commercialised or whose use is diffused). In this thesis, 'commercialisation' is taken to be commercialisation in the international market and, also confirms the introduction of a new product from biodiversity. Based on this assumption, the thesis provides background and evidence suggesting how policies related to the use of biodiversity might be formulated in biodiverse developing countries. It proposes a framework for analysing the biodiversity-based innovation process, derived from the theory, which reflects the experience of the cases examined. The framework is developed in relation to a historical case study of the Jersey cow and, then, is applied to the cases of two South American plant species. All the three case studies involve innovation activities from where public and private goods and services [20] emerge. The characteristics of these goods are determined partly by their nature and partly by the respective institutional arrangements (Hess and Ostrom, 2007 p. 43), such as property rules in relation to right of access to land hosting the resources from biodiversity. The three case studies provide a visualisation of different social practices and institutional arrangements related to biodiversity-based innovation, and how they define the forms of governance linked to the goods emerging from the use of biodiversity. Depending on the ownership and consumption conditions of these goods (i.e., public or private),[21] benefits[22] can accrue to individuals or to groups, or both (see Section 1.2).

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[20] Here we use the term goods to refer to both goods and services.

[21] Goods can be categorised as (i) private, (ii) common-pool resources, (iii) toll or club goods and (iv) public goods. Different forms of governance relate to each of the categories. See Section 1.4.

[22] In this thesis, benefits include income and any other social welfare enhancers. Income includes the components of 'labour (wages, salaries, bonuses, earnings from nonwage labour, and other remuneration statutorily classified as labour related) and those from capital (rent, dividends, interest, profit, capital gains, royalties, and other income derived from the mere fact of owning capital in the form of land, real estate, financial instruments, industrial equipment, etc, again regardless of its precise legal classification)' (Piketty, 2014 p. 18).

The extent to which policy can promote greater benefits for biodiverse countries and more equitable sharing (compared to present practice) of the benefits from biodiversity-based innovation, is informed by the following research questions:

- How are new products from biodiversity (i.e., *naturally* occurring resources from biodiversity) commercialised?
- What forms of governance over public and private goods and services are implicated in the appropriation of the benefits from the use of biodiversity?

1.2 Motivation (I) Policy-making, individual decision and collective choice

The research questions are motivated by an interest in promoting policies that would increase the chances for developing countries such as Colombia, Peru and Bolivia which have high levels of biodiversity, to commercialise biodiversity-based innovations and receive greater economic benefit. This benefit would ensure the welfare of these countries' populations, large proportion of which experience poverty [23] and suffer malnutrition. [24] Commentators acknowledge that social welfare involves not only the aggregate amount of the benefits produced, but also issues related to equity in collective choices. [25]This makes it necessary to find alternative policy approaches that consider growth, the distribution of benefits and innovation (Ely *et al.*, 2010).

Traditional approaches to policy include, among other things, the enlargement of total output via monetary policy (Friedman, [1968] 1995), investment promotion (Borensztein *et al.*, 1998), productivity improvements (Solow, 1956) and discovery and exploitation of new products (Romer and NBER, 1989). In those approaches, the benefits to society come from the role of markets in reducing the relative prices of goods, or from

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[23] The poverty, undernourishment and underweight statistics differ in terms of their scope and the measures used, but, nevertheless, are very similar. In all cases, there is a clear difference between developed and developing countries. The figures in this thesis depend on data availability, we use the most appropriate figures to support our arguments.

[24] In 2015, 14.7 m. people (1.8% of the population) in the developed regions are undernourished; in developing regions this figure is 779.9 m. or 12.9% of their population. In Africa, 20% of the population is undernourished, in Oceania the figure is 14.2%, in Asia 12.1% and in Latin America and the Caribbean it is 5.5% (see FAO, 2015b p. 8). In the Latin American countries of Colombia, Peru and Ecuador some 8% to 11% of the population are undernourished and Bolivia the figure is 16% (see FAO, 2015b).

[25] This thesis considers collective choice to be a bargaining solution based on the actors' bargaining power. This is preferred to a criterion for efficiency of social action. We recognise that actors differ in their human skills, capital and access to the resources provided by biodiversity (see Sen, 1970).

the knowledge spillovers associated to the quasi-public character of knowledge. There can be non-market means of distribution: A pot of money can be accumulated from taxation and redistributed to try to increase social welfare (Diamond and Mirrlees, 1971),[26] however, this risks non-efficient use of resources compared to their being managed by the private sector (Samuelson, 1954). Ownership can be collectivised in an attempt to reset the actors' endowments, but this overlooks the diversity of skills, the incentives offered to increase productivity and the coordination costs (Kung, 2000; Brandt *et al.*, 2002). Alternatively, the appropriation of the benefits from rather than the ownership of a good could be considered.

Actors (including some in developing countries) favour private goods because these offer the possibility of income generation if appropriability is extended. Also, actors seeking to benefit from the 'biotechnology revolution', who might view biodiversity as a potential input to pharmaceuticals and other new biological products including new foodstuffs, favour private goods. Privatisation of goods (including knowledge) is the trend espoused by the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) (see Section 1.4 and Annex A). The problems related to collective action and social dilemmas such as the Prisoner's Dilemma, free riding, poaching, polluting, and non-cooperation, which are discussed in the traditional commons literature (Hess and Ostrom, 2006 p. 337), explain the frequent disregard of the governances of public goods. However, examples such as the Free/Open Source Software (FOSS) movement, the Open Archives Initiative, the Digital Resources of the Commons and the Open Source Seed Initiative (OSSI),[27] offer alternative approaches (forms) to collective governance of the *commons* (i.e., goods, resources or resource systems that are shared or held in common).

In addition to private goods, there are three other forms of governance that affect the appropriation of benefits in the context of resources with 'commons' attributes (e.g., those arising from reproducibility, such as biodiversity). The first form of governance refers to common-pool resources, which are resources that are exploited in common and

[26] The tax distribution is based on the bargaining power of the actors involved in the policy-making process and not necessarily to optimise the social welfare.
[27] Lagoze and Sompel (2001); Bonaccorsi and Rossi (2003); See Lakhani and von Hippel (2003); and IU (2009 (2016)); Kloppenburg (2010; 2014); IAASC (2016).

which can be (or not) subtractable (e.g., fisheries).[28] Common-pool resources are a general category whose governance can involve different practices, including limiting the actors and their scope of action (i.e., excludability) or any other arrangement that preserves the use of the resource for future exploitation (i.e., subtractability). The second form of governance refers to club goods. This is a special case of common-pool resource, used to describe a resource that is collectively created or maintained, involving limits on the number and scope of action of those exploiting the resource. The third form is public goods, which refers to 'commons' resources that, in particular, are difficult to subtract, and which have no restriction on entry, actors or their actions (Hess and Ostrom, 2006 p. 337). Privatisation is the fourth governance form. Each of these four governance forms is suited to appropriation of the private and collective benefits arising from biodiversity-based innovation.

Governments in biodiverse countries may promote policies to increase the number and commercialisation of new products with the expectation of increasing wealth. However, the risk is that the unequal distribution of benefits, which, so far seems typical, will be sustained, further increasing the gap between poor and rich. The problem of inequality affects stability, economic efficiency and sustainability in the long term (Stiglitz, 2012; Davtyan, 2014). The divergences (increases and expansion) related to inequality are explained by (i) the contextual character of knowledge (costs related to diffusion of knowledge) and (ii) the appropriation and concentration of wealth in periods of low growth and high capital returns.[29] Convergence (reduction and compression) of

[28] Common-pool resources often involve joint use of a 'commons' on land or at sea, allowing many potential actors to exploit resources by removing some part of the resource for consumption. E.g., in uncultivated land where exclusion of entry is infeasible or not pursued, actors may enter to remove resources (e.g., forests) for consumption.

[29] Piketty (2014) explains the relationship between the accumulation (or appropriation) of wealth and the concentration of wealth. Appropriation in this thesis, refers to the flow of benefits (such as income) in a period, which adds to an individual's or a country's wealth (stock). Piketty suggests that the divergence in inequality is caused by periods of low growth when those with high accumulations of wealth can obtain higher returns from that wealth, since the relative share of returns on capital tend to be higher (i.e., 'top managers by and large have the power to set their own remunerations, in some cases without limit and in many cases without any clear relation to their individual productivity' (Piketty, 2014 p. 24). In periods of high growth, the factors that contribute to inequality include the fact that those with accumulated wealth show higher rates of saving, that unpredictable and arbitrary returns on capital can jeopardise knowledge creation, and that the high prices of real estate and petroleum remunerate specific actors. The opportunities for less developed economies to leap forward in productivity and to increase their national incomes are restricted by 'the process of accumulation and concentration of wealth when growth is weak and the return on capital is high' (Piketty, 2014 pp. 39-50).

inequality should be enabled by the diffusion of knowledge and investment in training and skills. Although this would allow emergent economies to catch up with the advanced economies by adopting appropriate modes of production and acquiring skills, the appropriation and concentration of wealth' (i.e., divergent forces) are strong (i.e., difficult to change its direction) and differentiated. This differentiation occurs at different levels, including country (e.g., Central European countries vs Andean countries) and sector (e.g., food sector vs pharmaceuticals sector). This thesis considers the knowledge underlying exploitation of biodiversity for innovation, relevant to convergence of inequality and the appropriation within sectors (see Section 1.3).

Biodiversity-based innovation is regarded as a process of variation and selection (Nelson and Winter, 1982 p. 43) in the use of specific species from biodiversity. Two hypothetical cases can be used to explain the concepts and logic underlying the innovation process. In the first case, users of the resources from biodiversity have skills and underlying knowledge (Nelson and Winter, 1982 p. 73). Actors' decisions about the use of biodiversity to obtain certain goods are made at the micro level, based on each actor satisfying his or her individual needs. These decisions result in a set of different uses of biodiversity (i.e., variation). A lack of institutional arrangements restricts cooperation such that each individual actor is concerned only with his/her own needs. This result is that the uses of biodiversity are not diffused and, in the extreme case, this individual exploitation can lead to deterioration of the resource to the point of extinction.[30]

In the second case, which involves an institutional arrangement, cooperation among actors is enabled (Nelson and Winter, 1982 p. 98). The actors address their individual needs while simultaneously pursuing an agreed (collective) goal. The actors might specialise in a specific skill and a subset of the actors might take responsibility for the collective effort in order to maintain the resource. In this case, the actors shape the use of biodiversity (i.e., variation) and take account of the voices (Hirschman, 1970) and agency of other actors (i.e., specialised socially constructed skills and underlying

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[30] Hirschman (1970) departs from the economic perspective of optimal performance, and proposes that *slack performance* is more common in economics and politics (see Hirschman, 1970 pp. 5-15). In the long term, users' slack performance of the technology leads to its deterioration and disappearance. Similarly, Nelson and Winter (1982) consider that the firm does not have a single goal, but rather many goals driven by 'large-scale motivational forces', to which the firms response is 'slugging, halting, and sometimes inconsistent' (Nelson and Winter, 1982 p. 58).

knowledge) (Barker, 2000 p. 236). Since actors search for improved uses to better utilise resources, those uses of biodiversity suitable to address individual needs and organisational goals will be valued and diffused (i.e., selection). We analyse the appropriation of the benefits in this second case, where the actors cooperate in an institutional context.

Actors' decisions determine the appropriation of benefits in at least two ways. First, actors through their cooperation, they make themselves heard (see Ch.4 Sub-section 4.1.2) and also exert power by controlling the means under control such as the capital and labour used in production (see Section 1.4).[31] Each actor benefits' according to his or her relative bargaining power (Dow, 1993) over the other actors, through substituting or complementary means.[32] Second, each actor exerts relative bargaining power when countries (states) define their formal institutions governing (i.e., policies) commercialisation or ownership (or access to or control over) (North, 1990 p. 16). The enforcement of these laws nationally (and internationally) influences or determines the appropriation of benefits (i.e., the rate and direction of commercialisation) from an innovation. In both cases, the actors' decision determines collective choices and outcomes.

Based on a better understanding of both the innovation process and the appropriation of benefits and their relationship to institutional arrangements, it is possible 'to find opportunities to influence the technological change and its […]

[31] This thesis uses the concept of *capital* as not including human capital (or labour). 'Capital is defined as the sum total of nonhuman assets that can be owned and exchanged on some market. Capital includes all forms of real property (including residential real estate) as well as financial and professional capital (plants, infrastructure, machinery, patents, and so on)' (Piketty, 2014 pp. 46-7). The concept of capital does not include biodiversity. Piketty suggest that, the boundaries to capital have 'evolved considerably over time'. In the case of biodiversity, institutional change derives from the CBD and the Nagoya Protocol. Discussion of the boundaries to (legal aspect of) ownership of biodiversity is beyond the scope of this thesis. Regarding the qualification of labour, the idea is based on the observation that it is possible to improve the productive capacities of an individual in a variety of ways (e.g., via experience and education). An individual with no experience or education has very little human capital and his or her productive capacity is limited. Augmenting the 'quality' of human labour with investment in human capital allows improvements to productive capacity.

[32] In the dichotomy between substitute and complementary inputs, substitute refer to inputs that are not necessary to increase if other inputs are increased. Complementary means must be increased when other inputs are increased. E.g., if one is using nuts and bolts to assemble something, the use of more bolts requires more nuts. Bargaining power is reduced among actors with substitute means. Actor with complementary means can bargain over the benefits that each receives. This thesis considers the complementary means required to use biodiversity and the bargaining the among actors that control, access or own such complementary means.

consequences', at an early stage, when 'accountability and control could be exercised' (Williams and Edge, 1996 p. 868),[33] and to consider the relative bargaining power of the actors in policy making and enforcement. In the theoretical approach proposed in this thesis (see Ch. 2), the appropriation of benefits is assumed to be the result of technological change and the institutional arrangements related to biodiversity-based innovation.

1.3 Motivation (II) Food and benefits arising from biodiversity

This section provides the context to the main forces explaining the inequality in the food sector considered in the CBD and the Nagoya Protocol. It outlined the motivations for and the research method required to study this sector.

The research presented in this thesis aims at understanding of how some units of biodiversity (i.e., animal or plant species) become innovations and what it is that affects the distribution of their benefits. It provides evidence that will inform stakeholders and foster democratic debate among the users of biodiversity about the type of policies that are needed. Although the provision of evidence is not sufficient to determine action, it is informative for policy makers who lack a comprehensive understanding of those actions and how they occur. Historical evidence can inform the extent to which achievement of the CBD's and the Nagoya protocol's principal aims of greater benefit for biodiverse countries and equitable sharing of the benefits from biodiversity-based innovation is possible or not. Given the need of scope 'to contribute to the choices that policy-makers and practitioners make' (Boaz *et al.*, 2008 p. 247), this doctoral research examines innovation in the food sector because of its significance for social welfare.

The benefits from biodiversity derive from the human consumption of goods such as clean air, fresh water, medicines, and food, among others (Sukhdev *et al.*, 2010 p. 7). Food, currently, is produced mainly by farmers (although some is gathered by individuals). This is part of a well-established process. Over the last 10,000 years, communities seem

[33] Williams and Edge (1996) provide a critique of innovation that is not explained by an inner technical logic (i.e., technological determinism). They acknowledge the social factors shaping the path of the technology. Despite the complex socio-economic processes involved in the innovation process, Williams and Edge suggest that the examination of shaping identifies opportunities that enable it (see Williams and Edge, 1996 pp. 866-8).

to have operated fairly open exchange of animals and seeds. Instead of being self-sufficient in relation to the biodiversity used for food and agriculture, countries have become highly interdependent with respect to the most important crops (Esquinas Alcázar, 2004 pp. 1-2; Kloppenburg, 2004 pp. 175-184). This long history of exchange of seeds has involved '[a] process of domestication of plants and animals, and the spread of agriculture were slow enough to allow a new equilibrium to emerge. […] Genetic diversity was maintained, and even increased during this long period; the heterogeneous varieties developed by farmers in each location became well-adapted to varying local conditions' (Esquinas-Alcázar, 2005 p. 497).

In the most recent centuries, the character of the open exchange of plants and animals spanning thousands of years has changed. Biodiversity plant, animal and microbial samples have been collected and some of their uses and underlying knowledge has been codified in pre-existing written languages.[34] These collections (and codified knowledge) were held first in colonial occupied territories and then were transferred from developing countries with rich biodiverse environments, to serve as seed for cultivation or breeding livestock for animal husbandry and as research inputs. Technological change and different institutional arrangements have allowed groups of users to access these collections (Godt, 2013), and the discoveries and inventions derived from their embedded knowledge. In some cases, they have enabled access to the economic benefits resulting from the commercialisation of biodiversity-based innovation. Certain countries have derived benefits from the generation of surplus and the commercialisation of biodiversity-based innovations: These countries have recognised the 'value' in the possession of biodiversity and the underlying knowledge (see Section 1.4).

Convergence of inequality might be expected because knowledge is quasi-public in character (which applies also to biodiversity related knowledge). Thus, it can be spread and exchanged via mobility of people, open source forms of knowledge dissemination,

[34] Cowan *et al*. (2000) explain the costs related to the codification of knowledge. These costs initially are very high, when the basic codebook is being created (involving the development of models and 'vocabulary with which to express those models' (Cowan *et al.*, 2000 p. 225)) and before it is sufficiently large and established to stabilise a language and impose the standardised use. Then costs of codification become lower. New documents introduce new concepts, notation and terminology. Adopting a particular language for these documents implies the adoption of particular models and a certain vocabulary.

investment, imitation, reverse engineering, licensing and technology transfer (Dosi and Stiglitz, 2014). However, convergence of inequality is limited by the degree of excludability from use of the knowledge.[35] For example, it is not difficult to exclude others from using (and reaping the benefits of) knowledge if complementary means are required to obtain the full benefits from the commercialisation of biodiversity-based innovations (see Section 1.4), but it is more difficult to exclude people from using knowledge if its use does not require complementary means. Thus, while, under certain circumstances, open exchange of biodiversity and its underlying knowledge took place, technological change and institutional arrangements governing the complementary means required to exploit that knowledge has made easier to exclude some actors from its exploitation. In addition, these technological changes and institutional arrangements favour the commercialisation of biodiversity-based innovations and appropriation of the resulting benefits.

Since the early 1800, the equilibrium derived from the long-term exchange of biodiverse species has changed; many animals and plants have become extinct while others have passed from being local use to diffusion far beyond from their regions of origin.[36] Some argue that this practice has disrupted biodiversity to the extent that it is threatening the sustainability of food production (Frison *et al.*, 2011 p. 239; FAO *et al.*, 2016 p. 7). Some authors use the term biodiversity to refer to practices rather than

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[35] Explaining convergence in terms of access to knowledge does not mean that differences in social welfare (or development) are the consequence only of the appropriation of benefits. Rather, it implies that knowledge is held by people who have different 'labour power', or, as Marx would have put it, have different capacity to generate surplus: Human capital matters. The quality and level of education and depth of experience have a major influence on the productive power of labour. Somewhat more contestable is the idea that cultural differences among people account for some of the gaps people with different ability to produce surplus; the balance between individual and collective responsibility, accountability and initiative differs among societies and account for differences in these societies' capacity to generate wealth. It has been argued, also, that worldliness and the balances evoked by religious belief systems, which assign different agency and responsibility to human beings and the divine, contribute to societal capabilities for achieving growth and development and the changes required for their achievemen. In this respects, Fukuyama (2001) includes, together with religion, 'tradition, shared historical experience and other types of cultural norms' as determinants of development (see Fukuyama, 2001). Ekelund *et al.* (2002) analyse the differences in economic growth between the Protestant and Roman Catholic churches (see Ekelund *et al.*, 2002).

[36] The loss of equilibrium can be considered as loss of biodiversity. The wide dispersal of a limited number of breeds from major livestock species is related, among other things, to a decline in locally adapted breeds (see FAO *et al.*, 2015 p. 15). The loss of biodiversity has been provoked not by the introduction of new species including plant varieties and animal breeds, since the movement of species via human migration has continued for thousands of years, but by intensive crop production, which prioritises mono-cropping.

resources. Thus, Frison *et al.* (2011) indicate that as an alternative to the monocropping of a few broadly diffused species, biodiversity 'can increase the productivity of farming systems in a range of growing conditions, and more diverse farming systems are generally more resilient in the face of perturbations' (Frison *et al.*, 2011 p. 238). Although large *ex-situ* collections of mono-cultivated crops are held in developed countries, the same types of collections are found with *in-situ* biodiversity in developing countries. These in-situ collections are important because of their ability to maintain and *produce* greater biodiversity, which will provide more options for resisting shocks or disturbances in mono-cultivated crops systems (i.e., to manage risk) (Duffy and John, 2006; Sthapit *et al.*, 2008) [37] (see Ch. 5 Sub-section 5.1.1). In other words, mono-cultivated crops may generate short or medium term gains in productivity and output but risk being damaged by the emergence of new environmental factors (disease, pests, climate change, etc.). Experience with similar or identical challenges in developing countries is likely to generate solutions or mitigation strategies that would be neither obvious or trialled in developed countries. Modern mono-cultivated crop agriculture, which focusses on narrowing the range of variability to improve control of a few variables (e.g., yield), does not place much credence in these types of experiments or the knowledge gained from them.

Despite the broad applicability of biodiversity across several sectors, this thesis focusses on study of biodiversity utilisation in the food sector for four reasons:

First, we need to understand the processes involved in commercialising biodiversity-based innovations. The introduction of these processes have led to an unequal distribution of benefits, both within and between countries in which this biodiversity originates and between such countries and less biodiverse developed countries. The size of these benefits is particularly conspicuous in the case of the food sector. A better understanding would be informative for policy-makers and stakeholders

[37] As briefly referred to in Section 1.1, the Nagoya protocol is a complementary instrument to the extent that it supports the other two goals of the CBD: (i) The conservation of biological diversity, and (ii) The sustainable use of the components of biological diversity. These objectives were developed throughout The *Cartagena Protocol on Biosafety to the Convention on Biological Diversity,* an international treaty governing the movements of living modified organisms (LMOs) resulting from modern biotechnology from one country to another that may have an adverse effect on the conservation and sustainable use of biological diversity.

about how to achieve a more equitable sharing of the benefits deriving from the use of biodiversity, to increase welfare in biodiverse developing countries (see Sections 1.1 and 1.2).

Second, biodiverse-rich developing countries have groups of their populations that are undernourished. Extreme poverty is the norm in rural areas and the prevalence of underweight children aged under five years is greater in rural areas (FAO, 2015a p. 7). Urban areas show slightly better performance on both counts. Hence, observing the agricultural stages in the food sector would provide information about how the resources from biodiversity are being commercialised and the benefits appropriated. A change to the appropriation of benefits would affect the welfare of groups such as indigenous peoples and small farmers.[38]

Third, the interest in appropriating the benefits derived from the commercialisation of new food sector products has attracted the attention of various authors writing in different disciplines. For instance, the food sector, especially in the agricultural stages, contributes to greenhouse gas emissions and is a major cause of deforestation, land use change, loss of biodiversity, water shortages and pollution. Cattle herding is the most important cause of food sector greenhouse gas emissions and occupies a large percentage of agricultural land use.[39] Thus, the innovation process can have *unintended consequences* which need to be studied.

Fourth, indigenous people and small farmers maintain close relationships with biodiversity, by are often excluded from the economic benefits derived from its use. Traditional indigenous territories coincide with areas that host 80% of the earth's biodiversity and indigenous peoples are the 'carriers' of ancestral knowledge about its

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[38] There is no reason to assume that governments, either colonial or post-colonial, are interested in the social welfare of the entire population. Contemporary social systems, including democracy and communism, have tried to address this with varying degrees of success; democracy allows exclusion if the majority chooses to ignore or exclude the minority and the universalism of communism fails as the result of corruption or the tendency to view individuals as instrumental in the collective. Mulligan *et al.* (2004) compare data on democracies and non-democracies, and found no significant differences regarding economic or social policies. Hewitt (1977 p. 450) suggests there are differences between democracies on their own, and democracies that include democratic socialist parties: 'The stronger the democratic socialist parties, the more egalitarian is the contemporary class system'. His findings is supported by a study by Haggard and Kaufman (2008) which identifies a range of democracies and nondemocracies and different effects on the distribution of interests and organisations; they suggest that the effects of democracy are 'conditional on economic and fiscal circumstances and the organisation of social interest' (Haggard and Kaufman, 2008 p. 362).

[39] Some of these drawbacks have been documented. See Millstone and Lang (2008); Sukhdev *et al.* (2010); Turral *et al.* (2011); Gerber *et al.* (2013 p. 15); Garnett (2014 p. 3).

use (Sobrevila, 2008). Despite their association with biodiversity loss, farmers have the *agency* to contribute to the conservation of biodiversity by (i) sharing the land between crop production and conservation or sparing it for conservation (Phalan *et al.*, 2011), and (ii) by adapting their agricultural routines: Reinforcing soil formation to reduce the need for fertilisers and benefiting from pollinators and biological pest control (Pimentel *et al.*, 1997). These factors need to be understood in relation to the innovation process.

These aspects cannot be addressed in a single thesis. There are several research methods that could be used to examine each of these issues, but the methodology employed here (see Ch. 3) is applied to an examination of how the operation of the process of innovation towards commercialisation (the first aspect above), both historically and in a contemporary context.

The proposed methodology makes this research of interest because science policy and innovation studies tend to exclude the agriculture sector, which is responsible for most food production, and instead focuses on 'manufacturing and particularly on hi-tech manufacturing' (Martin, 2010 p. 10). Science policy and innovation studies on agriculture are the exception (van Zwanenberg and Millstone, 2005; Logar, 2011) among a large body of work in disciplines such as economics (Papi and Nunn, 1986; Huffman and Evenson, 2006), development and history (Wright, 1987), which tend to emphasise developed rather than developing countries (Ahmed *et al.*, 2015).

As might be expected, the emphasis on product innovation and manufacturing productivity is central in wealthier countries, where the prevailing view seems to be that agricultural commodities should become ever more standardised to produce the raw materials for processed foods from the manufacturing sector, and provide ever cheaper prices for mass distribution via the wholesale and retail sectors (Millstone and Lang, 2008).

At the same time, in many developing countries, the agricultural sector is the most important source of employment (e.g., 29.6% of the total workforce or around one billion workers (ILO, 2016)), although with limited productivity and small wages. Many developing countries are host to large biodiverse ecosystems. Science policy and innovation studies[40] need appropriate methods to investigate the innovation processes in the food sector and specially the agricultural stage in biodiverse developing countries.

To summarise, evidence-based policies related to the use of biodiversity are necessary to promote greater benefits for biodiverse countries and more equitable sharing of the benefits arising from use of biodiversity. This is the – yet not realised - aim of the Nagoya Protocol. The limited improvement resulting from the implementation of the CBD show that there are lessons to be learned from historical studies and science policy and innovation research. The agricultural stage of the food sector is interesting and important, given the opportunities it offers for the solution to global poverty, climate change and inequality problems.

1.4 Biodiversity use and appropriation of its benefits – A historical view

Goods emerge from the use of biodiversity; the benefits derived from these goods accrue to individuals or to groups. The benefits accrued are related to the capabilities (actors' skills and organisational routines) (Nelson and Winter, 1982) for appropriating these benefits. Actors (and organisations) have accumulated knowledge, both codified articulated and unarticulated (Cowan *et al.*, 2000), on which basis they set value in use (i.e., attributes of practice) on the goods emerged from using biodiversity. Rights-based and structural and relational means (Ribot and Peluso, 2003)[41] or, more generally

[40] Traditional science policy methods involve modelling, statistical inference, operations research, cost-benefit analysis, and risk-benefit analysis for policy evaluation. However, 'institutions' and subjective values are gaining more visibility (see Wagle, 2000). To improve policy making requires reconciliation between the supply of scientific information and users' demands. The source of these demands and the reason for them, and the context of and process involved in using this information are becoming the focus of investigations (see McNie, 2007). A historical perspective on innovation studies provides an understanding of the broader scope (from technology to transitions in socio-technical regimes), the influence of institutions on actors' decisions, and the development of more coherent methods in innovation studies (see Smith *et al.*, 2010). Despite the advances that have been made and the differentiation being applied in science policy and innovation studies, new methods, techniques and instruments need to be developed to support the players involved in innovation (see Smits, 2002).

[41] Ribot and Peluso (2003) criticise 'property' as the foundation of benefits. The propose 'access' as 'the *ability* to derive benefits from things' (original emphasis). They consider a 'wider range of means, relations, and processes' that enhance the appropriation of the benefits (see Ribot and Peluso, 2003) which we extend to benefits arising from biodiversity. This thesis refers to this 'wider range or means, relations, and processes' to the ownership and control of biodiversity, as 'complementary means'. Ribot and Peluso refer also to rights-based legal access and illegal access. Illegal access 'is a form of direct access defined against those based on the sanctions of custom, convention, or law. […] Illegal access refers to the enjoyment of

complementary means[42] (in Section 1.3 we discussed the means necessary to reap the full benefits from commercialisation of biodiversity-based innovation), constrain or enhance actors' capabilities to appropriate benefits. This section introduces different *forms of appropriation* of the benefits arising from biodiversity and highlights the associated technological changes and institutional arrangements and the constraints or on enhancements to these benefits.

Throughout this thesis, structural concepts are used to trace 'patterns of social structure' (Wittfogel, 1957 p.ii) and associated technological and institutional change, which are used to contextualise the case studies (Chapter 5). The portion of the population engaged in activities other than producing or gathering food is representative of the whole population's capability for involvement in activities not related to subsistence. Thus, the percentage of the population engaged only in producing food can be explained by the technologies available and the institutional arrangements surrounding this activity.

Relatively little technology is involved in the hunting and gathering activities that prevailed prior to the development of cultivation and herding techniques some 10,000-12,000 years ago. Archaeological reports show that cultivation/husbandry, the first *epochal innovation* in humankind as Kuznets (1966) describes technological changes and institutional arrangements, were the antecedents to the development of techniques for storage and processing. In the Central Andes, these techniques included 'storage practices (of dehydration by exposing food to the air and the sun), cooking practices (toasting, roasting, and boiling), as well as with milling, crushing, grinding' (author's translation from Spanish) (Babot, 2011 p. 427). These practices are indicative of the transition towards the application of cultivation/husbandry techniques, including soil movement, irrigation and plant protection. Cultivation/husbandry provided a surplus that allowed population expansion and the bartering or commercialisation of those goods not

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benefits from things in ways that are not socially sanctioned by state and society' (see Ribot and Peluso, 2003 p. 164). Such access is described in this thesis as biopiracy (see Ch. 6).

[42] Teece (1986) refers to 'complementary assets'. He bases his analysis on a dual dichotomy between participating or not in the innovation process, and having or not an intellectual property regime. He demonstrates that 'when imitation is easy, markets do not work well, and the profits (i.e., benefits) from innovation may accrue to the owners of certain complementary assets, rather than to the developers of the intellectual property' (see Teece, 1986 p. 285). Thus, while actors' knowledge derive value from the goods emerged, complementary means enhance the appropriation of the benefits.

used for self-consumption.[43] Control of the territory and the family kinship relations that ensured the labour required for cultivation/husbandry and postharvest techniques, allowed increased access to plants and animals. Property rules related to land use informed indigenous peoples about how to manage their relationships with community members and non-members (e.g., to prevent hunting of endangered species, and whether to bury their dead).

Over the last few thousand years, cultivation/husbandry have become typical ways to appropriate benefits from the use of biodiversity across the world: Cultivation and husbandry techniques generate surplus saleable goods surplus (following perhaps harvest/slaughter, processing, packaging and distribution). The presence or not of certain species (or species types) in environments where indigenous communities have settled, delimits the technologies available and reinforces the valuable and distinguishable species phenotypic attributes.[44] In Meso America (extending from central Mexico to Belize, Guatemala, El Salvador, Honduras, Nicaragua, and northern Costa Rica), the world's only ancient primary civilisation with no domestic herbivore, an alternative source of proteins was part of the diet. Indigenous communities developed cultivation/husbandry to appropriate the benefits from seed crops and the maguey (*Agave Americana* L.), and fish and insects provided the protein in their diets (Parsons, 2010). In the Andean region, pastoralism was based on camelids (i.e., llama and alpaca) (Moore *et al.*, 2010; Bruno, 2014), with associated territories dedicated to production of tubers and grains in the highlands of the Central Andes, which were occupied by extended groups of families or *ayllus* (the traditional form of family group in the Andes) (Carter and Albó, 1988) and a multi-community polity (Bruno, 2008 p. 52).

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[43] The commercialisation of goods emerging from the use of biodiversity is an intermediate step towards the consumption of such goods by buyers. Commercialisation provides benefits to those who produce and sell the goods. It provides payments which can be used in exchange for other goods that fulfil their individual needs or organisational goals.

[44] The first thesis research question refers to '*naturally* occurring resources from biodiversity'. The emphasis in this thesis research is on resources that have been domesticated, subjected to cultivation/husbandry and harvesting/slaughtering techniques, processing, packaging and distribution to achieve a saleable state. Although would seem to question the description of *naturally* occurring, it is used to (i) emphasise that, in the combination of something from nature and its uses (i.e. knowledge), the use is the one novel, and (ii) distinguish it from these obtained from modern biotechnological techniques (e.g., genetic engineering, cell fusion to shape LMOs), and by synthesising an active ingredient chemical structure.

Technological change (and associated institutional arrangements) affect the ways in which actors and organisations appropriate the benefits from the goods emerging from biodiversity. Exploitation of natural resources has evolved in several ways. Crops can be gathered on a large scale using machines such as combine harvesters, and fish can be caught in large quantities by large trawlers. These technologies are available to actors (and organisations) with the structural or relational means such as the capital required to buy/rent them and the skills to operate them. In addition, during the 19th century major advances were made in the preservation and processing of natural materials. In short, technological change has allowed certain actors (and organisations) to define the direction and increase the scale of the benefits appropriated.

Humans transported their seed and livestock across the territories in which they settled. In the 16th century, wheat, which originated in Middle East, rice which came from East Asia, (FAO *et al.*, 2016 p. 3), chickens which originated in India, sheep and cattle from Southwest Asia, pigs from Southern Asia, horses from Kazakhstan and donkeys which originated in Sudan were already available in Europe, and were introduced by Europeans to America (FAO *et al.*, 2015 p. 11). Maize and potatoes (*Solanum tuberosum*) from America were sent to Europe and, together with rice, wheat, barley and pulses, expanded around the world (Murphy, 2007 Parts II-IV). This movement enabled trials (comparisons) and identification of places and technological sets, which led to outstanding performance in cultivation. The level of the appropriable benefits from agriculture (i.e., raw or processed goods) increased thanks to this increased productivity.

Actors and organisations that are providers of raw and processed goods from agriculture, are part of a value chain and, as such, supply manufacturing (e.g., food and pharmaceutical industry), demand and satisfy dealers and final consumers. Given that biodiversity can be shared among countries, communities or farmers, competition among providers to offer the lowest prices to industry, has led to the bargaining power of providers with access to biodiversity (of substitute inputs) being reduced.

The pace of change in technologies and institutional arrangements increased during the 20th century resulting in the emergence of new forms of appropriation of the benefits derived from the use of biodiversity. Until the 19th century, colonial control of territory, plant transfer (Mooney, 1983 p. 86), and the establishment of botanical gardens

(Brockway, 1979 pp. 451-9; Rangnekar, 2000 p. 4) allowed learning (of the biodiversity underlying knowledge) and access to biodiversity and the eventual appropriation of the benefits arising from these resources through cultivation/husbandry. In the 20th century, new power relationships emerged related to (dis)possessing the uses of and knowledge about biodiversity and the related institutional arrangements developed: Plant breeders' rights (PBR), protection of new plant varieties, patenting of live matter including plants and microbes, and compounds of biodiversity, commodification of bio-information and the reaffirmation of nation states' sovereign rights over their biological resources (see Annex A).

The appropriation of the benefits emerging from technological change and institutional arrangements is enhanced (or constrained) by complementary means, which include rights-based and structural and relational means (Ribot and Peluso, 2003). Table 1 summarises the different forms of appropriation, especially during the 20th century. For each form of appropriation, it sets out the technology and knowledge typically related to that form, and the complementary means and institutional arrangements.

The licensing of protected new plant varieties, use of patented inventions and access to databases has allowed the appropriation of benefits from the use of biodiversity in research. Structural and relational means such as access to labour, market and capital, enhance the appropriation of those benefits, while reducing the relative bargaining power of those with access to biodiversity and land who, otherwise, would appropriate the (smaller) benefit generated by the use of this biodiversity.[45]

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[45] Comparison of benefits derived by those with access to biodiversity can be conducted in terms of the benefits from its use in the absence of technology. Although such a comparison would be unrealistic, up to the beginning of the 19th century, population growth can be seen as demonstrating a Malthusian rate limited by lack of growth in the availability of food. In this perspective, without the 19th and 20th century innovations related to the recent forms of appropriation of benefits, the benefits to those with access to biodiversity would be limited to the growth of the population typical of pre the 19th century. Evans (1998) relates both technological and social agriculture innovations in recent centuries to population growth (see Evans, 1998 pp. 17-18). This would mean that, the hypothetical benefits would be so small that 5 or 6 billion people would have starved to death or never have been born in the last century because of the resulting smaller numbers of the population who would have starved to death before having the chance to reproduce.

TABLE 1. FORMS OF APPROPRIATION, TYPICAL TECHNOLOGY AND UNDERLYING KNOWLEDGE

			Complementary means			
Forms of appropriation	Technology source of benefits	Biodiversity related knowledge	1. What is appropriated /generate benefits	2.1 Rights-based means	2.2 Structural and relational means	Institutional arrangements (Power relations)
A. Hunting /gathering	Storage/cooking/processing	Identification and preferences for species and part of them	Food for self-consumption	Control of land and property of movable tools	Labour (kindship relationships)	Small communities
B. Cultivation /husbandry	Soil manipulation, water regulation, soil fertility restoring, production diversification (3). Harvest/slaughter, processing, packaging for distribution	Crop improvement / breeding	Revenue from commercialising raw and processed food	Land	Labour, capital, market knowledge (2)	From Ayllu and multi-community polity (local market) to nation States (global market).
C. 1 Plant Breeding Rights, PBR	Traditional breeding	Improved understanding of genetic principles	Licence fee for using the seed	Protected variety		UPOV
C.2 Patentability of life matter uses and of compounds	Modern biotech-based breeding and chemical identification	Crop improvement / breeding Compound extraction/ replication	Licence for the use of modified life matter and the production of compound	Patent	Labour, capital, market, access to authority	Patent and copyright systems based on nation states blocks
C.3 Comodification of bioinformation	Bioinformatics	Genetics and genomics	Licence fee for information (tissue samples, extracted DNA, sequenced DNA)	Databases		
C.4 Authorization to Access Biodiversity		Taxonomy and biogeography	Country biodiversity	State sovereignity	Knowledge, access to authority, social identity (traditional knowledge)	CBD- National Authority

Source: Based on Ribot and Peluso's access and means scheme. (1) (Ribot and Peluso, 2003 p. 168); (2) (Ribot and Peluso, 2003 p. 169); (3) (Netting, 1993 pp. 28-9)

To summarise this section and chapter, technological change and institutional arrangements combine to enhance the use made of biodiversity. Rights-based, structural and relational means constrain (or enhance) the appropriation of the benefits from this use. Several forms of appropriation of these benefits have led to their unequal distribution, and ignore the contribution made by collective action and common-pool resources to the development of the innovation. The Nagoya Protocol is part of a trend for privatisation of goods emerging from biodiversity as appropriability is extended. However, it leaves the door open to exploration of forms of collective action and to preserve and maintain common-pool resources for the appropriation of benefits. A framework of analysis and evidence related to a better understanding of the complementarity between the public and private goods in the appropriation of benefits are required.

1.5 Structure of the thesis

This introductory chapter outlined the background to this doctoral research, the phenomenon being analysed, its historical and contemporary policy relevance, and the changes that have occurred to the forms of appropriation of benefits over time. Below, the broad research questions examined are presented.

Chapter 2 reviews the relevant literature, and Chapter 3 presents a preliminary research design. The dairy cow is used as the basis for (heuristic example) the theoretical approach to biodiversity-based innovation discussed in Chapter 4. Chapter 5 provides the context to the two Andean species used as case-studies, and elaborates the research design in order to introduce the elements required to the case studies. Chapter 6 and 7 adopt a 'whole research design', to the analysis of the two case species. The research addresses two questions related to the three major aspects of (i) the innovation process, (ii) institutional arrangements, and (iii) the appropriation of the benefits arising from biodiversity-based innovation, and some additional issues linked to these aspects.

In relation to the innovation process the questions addressed are:

- How are biodiversity-based innovation and social practices shaped collectively?
- What are the roles of voice (when possible) and choice in the shaping and stabilising technology?

In the case of the institutional arrangements affecting the innovation process the questions addressed are:

- How do institutions and organisations affect the shaping and standardisation of the biodiversity-based innovation?
- What is the role of knowledge codification in shaping the technology?

Finally, in the case of appropriation of benefits the questions addressed are:

- How do the public and private goods that emerge from biodiversity-based innovation process, governed?
- How do actors and organisations give meaning (values in use) to emerging goods and appropriate the benefits from biodiversity-based innovation?

One section in each Chapter 6 and 7 is dedicated to each element, and one sub-section is devoted to each question.

Chapter 8 discusses the commonalities across cases, and their policy implications. Chapter 9 discusses the original contributions of this doctoral research, the recommendations for policy making and suggests some avenues for future investigation.

2 Innovation process and appropriation of benefits

To achieve the objectives of this doctoral research, the theoretical approach adopted in this thesis must support an understanding of how the biodiversity-based innovation process generates benefits and how those benefits are appropriated by various parties. In addition, regarding the motivations to study the food sector (see Ch. 1 Section 1.3), it is important to go beyond the micro level of the innovation process.

Several theoretical approaches have been developed to understand how innovation emerges, they tend to focus on the micro level where actors' decisions about the shaping of the innovation are formed. A focus on the meso or macro levels uncovers the social structural conditions relevant for the appropriation of benefits. The theoretical approach adopted here considers the micro, meso and macro levels.

Innovation related to biodiversity reflects technological changes, such as application of genetic laws determining heritage and (more recently) the information technologies available to record information ranging from data on breeding outcomes to the underlying genetic data. It also has involved the evolution of institutional arrangements, such as the building of nation states[46] and standardisation of the language used to articulate and codify knowledge. In these processes, certain groups of actors have assumed central roles and others have been displaced. Some of these latter were involved closely in shaping processes at earlier points in time when different types of bargaining and appropriation of benefits were connected to the use of biodiversity. Thus, the historical evolution of institutional arrangements has entailed displacement, dispossession and, sometimes, direct conflict. Finally, the changing nature and opportunities for the appropriation of benefits have produced unintended consequences for the distribution of benefits among actors and, therefore, for the whole of society.

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[46] -Nation states building is trendy form of actor cooperation adopted in an attempt to address the actors' individual needs and social goals. Despite the popularity of nationalism and nation states, social practices, such as migration and the integration of policies, have shifted towards 'transnational communities' (e.g., the European Union, the United Nations) (see Wimmer and Glick Schiller, 2002).

This chapter presents the scope and elements and a synthesis of the theoretical approach proposed to study biodiversity-based innovation. Chapter 3 presents a preliminary research design for the theoretical approach, which is used to guide the case of the Jersey cow.

2.1 The scope of the theoretical approach

The theoretical approach employed in this thesis draws on elements of evolutionary (Nelson and Winter, 1982; Edquist, 1997 Ch. 1) and institutional economics (Hodgson, 1988 pp. 140-4; North, 1990) and how they inform and extend a central question in the sociology of technology: How are technology (i.e., innovation understood as the output) and social practices shaped collectively? In this thesis, the concept of 'technology' refers to stock (versus process) or the broad stock of novel products ('innovations') at a particular stage in time that might even be subject to change (e.g., technological change), while 'innovation' refers to the process (e.g., innovation process) or a particular novel (or improved) technology that reaches the market[47]. Technique refers the set of technologies used by an actor or organisation (e.g., a firm or indigenous community) for the performance of an activity. In any case, the conventional definition of innovation as a 'commercialised invention' is helpful for drawing attention to the processes required following the origination of a new idea related to something useful (an invention), but this narrower definition centres on market processes. Innovation can also be understood - and in this thesis is understood - as referring to a broader range of social processes by which ideas are refined and brought into more widespread use regardless of whether the diffusion involves market or other social processes.

The sociology of technology focusses on the micro level relationships between people (i.e., actors) and technologies. Sociological studies consider three layers of technological meaning: Technology as a *physical object* or *artefact*; technology as a set of *activities* or *processes*; and technology in terms of *what* people know or *do* (Bijker *et al.*,

[47] In this thesis, benefits from innovation can be gained through the diffusion of its use, which can include by its commercialisation.

[1989] 2012 p. xlii). Although these layers of meaning may appear difficult to separate, in this thesis the first layer of meaning is emphasised.

Sociological approaches are articulated by the Social Construction of Technology (SCOT) scholarly tradition (Pinch and Bijker, 1984; Bijker, 1995). SCOT studies initially focussed on physical objects or artefacts (e.g., bicycles and refrigerators) and then expanded to include whole systems (electricity systems, expert systems) and to explore their co-evolution with institutions and organisations (Bijker *et al.*, [1989] 2012 p. xxii). Markets and marketing (Arce and Marsden, 1993; Hinrichs, 2000; Bender and Westgren, 2001), learning experience and diffusion (Munshi, 2004), standardisation and quality systems (Lee, 2012), and unstable food systems (Jorgensen *et al.*, 2009) have also been studied. This trend is coherent with the inclusion of the micro, macro and meso levels.

This thesis builds on Hirschman's (1970) observation that lack of the users' voice can result in the deterioration of (fall off in the use of) or even disappearance of a technology (Hirschman, 1970 pp. 5-12). Voice, in the broadest sense, refers to advocacy and the incorporation of ideas, practices and artefacts into the narratives of everyday life. When voices are raised about the problems with using (or more generally the meanings of) an artefact at the time it is being used, this allows those with agency to design and redesign the artefact. The meanings of an artefact problematise it (and its use) and become inputs to their (re)design to resolve the issues 'voiced'. Different levels of (re)design of an artefact can occur based on the potential inventor/innovator knowledge and the institutional arrangements enabling such (re)design. Users can assess if the redesign constitutes an 'improvement', and the artefact becomes useful to the extent that it addresses individual needs and organisational goals. Thus, many of the more useful functions of an artefact are the result of socio-technical shaping and are not inherent in the artefact (Bijker, 1995 p. 13).

Following the SCOT approach, the biological species from which food is obtained can be considered artefacts over which collective choice is exercised. As in the case of non-living artefacts, there is interaction between intent and physical constraints (between design and application), which presents problems (or *meanings*) that involve actors' decisions in the species shaping process and an ultimate solution (Bijker *et al.*, [1989] 2012). Eventually, after repeat problem solving processes (to consider meanings), a biological species, in its 'domesticated' or 'human centred' use will reach a certain level of stability. This stability supports the broad use of species and allows one to refer to the diffusion and commercialisation of new products based on existing species.

Several studies focus on living organisms: Smith and Daniel (1975) adopts a sociological and historical perspective on universal knowledge of chickens in relation to organisational changes associated to cockfighting, domestication of chickens, chicken farming, egg production and use of chicken meat and eggs (Smith and Daniel, 1975), but do not consider how or why they occur. Karen Rader (2004) researched the mice used in medical research (Rader, 2004); she takes the view that they are an invented scientific device, that they gained meaning by their being useful to a group of users, and that they became standardised through negotiation. Anna L. Tsing (2015) uses the case of the Matsutake mushroom, a delicacy in Japanese cuisine, to explain the unintended consequences of capitalism in creating *spaces* for its production. She traces the way that economic benefits are created to justify mushroom production in such spaces (Tsing, 2015).

Several approaches focus on the innovation process: The diffusion of innovation (Rogers, 1983), organisational knowledge creation (Nonaka, 1994), learning processes (Lundvall and Johnson, 1994) and open (vs closed) innovation (Gassmann and Enkel, 2004). However, this thesis adopts the SCOT approach because it considers what occurs to the technology at the time that users interact with it, which addresses the unintended consequences of technology shaping (and technology utilisation) (Bijker, [1989] 2012 p. 170).[48] The existence of unintended consequences means that the path shaping of the technology[49] cannot be foreseen at the time when the invention (or its utilisation) becomes an innovation. Similarly, unintentional circumstances affect the shaping process

[48] Bijker (2012) refers to the case of Bakelite. Bakelite did not require a sophisticated chemical experience, so Baekeland's intention was to remain detached from the manufacturing process. However, the users of similar technologies, such as rubber, celluloid and other plastics, failed to use the technology, Which prompted Baekeland's involvement in the manufacturing process and his efforts to enlist people by creating Bakelite Corporation (Bijker, [1989] 2012 pp. 170-1).

[49] The concept of path shaping is similar to the concept of technological trajectory (Dosi, 1982). The path is shaped by a combination of changes in the species and in the actors' uses. While technological trajectories are contextualized by the technological paradigm (Dosi, 1982), path shaping is contextualized by the state of evolution of the species (e.g., domestication) and the accumulation and retention of the underlying knowledge.

by defining the conditions in which the innovation take place (Law, [1989] 2012 p. 122).[50] Unintentional circumstances are external to the shaping process (or at least difficult to modify given the inventor/innovator capacity), but without them the shaping process might proceed in very different ways have different consequences.

While this thesis focusses on *what* is shaped and *how* it is shaped, other approaches give more emphasis to *who* (i.e., inventors or entrepreneurs) is responsible for those changes (and the choices that produce changes to the shaping) or *where* these processes occur (i.e., where the actors are located and how, in an innovation system,[51] the actors are related to one another) (Lundvall *et al.*, 2002).

Scholars, such as Winner (1993), have suggested that the SCOT approach fails to take account of those people who did not have the chance to be consulted (or involved), but who are affected by the technology (Winner, 1993 p. 369). This thesis considers this group by examining the appropriation of benefits arising from the technology. Hence, the SCOT approach is extended by the incorporation of elements from two other approaches: Evolutionary economics and institutional economics. These approaches coincide in recognising that innovation and learning, part of countries' economic and social development, produce more benefits than just revenue for specific actors or enable increases in productivity (North, 1990; Hodgson, 1999). This recognition helps to identify issues related to the distribution of benefits and the promotion of economic growth and *welfare* more generally, which are a central motivation of this thesis.

Both evolutionary and institutional economics examine the institutional arrangements that define the conditions for the sharing of benefits among actors. Given

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[50] Law (2012) explains the case of the expansion of the Portuguese navy fleet expansion in the 14th-16th centuries. Although the shaping of a technology (the fleet of ships built to trade with India) is explained as 'a relatively stable set of associated entities' (including the cannons, the ship, ship's master, the gunner, the powder, and the navigation system), there are certain circumstances that highlight its contextual and limited condition. For example, (i) there was no-well armed Muslim shipping in the Indian Ocean' that could challenge Portuguese ships seeking the trade with India; (ii) the Chinese, who might have challenged this trade, were confined to coastal shipping; (iii) the combination of state support and profit seeking merchants was sufficient to overcome 'Muslin merchants trading on their own account and not for their monarchs', and (iv) a shortage of timber constrained the ability of other monarchs to construct a fleet of ships capable of stopping the Portuguese army. These were unintentional circumstances that favoured the expansion of the Portuguese ship fleet (Law, [1989] 2012 p. 122).

[51] The traditional concept of National System of Innovation (NSI), has extended to Regional System of Innovation (RSI) (see Cooke *et al.*, 1997), Sectoral System of Innovation (SSI) (see Malerba, 2002), among others.

the slack (Hirschman, 1970) in the exploitation of technological opportunities, and the 'laxity, slippage, rule-breaking defiance, and even sabotage' in organisational routines and operations (Nelson and Winter, 1982 p. 108), actors and organisations compete to make improvements that generate new or better benefits by increasing knowledge. The outcome of this process is one definition of innovation[52]. Institutional arrangements define the set of opportunities in terms of an economic income redistribution or a productivity increase, or both (North, 1990 p. 64). While investment in knowledge creation is based on perception of the benefits (North, 1990 p. 75), the bargaining power derived from the institutional arrangements (North, 2006 p. 63) determines the benefits received by each actor. Evolutionary and institutional economics emphasise that innovation and learning are part of the economic and social core of countries, and that they can generate benefits for all of society.

An economic perspective (i.e., evolutionary and institutional economics), combined with a sociology of technology approach, is useful in the context of this thesis. These two approaches allow active consideration of 'choice' (i.e., among several knowledge options or competencies for benefits), which is needed to supplement the sociological perspective of 'interests'. Within addition to understanding how the appropriation of benefits occurs, this framework supports analysis of the normative question related to identifying how more equitable sharing of the benefits from using biodiversity can be achieved.

As a step towards answering this normative question, it is proposed that the goods emerging from biodiversity should be accompanied by arrangements that define the appropriation of benefits. These arrangements are subject to public or private governance. Thus, the goods that emerge from the shaping of species originating from biodiversity are accompanied by arrangements for the appropriation of benefits by individuals or groups or both. A collective choice for a 'more equitable' sharing of benefits may depend upon the 'rules of the game' (i.e., laws, norms and standards), as well as the bargaining power of the individuals responsible for production (i.e., the owners of complementary means, such as capital and labour). In a democracy, these choices are

[52] As indicated at the beginning of Sub-section 2.1 a comprehensive definition of innovation includes all of the forms of appropriation of benefits, some of which may be additional to market commercialisation.

dependent on the preferences of individuals (Sen, 1970 p. 2), who may, through democratic mechanisms, elect lawmakers or collective bargaining representatives capable of changing institutional arrangements. In this thesis, rather than conducting a *post-hoc* evaluation of outcomes, social welfare is analysed in terms of how the actors participate in the social shaping of the technology (Bijker and Law, 1992 p. 3) (i.e., raising their voices or not about a use, or as inventor/innovator with agency on the artefact), and how institutions define the form in which the benefits may be appropriated. It is expected that actors strive to avoid being excluded from the appropriation of benefits when, (i) the expected benefits are higher than the costs of taking part in the technology shaping, and (ii) the actors' voices or agency give them bargaining power to define the institutions that will define benefits' appropriation. Beyond this, governance provisions favouring more equitable social distribution of benefits are likely to depend upon appeals to social justice, which types of campaigns are not considered in this thesis.

These three approaches, the sociology of technology and evolutionary and institutional economics, provide complementary perspectives for observation and analysis (i.e., who learns and what is learned), and different understandings of the processes (e.g., variety generation and selection compared to deliberation and choice). For example, the evolutionary perspective considers that 'choice', which often involves 'emergent' properties stemming from decentralised and uncontrolled choices, occurs within market processes while institutional and sociological approaches are often predicated on some sort of constituted decision process and the actors. Institutionalism emphasises the role of collective authority to decide (i.e., ruler vs constituent groups) (North, 1990 p. 49), while sociological approaches give primacy to the interests of those who control key levels in the decision making processes (including vested interests) (Bijker and Law, 1992).

Other approaches were considered among the social constructivists. One of the approaches considered was the Actor Network Theory (ANT). However, it was not chosen to be an approach used in this thesis because the difficulty of separating the actors' agency in the shaping process from the species given condition (i.e., unintentional circumstances). As it is known, ANT does not separate the human capacity from the nonhumans to act or participate in the shaping process (Latour, 2005). Also, due to the policy making interest of this thesis, the SCOT approach was preferred to the ANT, which is more descriptive than prescriptive.

Despite power issues were included by Bijker in 1995 in “Of Bicycles, Bakelites, and Bulbs: toward a theory of sociotechnical change” (Bijker, 1995), this thesis does not attempt to analyse the role of power in the shaping process. Instead, the thesis includes power as part of the determinants of the distribution of benefits arising from the use of the technology. Thus, this thesis goes further from the discussion of how the social construction of the technology takes place, to explain how benefits arise from the shaping process. In doing that, the thesis understands the institutional arrangement in which some actors have the bargaining power to benefit through substituting or finding complementary means to use the species, and exerts relative bargaining power when formal institutions governing commercialisation or ownership (or access to or control over) products from biodiversity are employed (see Chapter 1 Section 1.2).

2.2 Elements of the theoretical approach

The three approaches provide a set of concepts to address the research questions. In addition to these concepts, various authors have proposed ways to achieve results and reliable conclusions. The SCOT approach the following concepts to be central:

- artefact, which describes the innovation from the first stages to its commercialisation; and
- actors or social groups who use the artefact and, simultaneously, take part in its shaping (Bijker, 1995). Some of these actors become translators (Callon, 1986).

To understand the innovation process, this thesis considers how actors reach decisions about the shaping process and, when possible, what occurs to those who did not provide their meanings during the shaping process (or did not raise their voice), but were affected.

The main evolutionary economics concepts utilised in this thesis are:

- learned skills (and routines), which are the repetitive actions performed by actors (and the organisations created to address their needs cooperatively) to address their needs (and organisational goals) (Nelson and Winter, 1982 Chs 4-5);

- Uncertainty, which always occurs 'prior to the effort to exercise' a certain capability (how to). 'Capabilities to make good choices [...] may also be of uncertain effectiveness' (Nelson and Winter, 1982 p. 52).

The main institutional economics concepts used in this thesis are:

- costs of cooperation among actors (North, 1990) (or of human interaction) and the formation and maintenance of institutions, and the rules, norms and standards governing actors' production and exchange relationships (including those institutions governing ownership and use). These institutions include formal and informal mechanisms established to reduce the costs of cooperation (North, 1990 Part. 1);
- Codification (or not) of economically significant knowledge employed by actors (Cowan *et al.*, 2000 p. 240).

The evolutionary and institutional concepts and the SCOT concepts are used in combination to address the research questions.

2.3 Toward a synthesis of the theoretical approach: Innovation, (re)design and learning

If knowledge is central to innovation and knowledge is gained through learning, how can biodiversity-based innovation be explained as a learning process? This question is the focus of this section. Identifying aspects of the learning process should allow a better understanding of biodiversity-based innovation. Also, the learning process gives unity and coherence to the three proposed approaches. The narrative centres around the actors that use the artefact, which, through (re)design, becomes an innovation. Actors use artefacts by performing their skills (and organisational routines) to address their needs (and organisational goals).

The learning process allows actors to accumulate and retain a set of knowledge that includes a mixture of the actors' innate and learned skills. Actors use artefacts within different routines; some actors *control* (i.e., to ensure the achievement of a well-known goal through adherence to organisational routines, such as buying a standard type of machine in the market (Nelson and Winter, 1982 p. 113)). Other actors *replicate* or *contract* use of the artefact to allow them to recreate. or restrict the variance in routines. For example, when installing a new factory, actors buy machines based on the routines in already established factories (Nelson and Winter, 1982 p. 118). Yet other actors *imitate*; they adapt an organisational routine to pursue a certain goal (e.g., imitate the establishment of a factory with a novel combination of highly standardised technological elements). In this last case, some actors become inventors/innovators through their imitation activity but with ‘an extremely sparse set of clues about the details of the imitatee’s performance’ (Nelson and Winter, 1982 p. 124) (e.g., establish a factory without the help of blueprints related to an already existing one).

The concepts involved in these three approaches are combined. Actors in the SCOT approach include users with various skills. Each actor that uses the artefact gives the artefact meaning in terms of the skills (and routines) performed by each actor. Actors can be grouped around the same meaning given to the artefact. This meaning includes *what* actors think about the artefact and *how* it might be (re)designed (Bijker, [1989] 2012 p. 34). While the *what* refers to accepting (i.e., giving voice by using the artefact, buying the emerging goods or articulating a favourable message), or problematising the artefact (i.e., neither using nor buying the goods that have emerged from use, or articulating a negative message) (Hirschman, 1970)),[53] the *how* refers to the actors’ capability to ‘act’ (agency) (Bishop, 1989; Barker, 2000)[54] or not, on the artefact (i.e., to (re)design the artefact).

Among those user of the artefact, those that act (i.e., have agency over its (re)design) *are potential* inventors/innovators. Other users can give new meanings to the artefact, but cannot (re)design it (or, therefore, invent/innovate). Lack of users’ voice will result in the deterioration and eventual disappearance of the technology (Hirschman, 1970 pp. 5-12). Hence, those who assign a meaning to the artefact use their interpretative flexibility to define this meaning and voice their views through use of the artefact; however, they can also articulate a message about problematic meanings, providing inputs to the inventor/innovator. Inventors/innovators may consider the meanings given by other users in the (re)design the artefact and, based on these and their own ideas may have the capability to generate further variations. The inventor’s/innovator’s capability to (re)design and the meanings given by other users

[53] Hirschman refers to ‘voice’ and ‘exit’ (or problematising as we refer) in a political (i.e., governments, parties and polls) and economic (i.e., markets, companies and sells) context. ’Voice’ and ‘exit’ are used in this thesis in an innovation context, where users give meaning to the use of species, and organisations and institutions govern the exchange and use of ‘shaped species’ or ‘new varieties’ or breeds, ‘improved’ through the shaping process.

[54] Bishop (1989 pp. 1, 44) recognises that, despite humans being part of nature, they have agency to transform nature. He considers a causal theory of action recognising that actions are constituted by behavioural events with an appropriate kind of ‘mental causal history’.

whose identification of problems or issues become inputs to the (re)design of the artefact, are interlinked. (Re)design of the artefact provides variation (i.e., diversity) from which actors can select (drawing on evolutionary economics concepts). Differences between the intent of the inventor/innovator and the physical constraints enables actors to take decisions and develop solutions. The process of problematising and (re)designing (shaping in the SCOT tradition) is repeated until some (at least temporary) stabilisation is achieved.

The scope of the notion of actor meanings is also very broad: A meaning might favour or reject control or replication of an artefact's use, or influence an imitation of its use in a new situation. However, a meaning can also lead to use of the artefact being discontinued. Those with agency to (re)design the artefact may or may not take account of the meaning associated to the artefact by its users of the artefact. Whether users' meanings are considered might depend on the institutional arrangements and the extent to which users voice their views or not.[55]

Actors make their decisions according to the meaning they convey or how the artefact can be (re)designed under the prevailing institutional arrangements. Those decisions, in the first instance, are driven by the benefits expected by those actors with agency to (re)design the artefact. From the use of each artefact may have the potential to one or more different goods to emerge. Each good will have a public or private form of governance, and the form of this governance may be considered by the actor making the decisions. The 'form of governance' over goods is given by the nature of the artefact (i.e., technological attributes such as the reproducibility of a genotype)[56] and by the institutional arrangements under which actors and organisations operate (i.e., formal constraints such as the intellectual property regime, and informal constraints such as

[55] Those with agency have room to act to the extent that, given an institutional arrangement (e.g., lack of sanction or reward for entrepreneurship), they can anticipate users' meanings or encourage their expressing by soliciting users' views. An example here from the end of the 19th century was anticipating that women in Europe would become potential users of tricycles (see Bijker *et al.*, [1989] 2012 p. 27)), something that would have been impossible in earlier decades due to social limitations imposed on women's activities (i.e., institutional arrangements).

[56] Technological attributes of species from biodiversity are those characteristics intrinsic to the species associated with its reproduction. Reproduction implies replication of the genotype (i.e., deoxyribonucleic acid or DNA) and a range of subtle changes to the phenotype (i.e., a form of variability in evolutionary economics terms). See fn. 2 about relationship biodiversity and genetic resources. See also Ch. 4 Section 4.1 on the genotype - phenotype relationship.

taboos and traditions (North, 1990 Part I)).[57] Because institutional arrangements can change and because the actors operating within them have different skills (and bargaining power), the appropriated benefits differ (i) according to the result of bargaining over the establishment and enforcement of institutional arrangements (thus, favouring those with greater bargaining power), and (ii) based on the actors' meanings given to the use of the artefact (i.e., value in use expected from the emerging goods).

Since articulation and codification (or not) of knowledge may influence the institutions (such as codes or standards) involved in the (re)design process and, hence, also the (re)designs, it is useful to understand how this influence might occur. The explanation is simplified by using a hypothetical case and considering two groups (each from a different organisation). The first group is users with experience of and an understanding of the artefact in their everyday lives. The second group consists of potential inventors/innovators, who are aware of but are not user of the artefact. This second group perceives a potential use for either themselves or for others if the artefact were to be (re)designed.[58] Articulated and codified knowledge (i.e., meanings) can be useful inputs to the (re)design of artefacts since, once an actor articulates meaning about the artefact and this meaning is codified, the associated knowledge can be accessed more easily and understood by the local actor, and other potential inventors/innovators, and used in a (re)design.[59] The first group has the need neither to articulate nor codify the

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[57] The analysis proposed is very similar to that in Halewood (2013), which critically discusses the public or private character of Plant Genetic Resources for Food and Agriculture (PGRFA) (see Halewood, 2013). In this thesis, characterisation considers two aspects: The 'technological attributes' in terms of the subtractability (or rivalry in Halewood's terms) of the plant, and the 'man-made' institutional arrangements (or in Halewood's terms, the legal exclusion). In contrast to Halewood's analysis, which focusses on the plant's public or private character, this thesis uses the 'form of governance' to emphasise the actor's point of view and capabilities.

[58] The simplification is explained in terms of the skills and organisational routines required to be an inventor/innovator. Thus, in principle, an actor has the skills and routines to control and, eventually, replicate the use of the artefact. While using the artefact, they give it meaning. On the other hand, after the inventor/innovator engages in the imitation of a routine using the artefact, he or she develops other skills and organisational routines different from those of the actors controlling and replicating the artefact. While it is possible for an inventor/innovator to emerge from the user group, this would require them to have additional skills to those skills and routines needed to control and replicate the artefact. This would mean they were different from the others in the user group. Thus, this possibility is excluded in the simplification.

[59] Cowan and Foray (1997) explain the advantages of codification: It can reduce the costs of knowledge acquisition, and reduce the costs and improve the reliability of information storage and recall. Understanding (or recalling) implies acquisition of the language and models required to receive messages. Also, codification of information reduces asymmetric information, which is 'one of the important features (or at least potentially important features) of quality assurance standards'. In any case, Cowan and Foray

knowledge since they have no need to (re)design or replicate the artefact (and its use) beyond their control. Instead, the actors in the second group are aware of the advantages of articulation and can perceive benefits.[60]

The scope of the (re)designing of an artefact is bounded by the understanding of the potential inventor/innovator. The codification of knowledge can facilitate the sharing of knowledge among the second group of potential inventors/innovators, but not necessarily with the first group of users; also the type of knowledge shared can be restricted: Therefore, codification does not necessarily imply public access to knowledge (Cowan and Foray, 1997 p.599). Knowledge codification allows different levels of control to the second group (who codify) over goods emerging from the use of biodiversity, and the appropriation of benefits arising from such goods. Also, the potential inventor/innovator can gain certain power as a translator, problematising what he considers relevant, perhaps displacing actors and their meanings from the first group, and mobilising the resources to solve problems (Callon, 1986) in the (re)design.

Users with voice, and inventors/innovators, expect that the benefits (present and future) will exceed the costs of participating in the (re)design of artefacts. Since (re)design of an artefact and its application are not linear, there are high levels of uncertainty for participants and participation might not result in the appropriation of any benefit. This applies particularly to those with a voice, but without initial bargaining power or that find their bargaining power is reduced during the shaping process.

Analysis of the appropriation of benefits is conducted in relation to the governance over the public and private goods emerging from the purposive development of the skills and routines associated with the shaping of technology. Each of the organisations to which the actors (including potential inventors/innovators) belong, provides the motivations for those actors to bear the costs of producing and governing such goods.

(1997 p. 599) insist also that 'putting knowledge into a code serves both objectives: Sharing the knowledge among a certain group (of firms, or scientists) and keeping (intentionally or unintentionally) other agents out of the club. Thus, codification does not necessarily reinforce the public good character of knowledge. However, the existence of high fixed costs to produce a specific language (to protect the codified knowledge) would discourage any kind of strategy of private codification and would increase the incentives to make the codes public or semi-public. Thus, codification is a strategic instrument available at a certain cost for agents (or groups of agents) to pursue any strategy'.

[60] Intuitively, it is easy to consider other cases with uncodified and unarticulated knowledge, each of them with different costs and expected benefits.

Motivations include (i) adherence to 'the routinized organisational mechanisms that "enforce the rules"' (e.g., the wages paid for the performance of a task), (ii) standard and measurable behaviours (or outputs) that are outstanding and imply rewards (or freedom from sanction); and (iii) other motivations resulting from the rule-enforcement system (e.g., public recognition of a long and effective academic career) (Nelson and Winter, 1982 pp. 109-110).

Appropriable benefits arise from both public and private goods. Benefits accrue to individuals, to groups or both and, while some actors obtain high levels of benefits from both public and private goods, others do not. The form of governance over the public or private goods, which is the topic of the second research question, is based on the goods and their consumers (i.e., governing actors) at the time of consumption. For example, governance over a potato (or in Hess and Ostrom (2006) a doughnut) for one individual's consumption entails restrictions on the ability of others to consume it, however, enjoying a sunset does not restrict others from its consumption and it would be costly to restrict others from enjoying it (i.e., the familiar subtractability vs non-subtractability characteristic). Similarly, access to libraries is limited, so libraries are available to those who can travel to them and then access to their content is subject to certain governance conditions (i.e., first-come, first-served) since the space for and number of books is limited; however, it is difficult to *exclude* someone from using the library. Analysis of both excludability (e.g., institutional arrangements defining ownership, access or control) and subtractability (e.g., technological attributes related to consumption) should help to identify the form of governance over the goods (i.e., public goods, common-pool resources, toll or club goods, and private goods). Hence, the particular condition of living organisms of biodiversity are be analysed in terms of their essential elements: The reproducibility of live organisms (i.e., the claimed expansible nature of information (Cleveland, 1982)), which reduces their subtractability, and the conditions for this reproduction (e.g., a viable population).

Social welfare is dependent on individual decisions to the extent that (i) actors' skills and their role in organisational routines involves raising their voices and, eventually, the capability to act (agency); (ii) each actor exerts bargaining power through control of its means, including capital and labour, which enhance (or constrain) the appropriation of benefits; and (iii) actors' relative bargaining power is exerted when countries define formal institutions governing the commercialisation of goods emerging from biodiversity and the appropriation of benefits. The set of shaping paths provided by the institutional arrangements that actors' decisions (and organisational goals) create, influence income redistribution and changes to productivity. Greater benefits for biodiverse countries and equitable sharing of benefits are potential outcomes that derive from the existence of benefits and actors' skills and bargaining power.[61]

The proposed theoretical approach allows an understanding of the shaping of the technology under the institutional arrangements which explain how the benefits from goods emerging from biodiversity might be appropriated. Both those with agency to (re)design the technology, and the users that provide meanings, exist in an intertwined relationship. Evidence related to the shaping process and the appropriation of benefits could inform policy-making in biodiverse developing countries interested in the benefits from the use of biodiversity. The chapter presents the research design to implement this theoretical approach and provides evidence about how benefits generating process operates in practice.

[61] See fn. 7 and Section 1.11.1 Need for evidence-based policy-making, for the scope of this thesis.

3 Research design for the heuristic example

As explained in Chapters 1 and 2, the Nagoya Protocol is an new international agreement based on a consensus developed and developing countries that there should be greater benefits for more biodiverse countries and more equitable sharing of the benefits from using biodiversity. It is paradoxically that, governing frameworks in the past have meant that more biodiverse countries, for the most part, have failed to benefit from this set of resources. The protocol, which has been implemented at the national level, is a statement of governing principles. However, some consider that the protocol has proved to be an impediment rather than an aid to the development of new products emerging from the use of biodiversity and, so far, implementation of the CBD and the Nagoya Protocol has been unsatisfactory in relation to their agreed objectives. Evidence is needed to inform policy making in biodiverse developing countries and to achieve the agreed aims.

The evidence will be produced by addressing the two research questions formulated in Chapter 1, Section 1.1. The theoretical approach presented in Chapter 2 introduced a set of concepts, in which actors, organisations and institutions are relevant for explaining the innovation process (Research question 1: How are new products from biodiversity commercialised?), and the appropriation of benefits (Research question 2: What forms of governance over public and private goods are implicated in the appropriation of the benefits from the use of biodiversity?). This theoretical approach should reveal the other actors involved in the innovation process in addition to the inventor/innovator. Section 3.1 discusses the unit of analysis used and justifies the choice of case study as the research strategy and selection of the three cases. This selection explains also the selection of the first case -study, which serves as a heuristic example of the theoretical approach described in Section 3.3. Section 3.2 presents the operationalisation of the theoretical concepts and the data analysis method. Section 3.4 presents the implemented research design (data collection method).

As discussed in Chapter 1, Section 1.4, in the 20th century various forms of appropriation of the benefits from biodiversity focussed on the privatisation of goods, but ignored the contribution made by common-pool resources and collective actions for generating benefits from the introduction of new marketable products from the use of biodiversity. This suggests the need for a more thorough investigation of the biodiversity-based innovation process and the appropriation of the resulting benefits.

The case study research design investigates the heuristic example of the Jersey cow (see Ch. 4) and is complemented by some further elements (introduced in Chapter 5), which extend and deepen the implementation of the research design. The theoretical approach described in Chapter 2 is operationalised in Chapters 4 and 5 in the form of a 'template' or set of relevant issues that are employed in the case study analysis in Chapters 6 and 7. The findings related to historical and current experience are developed in Chapter 8 and are linked to the conclusions and policy implications discussed in Chapter 9.

3.1 Exploring and applying the unit of analysis

To develop an analysis template for gathering and organising the evidence relevant for policy, this thesis research presents the heuristic example of a historical case of a breed of cattle, the Jersey dairy cow. The unit of analysis employed to define the cases is species. In the case of cattle, it is useful to focus on a specific breed. The examination of a species (or a breed within a species) draws on the SCOT literature. The SCOT began by explaining manufactured products, such as the bicycle, and then was extended to include broader and more complex types of socially constructed artefacts, such as long-distance controls (Law, 1984), the rate and direction of development of a country's science base (Pavitt, 1998) and technical (e.g., news media) (Boczkowski, 2005) and regional (e.g., California agriculture) systems (Henke, 2008).

Using species as the unit of analysis is useful, first, to learn about the concepts and methods proposed for a biodiversity-based innovation and second, to compare the innovation theory developed for other types of artefacts (i.e., manufactured products) to that related to biodiversity-based innovation. These issues are explored in this section following discussion of the choice of the Jersey cow as a case study.

The Jersey breed of cow belongs to the species *Bos taurus* (see Ch. 4 Section 4.1 and Ch. 5 Sub-section 5.1.1). The domesticated species emerged originally in the Near and Middle East and north of Africa some 5,000 years ago. Between the 1300s and the 1500s, some domesticated cows were introduced into the island of Jersey, and after several hundred years of breeding, in the 19th century were recognised to have some distinctive attributes. Jersey is a relatively isolated island, which made it suitable for conducting a breeding process to achieve a distinctive breed (see Ch. 4 Section 4.1). It was a significant achievement and, currently, Jersey dairy cows are among the most widespread dairy cattle in the world after the Dutch Friesian-Holstein breed.

The Jersey cow was chosen first because of the availability of information (in the English language) on the history of the breeding process. The case is interesting since Europe is not particularly rich in biodiversity (Myers *et al.*, 2000; Zachos and Habel, 2011). The process involved in breeding the Jersey cow is well-documented in primary and secondary literature. The star of the breeding process coincided with the increase in publication in Europe following Gutenberg's development of printing in the 15th century and the rise in literacy levels among all social spheres after the 16th century (Clanchy, 1983; Tyner, 1998 p. 19). These facts contributed to the introduction of codified records, including point scales for grading these cattle and herd books, which recorded the lineage of individual cows and bulls. Most of these records are in English, although material pertinent to historical experience with the Jersey cow is available in other languages including Latin, German, French and Italian.

The second reason for choosing the Jersey cow as a case study is that, since Jersey is an island, it is possible to delimit the scope of the breed to a point in time when it was being bred locally and then to trace its shaping as a 'technology' and more widely diffused use. It is possible to account for the diffusion in the use of the breed throughout the world, from its beginnings until an end in the first half of the 20th century. This isolated breeding process did not occur in other species, such as Andean potatoes or Meso American maize, despite their greater importance, or even to other breeds of cattle. The isolation island location makes the case of the Jersey cow similar to Andean species, whose origin and initial spread is restricted by specific environmental conditions related to altitude (i.e., altitudinal vegetation zones).

The third reason for selecting the Jersey cow is that the learning process involved in the biodiversity-based innovation of the Jersey cow involves a well-documented valuation process for cattle, which is less common for other species. The familiarity of the cow allows the reader to envisage how this valuation occurred and how the valuable elements of the breed were retained and reproduced by users through further breeding. It is significant also that the process of valuation involved instances of the same species and comparison with other breeds with less well-organised breeding practices. Similar breeds can be defined by where they were developed, by their attributes, the products or sub-products produced by these breeds, or the agricultural practices related to their husbandry.

The existence of breeds in animals, a subset of the biological classification group called species, represents biodiversity at the level of individual species. In terms of biology, breeds can be considered ephemeral in terms of their evolution, but are important in agricultural economy. In the case of the Jersey cow, examining the breed is possible for the reasons cited above and useful because breed improvement can be linked to very specific mechanisms. For the plant case studies considered in this thesis, the unit of analysis is the species because i) there is no comparable detailed information on the definition and improvement of breeds and ii) the history of their development is sufficiently confined in time and space to support a focussed investigation. In addition, for the two plant case studies, the scientific literature and conservation/reproduction practices focus on the species. Parry (2004) observed that this focus on species is part of the colonial system and the rise of 'centres of calculation', such as botanical gardens and herbariums. These centres were created under Royal control (mainly in Europe and related to the building of taxonomies typical in modern science) to compare biodiversity elements brought from around the world, and to give a name and a place to species in an ordering system (Parry, 2004 pp. 27-31).

Species are commonly referred to as a unit of biodiversity,[62] which helps to identify the uneven distribution of biodiversity among regions and countries. Thus, use of the word species identifies that some world regions have ecosystems with particularly larger numbers of species. These conditions coincide broadly with 34 biodiversity hotspots[63], covering only 2.3% of the Earth's land surface, which support around 50% of plant and 42% of terrestrial vertebrate animal species (Mittermeier, 2004). The species as a unit of analysis is used in the background of the research (see Ch. 1 section 1.1, to explain the paradoxical unfair and unequal distribution of benefits for biodiverse 'developing' countries versus non-biodiverse 'developed' countries); and it helps also to understand this problem.

Use of the species as the unit of analysis allows us to trace what occurs around a well-established concept, in relation to actors and areas of knowledge involved. It allows us to study dissimilar stories using the same unit of analysis and to understand how processes take place and to corroborate facts. Actors involved in biological practices consider species in terms of accession or material; agronomics actors consider species as crops, or crop varieties; sociology and history actors consider species in terms of consumption products; and economists see species as raw material, commodities or branded products. These disciplines have contributed to the shaping process in which social practices and innovation intertwine, but have not *a priori* defined them as an innovation. On the other hand, a more refined or broader classification of biodiversity would be problematic because some actors would not have a meaning for it (e.g., the commercialisation of mammals in a market).

Despite the well-established character of species as a concept, there are controversies. For example, biologists find it difficult to agree about such issues as where a species originate, given that plants and animals can move and sometimes these movements cannot be traced. For example, birds fly across continents (i.e., migrating from Europe to Africa and vice versa), while pollen and seeds are distributed by the air,

[62] Biodiversity is not characterised only by plant and animals. Other broad components of biodiversity are fungi, bacteria, and other microorganisms, in which use of species as a unit of analysis has limitations, especially because little is known about these components, and confirming any of them as a species is more difficult and liable to be inaccurate.

[63] What these 34 hotspots have in common is that they account for 'at least 1500 endemic plants species and have lost at least 70% of the original habitat extent' (Mittermeier, 2004).

rivers, the sea, animals or humans; identifying the location of species involves following clues and, when available, historical records. Since species naturally reproduce, disappear, migrate or give rise to new species, it is possible to consider species variety in terms of where it originates (in the case of endemic species either domesticated or wild), where the diversity arose (for speciation from an original species to more species), and to where it is dispersed (particularly after a species becomes abundant). Once biologists acknowledge the presence of a species, they can provide quantitative measures of the number of species in a country or region. Using species as the unit of analysis in this thesis allows identification of the origin of the species, and how human intervention (agency) enabled its speciation, diversification and dispersion.

Species and their use precede the forms of appropriation and distribution associated with their exploitation for human purposes. Therefore, attaching the term innovation to a species is not a reference to the species, but to the social practices surrounding humans' use of that species. In the innovation process, the new product introduced into the market can the species itself in a stage of evolution (or shaping); its acceptance as an innovation is judged according to its commercialisation in countries distant from its country of origin (i.e., where it was naturally occurring). The two Andean species recently introduced into the international market studied in this thesis are: Maca (*Lepidium meyenii*) and Quinua[64] (*Chenopodium quinoa*).

The two Andean species are used for food and were domesticated and have been used by indigenous people for thousands of years. They were introduced into the international market only in the last half century by biodiverse developing countries (i.e., Peru and Bolivia), although both could have been exported to other continents since colonial times in the 16th and 17th centuries. Similar to the worldwide use of potatoes and maize diffused since the 17th century, maca and quinua had the opportunity to be produced and exported everywhere from Europe. Chapter 5 discusses this process.

Since the broad diffusion (in terms of international commercialisation of products) of these two species is comparatively recent, information on their shaping process and diffusion is available. Peru and Bolivia with the longest experience of diffusing the use of

[64] Quinua has several names in indigenous American Andean languages. In this thesis we use quinua which is common in Latin America and among Spanish speakers.

these species. Both are Andean and mostly Spanish speaking countries (the researcher's native language is Spanish).

Unlike potatoes and maize crops, the two cases considered here were only locally commercialised until few decades ago when their production was decreasing. A lack of local commercialisation (and use) of crops influences the risks of their disappearance and therefore are relevant for considering policy issues in developing biodiverse countries.

The two cases also differ. The extent of their commercialisation varies: One is a staple (i.e., quinua grain), and the other is a therapeutic food (i.e., maca root). They differ in their underlying knowledge and in the institutional arrangements in which the shaping process takes place: maca origin is a single country (Peru) and its use until few decades ago was only in Peruvian territory, which allowed Peru to claim its unique origin (i.e., justify the biopiracy discourse), while quinua origin is shared between Peru and Bolivia, and it is easy to find historical reports of quinua use in all Andean countries and even, in several other countries around the world. To enable generalisation based on the comparison of the results, the different extent of commercialisation (diffusion), underlying knowledge, origin and historical use are included in the analysis. Drawing on several adds support to our arguments since there are commonalities among them (see Section 3.2).

Not all research authorities agree about considering biodiversity in terms of parts (species) of an ecosystem, rather than the aggregation of these species in the biodiverse ecology giving rise to their variety. Chapter 5 section 5.1 discusses this issue. The inclusion of the three cases allows a richer analysis than consideration of a single species. The two species provide information on the biodiversity-based innovation process and the appropriation of the benefits arising from this process. The case studies identify issues relevant for the policy making at the level of the actors involved and the institutional context. Awareness of unintended consequences in relation to the Jersey cow case, such as the fact that most Jersey cattle worldwide is not produced anymore in the island of Jersey[65] helps us to consider this issue in the proposed theoretical approach.

[65] There are other unintended consequences, not necessarily related to the Jersey cow, but to cattle in general. During the learning process in which actors evaluate species previously used in a territory, the social choice for the 'shaped species' involves forgetting those other species and, eventually, their

3.2 The methodology

To address the research questions presented in Chapter 1 Section 1.1, we adopt a multiple case-study research method. It draws on learning from a heuristic example of analysis of the shaping of the Jersey cow based on secondary information. The heuristic example is necessary because, so far, the SCOT approach has been applied to the manufacture and related food sector aspects (including the farming or manufacturing spaces), rather than to living species. Following the theoretical approach for a living organism, the heuristic example provides a template for the case study analysis employed in the remainder of the thesis.

Case study analysis 'focuses its attention on a single example of a broader phenomenon' (Gerring, 2004 p. 343). The broader phenomenon is the biodiversity-based innovation. A case study is 'an intensive study of a single unit for the purpose of understanding a larger class of (similar) units' (Gerring, 2004 p. 342) where the unit is the species. The analysis is facilitated by a unit of analysis that is spatially and temporarily bounded. Thus, centres of origin, centres of diversity or places of dispersion are used to spatially localise the species and analysis covering the previous five decades establishes the temporal boundaries.

Yin (1981; 2009) explains why to use case studies instead of other methodological approaches than eventually could be used in a social science research. However, considering the research questions (i.e., 'why' and 'how' questions), the kind of research that is done (a doctoral research thesis) and the interest for understanding a contemporary phenomenon (i.e. the biodiversity-based innovation), the case study is the most suitable approach to use. Rather than being based on random selection, the case studies were selected strategically to enable observation of aspects relevant to the research questions over a well-defined period of time. Also, 'multiple-case designs are likely to be stronger than single-case designs' (Yin, 2009 p. 24). Since the research

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underlying knowledge. Cattle herding currently is associated today two unintended consequences. First, genetic erosion, since the replacement of or preference for one breed leads to the diminution or disappearance of other breeds or species - a trend in recent decades (FAO *et al.*, 2015 p. 41). Second, cattle production is an important cause in the food system of greenhouse gas emission, and occupies an important percentage of agricultural land use (see Ch. 1 Section 1.3).

involves three cases (the Jersey cow and the two Andean cases) this adds robustness (necessary for generalization) and helps to avoid false conclusions. The cases are complementary, the two Andean cases corroborate the findings from the first case and exemplify aspects coherent with the theoretical approach.[66] Robustness is related to understanding how observations take place under different conditions and involving different attributes (Stake, 2005; Eisenhardt and Graebner, 2007 p. 27). Robustness is enhanced by triangulation (Stake, 1995 Ch. 7). In theory triangulation alternative explanations of a phenomenon need to be validated. Two other theoretical approaches are considered to allow theory triangulation: NSI as a determinant of innovation, and appropriation of benefits based on ownership.

The historical case is also useful to frame the documentary requirements for the analysis. The historical case helps to structure how to do the historical documentary research and, therefore, to identify which elements are relevant to include in the analysis, specifically of the institutional arrangements in which the innovation process takes place. Thus, the Jersey cow case helps to identify issues that were already analysed an on which there is secondary information; those issues were also analysed for the Andean cases either with primary or secondary information. For example, it was possible to identify how local languages and lingua franca were suitable (or not) in the diffusion of the knowledge-related with the use of the species, and how markets consolidate around the State sovereignty. Because the diffusion (commercialisation) of the use of the Jersey cow from a local condition to worldwide use has a larger literature, it was useful to use this literature to identify the elements of analysis to be used for the cases of maca and quinua.

The two Andean cases are steps of progressive learning since the geographically isolated character of maca is as strict as in the case of the Jersey cow, while it is not the case for quinua. Therefore, the theoretical approach is built with the Jersey cow case, and validated with the maca case, in which the geographically isolated character is confirmed by the lack of historical records about the use of maca outside its centre of origin and domestication. Finally, the theoretical approach is challenged (to gain robustness) with the quinua case since its geographically isolated character can be confirmed (its has a

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[66] Yin (2009 p. 54) suggests two types of replication, literal and theoretical. Literal replication 'predicts similar results', while theoretical replication 'predicts contrasting results but for anticipatable reasons'.

centre of origin around the Lake Titicaca basin), but its domestication and dispersion occurred hundreds of years ago in all Andean countries.

The analysis is based on information on three major elements in the theoretical approach developed in Chapter 3: (i) the innovation process; (ii) the institutional arrangements affecting the innovation process; and (iii) the appropriation of benefits arising from the biodiversity-based innovation. The case studies are embedded in a real-life context, where the boundaries between case and context are blurred (Yin, 1981 p. 59). The theoretical approach focusses on the unit of analysis and explains how the species shaping process occurs within a specific context (i.e., influenced by organisations and institutional arrangements). The method follows both organisations and institutions in a coherent manner: At the micro level where actors use the species and make decisions about it, and at the macro and meso levels where the organisational routines and the institutional arrangements influence actors' social practices. Language is included in institutional arrangements since it influences the conditions for (i.e., costs of and expected benefits from) the articulation and codification of knowledge relevant to the shaping process. Some public and private goods are examined to identify the prevailing forms of governance over these goods, how their forms change and how the appropriation of the benefits arising from the innovation process are determined as a result.

The SCOT approach involves an explicit emphasis on how different social groups understand the meanings of and relationships among technologies (social group features that may be difficult to observe). It also involves considerable subtlety in both gathering the data and making their features vivid and clear in a written narrative.[67] If it can be assumed that people say what they mean and mean what they say, this allows an easier focus on the observable signs of intent.

The SCOT approach claims to achieve symmetry and impartiality in the analysis of an artefact (Bijker, [1989] 2012 p. 102). Therefore, the resulting explanations should not be considered the relevant reason to the acceptance or rejection of an innovation.

[67] In comparison, a critical policy study for example (based on discourse analysis, and bargaining or negotiation theories) involves taking meanings and understandings more at face value and looking at the spaces of agreement and the deadlocks or gridlocks that block these agreements within policy-making.

Explanations regarding the origin, acceptance or rejection of an innovation are part of the social rather than the economic or natural world (Pinch and Bijker, 1984). Thus, both successfully commercialised products (or diffused uses) and unsuccessful cases are understood under similar conditions.

3.3 The theoretical approach adopted

The SCOT approach, which explains *how* innovation comes about, is extended by the inclusion of evolutionary and institutional economics, providing a macro and meso level context in which actors make decisions about the shaping of an innovation. Given the interest in the appropriation of the benefits arising from the use of biodiversity, this theoretical approach is applied to units of biodiversity, both livestock and plant species (see Section 3.1). SCOT was applied first to manufacturing; use of the SCOT approach allows conclusions about the possibilities to expand its use to the examination of naturally occurring species -which are the consequence of biodiversity.

Actors' uses and meanings are built prior to the shaping of the species. Tracing how these uses and meanings were built allows visualisation of the conditions and limitations governing them (i.e., the restrictions policy-makers face when governing the use of biodiversity). The species shaping process is not linear and, thus, it is difficult to identify a beginning and an end to the process that excludes prior or potentially succeeding developments. However, it is possible to identify points in time when certain characteristics emerge and when triggers of rate and direction of the shaping take place. In the case of the Jersey cow, after England consolidated its military power, internal trade became common, and the organisations created to promote trade triggered the shaping process. Later, trade (including exports of the Jersey cow) expanded to North America, Australia and some regions of Europe and Africa. In the case of the Andean species, use of the species genesis goes back to pre-colonial times, and the shaping process that is the focus of this thesis was a reaction to the decreased production of maca and quinua. It was a reaction also, to some extent, to the imperial/colonial/dictatorial order that saw authority determined principally by military power (see Ch. 5 Section 5.2) and to the more nuanced détente between nations and social groups where trade was regarded as superior to war. The creation of organisations enabling cooperation and engagement of actors in trade and research routines triggered variation and selection in the use of the species.

Tracing a species through history allows *identification* of the species and its natural habits (origin, diversity and dispersion) (see Ch. 5 Section 5.1.1) to the interest of the actors and organisations that engaged in routines enabling the shaping of the species. Actors and organisations reduce the costs of engaging by following institutional arrangements. The CBD and the Nagoya Protocol are organisations that can define this institutional arrangements.

The three elements of the analysis ((i) the innovation process, (ii) the institutional arrangements affecting the innovation process, and (iii) the appropriation of benefits arising from the biodiversity-based innovation) help to describe the shaping process. The following three sub-sections discusses each of these elements individually. We explain the selection of some and not other elements.

3.3.1 The innovation process

Biodiversity-based innovation was chosen as topic of this research because of the part played by biodiversity and, particularly species, in social welfare (see Ch. 1 Section 1.3). The interest in how the innovation process occurs is motivated by the lack of evidence for science and technology policy-making aimed at promoting greater benefits for biodiverse countries from using biodiversity, and more equitable sharing of these benefits.

Species, understood as an element of biodiversity, is the unit of analysis, rather than the aggregation of species. As observed earlier, for some purposes, aggregation, such as consideration of ecological relations between species, would require a different unit of analysis. However, species is relevant because in a process of learning that has taken place over thousands of years, humans beings have singled out individual species for cultivation and use.[68] Cultivation and husbandry, which took over from hunting and

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[68] The process of 'singling out' species is an interesting aspect of humans' relations to the natural world. Agricultural practices of mono-cultivation are widespread, but in terms of history and cultural variance not universal. Example.g., meso-American cultivation practices often involved co-planting different species such as squash and maize and the specific values of these practices offers potential for further research.

gathering, are common forms of appropriating the benefits from the use of species. Thus, some of the uses of species include innovation activities. Social welfare increases as a result of the benefits obtained from the commercialisation of new products (goods that emerge from the shaping process) or diffusion of use of the species.

The extended development of use processes goes beyond the scope of other theoretical approaches such as NSI. In the NSI approach, firms and nation states are important for driving innovation, which is defined primarily in terms of commercialisation by profit-seeking actors. However, uses and meanings can emerge prior to the establishment of firms, and modern nation states and actors and organisations may not be governed by the goal of profit maximisation. Also, the centre of origin of a species may not respect nation states frontiers; some species may originate within a nation-state boundary, but others may not (see Ch. 5 Section 5.1.1). Thus, the SCOT approach is preferred to the NSI approach.

An understanding of the long history of use of species gives an idea of how innovation in food takes place. In the historical past, dietary patterns were related to external factors, such as the presence of edible species in migration or settlement zones, and weather conditions (e.g., annual Mediterranean climatic cycle) that made available fruits or game for hunters and gatherers. However, in the last thousand years, dietary patterns have been shaped by the cultivation of crops and animal husbandry. Thus, as well as ecological and economic factors, cultural factors have influenced dietary patterns at the regional and international level. For example, cultural factors explain, why indigenous communities in the Lake Titicaca basin resisted replacing quinua with other high yielding species such as wheat or barley and despite the fact that these latter had displaced quinua from other regions of South America, such as the Bogota Sabana in today's Colombian territory, where it was once a staple. Understanding the different meanings that a species assumes through processes of variation and selection requires a theoretical approach that recognises unintentional circumstances (e.g., Mediterranean climatic cycle) and unintended consequences (e.g., displacement of quinua from the Bogota Sabana) in the shaping process. This is similar to Pinch and Bijker's SCOT analysis of the bicycle, which highlights take-up of pneumatic tyres by sporting riders after their original introduction to reduce vibration (Bijker and Pinch, [1989] 2012 p. 39).

The SCOT approach suggests similar attention to both the artefact (in this case species) and users, and the evolution of use associated or identified with innovation. The shaping process involves an understanding of the species' technological attributes (i.e., reproducibility and variability). Some actors identify opportunities and problems in current uses of species and have voiced their concerns (communicate). These communications become input for actors with agency over the species, in the attempts to shape it, to translate opportunity into reality and to address problems. Other approaches to innovation and technological change, such as science, technology and innovation studies or the economics of innovation, focus on actors and, particularly those that assume entrepreneurial or intermediary roles and devote less attention to the innovation (i.e., the artefact). This thesis focuses on both actors and artefacts in tracing how species from biodiversity are shaped and become innovations that are commercialised at the international level. Also, by exploring how the appropriation of benefits from the use of the species can be explained, we consider those users that, at a certain point in time, were consulted (or involved) but who were displaced.

3.3.2 Institutions and organisations involved in the innovation process

Evolutionary and institutional economics, used here to extend the SCOT approach, coincide in recognising that innovation and learning produce benefits different than maximisation of profits or increased productivity (North, 1990; Hodgson, 1999). These two approaches were selected for the additional elements they provide, such as variety generation and selection, which are useful for examining the innovation process and for addressing the context (which often is defined by institutional arrangements), against which actors make their decisions. Since many of the decisions considered in the case studies involve institutional arrangements other than markets, mainstream economics premised on rational, perfectly informed decision-makers and welfare optimisers, is too reductionist. We need a more realistic approach, in which knowledge is highly contextual and humans are multidimensional, allowing them to address different needs simultaneously and in complementary ways. The features of institutional economics are useful in thiscontext.

Actors cooperate to form, maintain and govern organisations in their attempt to cope with the risks involved in addressing their needs. The institutions (rules, norms and standards) adopted provide a framework for incentivising and governing actors' innovation activities. Organisations define goals regarding actors' needs, respond to the agreed incentives and are governed by institutions.

Actors' skills and organisational routines lead to control and replication (or eradication) of use of the species in an environment and, thus, govern subsistence and surplus food production, which latter can be used to satisfy the needs of others. Changes in the environment (e.g. abiotic degradation or related biotic stress), competition, adversity (e.g. strikes or war (Hirschman, 1970 p. 13)), and other pressures, drive actors and organisations to *imitate* the performance of their skills and routines outside the environments or organisations where they are experienced. Imitation provides variation by identifying alternative skills and routines to address needs and allows selection.

The learning process underlying actors' skills and organisational routines regarding species began at the time that the actors domesticated the species. Institutions, such as language and culture, provide the context for the learning process, while family or community represent the organisations in which generations of actors learn about control over and replication of these skills and routines. Although institutional arrangements and organisations become frameworks for the control and replication of regular skills and routines, they can facilitate innovation. Innovation takes place when actors perform their skills and routines with information that is not enough (i.e., a set of clues) (see Ch.2 Section 2.3) to just replicate these skills and routines (or imitate them (Nelson and Winter, 1982)) to address individual needs or organisational goals. Biodiversity based innovation is the novel combination of species and *how* they are used (underlying knowledge about the species) (see Ch. 4).

The case studies analyse language as an institution (a norm and standard whose use is dictated by rules). The building of nation states involved the stabilisation of language (often by dictating replacement of language varieties – e.g., dialects or entirely distinct languages) leading to high costs. Following stabilisation, a common language helps to create models for thinking and a vocabulary to express those models, which reduces the costs of codification.[69] Knowledge codification involves different costs and rewards for the actors who give voice during the shaping process. The three case studies provide a visualisation of the learning process involved in actors' use of language and codification of their meanings related to the species. Codification of the knowledge underlying use of species is helpful to potential inventors/innovators. Also, it affects the bargaining power among those involved in the shaping process and, therefore, the distribution of benefits.

3.3.3 Forms of governance and appropriation of benefits from goods from biodiversity

Actors and organisations exert different forms of ownership over the goods emerging from use of biodiversity. Rather than focussing on ownership of something, this thesis research investigates the appropriation of the benefits arising from the use of species from biodiversity. This acknowledges that, although actors in biodiverse countries have more opportunity to exert ownership (or access or control), these actors are unable to ensure sufficient production of food for all their societies, from the use of biodiversity. Proportions of their population, especially those living in rural areas, including small farmers and indigenous communities with a close relationship to biodiversity, continue to live in poverty and suffer undernourishment (see Ch.1 Section 1.2).

The different forms of governance over goods (i.e., private, common-pool resources, club goods and public goods) derive from (i) the skills and routines of actors in an institutional context and (ii) the technological attributes of the goods (e.g., reproducibility of live organisms, which reduce the subtractability of goods), including the conditions for their reproduction to achieve viable populations. In addition to analysis of

[69] The three case studies are interesting in terms of their spoken languages. Jersey has been part of the United Kingdom since the 13th century. However, until the 18th century residents of Jersey spoke Jèrriais and French, after which time, English was introduced and today is the most common spoken language. Barbour and Carmichael (2000) contend that 'language may sometimes reinforce national identity (as in England) while tending to subvert the nation-state (as in the United Kingdom)' (Barbour and Carmichael, 2000 Ch. 1). In the highlands of Peru where maca is produced, Quechua was the main spoken language up to the first half of the 20th century, despite Spanish having been the official language since colonial times. In Aymara, the territory where quinua is believed to have first been domesticated, Aymara is the main spoken language. Quinua is produced in the Lake Titicaca basin. Since colonial times and up to 1977, Spanish was the official language of Bolivian; presently 36 indigenous languages in addition to Spanish have been declared official languages (see Bolivia, 2012 art. 5).

the public or private character of goods, analysing the form of governance focusses on the extent to which actors' voices and agency affect the ownership of, access to and control over goods, and how actors' bargaining power over complementary means, or the definition and enforcement of institutional arrangements, might affect the appropriation of benefits.

Different forms of appropriation of the benefits of the technological and institutional change have prevailed throughout human history. The most common form of appropriation of the benefits related to use of biodiversity is cultivation/husbandry. While hunter-gatherer forms of appropriation do not involve an initial cost to access the species, cultivation/husbandry involves the farmers deciding to cover the costs of preparing land for cultivation and protecting the crop in the expectation that the output will be sufficient to satisfy his family's food needs and to supply a surplus.[70] Control over the land was the primary means for enhancing farmers' capabilities to appropriate benefit.

In the 250 years, European societies have achieved technological and institutional changes that have increased agricultural productivity and allowed most countries to satisfy the food requirements of their growing populations, and allowed many countries to reduce the percentage of the population dedicated to the production of food. Some actors and organisations have become specialised in activities to further increase agricultural productivity and allowed appropriation of benefits beyond cultivation/husbandry. Forms of appropriation of benefits from the use of biodiversity that emerged during the 20th century include PBR, patentability of living things' uses or compounds obtained from the use of biodiversity, and the commodification of bioinformation (see annex A). The appropriation of benefits is enhanced by complementary means such as the capital accumulated via commercialisation of processed agricultural products, or the knowledge and contacts needed for the commercialisation of products.

[70] Diamond (1997) discusses some of the reasons for the long lasting process of hunting and gathering before the emergence of cultivation/husbandry and the appropriation of their benefits. These reasons include decline in the availability of wild food, increased availability of domesticable wild plants, which made domestication more rewarding and is related to more stable and better weather conditions following the ice age, the cumulative development of technologies related to cultivation/husbandry, growth in the population and competing interests between farmers and hunters-gatherers (see Diamond, 1997 Ch. 6).

While analysis of forms of governance traces emerging goods, the appropriation of benefits focusses on the actors and organisations that participate in the governance of goods. The meanings that actors assign to the use of an artefact defines the value in use expected from the emerging good. Actors and organisations participate in shaping the species and exert bargaining power. This defines the benefits appropriated via bargain struck between actors with complementary means that enhance the capability to appropriate the benefits from commercialisation of the emerging goods, or diffusion in use of the species, and definition and enforcement of institutional arrangements to govern the commercialisation, control or ownership of the emerging goods.

3.4 The research design

Data gathering was conducted in two main phases. First, a literature review to identify the actors, organisations and institutional contexts. Second, we conducted semi-structured interviews with users of the species to obtain more information and to fill in some gaps. The interviews focussed on identifying how actors use the species, problems related to their use, why certain issues are problematic, and the goods emerging from the use of the species. A standard interview guideline was prepared (see Appendix A), that included opened ended questions to allow interviewees' to discuss their experience. The interviewees dictated how the interview was ordered and had the opportunity to include aspects not covered by the prepared questions.

The interviews helped to identify where information was available and who could supply missing information (i.e., snowball sampling). In any case, an initial list of participants was obtained from internet sources (i.e., researchers, producers, commercialisation companies representatives, public servants, and so on). Data collection was considered completed when consistent material was available for all the questions and interviewees repeated elements already gathered from previous interviewees. Around 60 interviews were conducted, in Peru, Bolivia and Colombia., Interviewees were coded to guarantee anonymity (see Appendix B). The interviewees included researchers from research centres and universities, representatives from the productive sector (i.e., dealers and farmers), government representatives and consumers (i.e., chefs). To validate the information obtained we employed triangulation. was

Corroboration of information might indicate it is a true fact or a generally held opinion. When there was disagreement among interviewees, we investigated the particular issue in more depth in order to understand the reason for these differences. The interviews were conducted in Spanish and were recorded. Written notes were also taken during the interviews.

The data analysis was done with the transcription of the notes taken during the interviews. With a unique document of notes, wordings that fits to answer each question were identified and rephrased with the concepts of the theoretical approach. The rephrased inputs were validated through the text for different interviewees. These rephrased and validated inputs were used in the versions of texts used in writing the intermediary and final chapters.

This chapter introduced the research design, which justifies species as the unit of analysis and multiple case studies as the research method. This research design will be complemented in Chapter 5. The complementary aspects of the research design carry forward the animal case (the Jersey cow) to the plant species cases (i.e., forms of biological reproduction), provide a framework to understand the patterns of social structure, and refer the long history of use of the species with some contemporary issues.

4 The Jersey dairy cow: A heuristic example from which the framework of analysis is devised

Dairy products and beef are the most commonly produced and consumed sources of animal protein and both are derived from cattle.[71] This chapter presents the process by which the Jersey cow, the second most widespread breed of cattle in the world, was shaped. The Jersey cow is used as a heuristic example from which the framework of analysis employed in this thesis is derived. This framework is applied to two contemporary cases in order to obtain evidence to inform policy making in biodiverse developing countries aimed at promoting biodiversity-based innovation to increase the benefits for biodiverse countries, and equitable sharing of these benefits. The different actors and their practices as they use species during the shaping process (i.e., breeding or cultivation) are identified, as are the benefits which accrue to individual actors or to groups.

The analysis focusses on how the Jersey dairy cow has been shaped as a biodiversity-based innovation since the 18th century, when it emerged as a distinct breed from the then contemporary breed varieties in Europe, up to the 20th century, when the breed became broadly commercialised around the world. It offers a brief review of cattle domestication and the use of Jersey milk (and dairy products more generally) in order to highlight the conditions in which use of the species originated, to clarify the species-breed relationship and to provide context to the shaping paths that Jersey cow farmers might have followed (i.e., non-linear), and the unintentional circumstances and unintended consequences involved in the shaping process.

In manufacturing somebody *invents* something, which becomes an innovation when it reaches the market; in the case of biodiversity-based innovation, nothing is invented (i.e., nothing is necessarily innovative or new). It emerges from nature (i.e.,

[71] FAO statistics for 2010 indicate that from a total supply of 80.09 grams per day of protein, wheat and wheat products contribute 15.97 grams, rice contributes with 10.25 grams, cattle contributes 11.74 grams (bovine meat 3.61 grams, milk 8.13 grams), poultry contribute 7.58 (poultry meat, 4.87 grams, eggs 2.71 grams) and pigmeat 4.53 grams per day of protein (see FAO, 2017).

naturally occurring biodiversity) based on the stage of its evolution combined with users underlying knowledge. For example, not all species from nature are edible or suitable for consumption (see Ch. 5 Section 5.1); however, there is sufficient variability in nature to allow our knowledge to define (i.e., to value and to identify) which species can be used. This thesis understands innovation as the combination[72] of something from nature and underlying knowledge about its use, which might become a new, distinctive attribute.

Variability exists within individual species, which can be subdivided into groups. In the case of animals, these groups are breeds (see Ch. 5 Section 5.1). The Jersey cow breed is a part of the variability in cattle. The case of biological invention (i.e., something new from biodiversity-based innovation) differs from invention in manufacturing in that the 'new breed' resulting from the former is less clearly delineated than the innovation produced as a result of the manufacturing inbention. This is because (i) agreeing what defines the 'breed' is a social practice, and (ii) the capability to manage reproduction is imperfect and involves maintenance of genetic diversity within the 'breed' alongside the 'standard' qualities that have been defined. In other words, the technology of (re)production in animal or plant species is less precisely controllable than the technology of reproduction of non-biological artefacts (e.g., manufactured products). In cattle, sexual reproduction is a technological attribute that ensures replication of the genotype, although within a range of subtle variations of the phenotype.

The innovative condition of the combination of something from nature and the underlying knowledge,[73] is related to the agency (socially constituted capability to act) involved in the *defining*, *basic* and *ancillary* information. This combination is the source of selection among variation (i.e., using the variability among individuals in a species to produce a group or breed of animal). The defining information comprises the knowledge arising from the social practice of agreeing what is valuable in the species (or breed) and

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[72] Schumpeter *et al.* ([1934] 2005 pp. 65-6) considers innovation as the 'carrying out of new combinations' of materials and forces within our reach. The concept covers five cases: (i) 'The introduction of a new good – that is one with which consumers are not yet familiar – or of a new quality of a good, (ii) The introduction of a new method of production [...], (iii) the opening of a new market [...], (iv) The conquest of a new source of supply of raw materials, and (v) The carrying out of a new organisation of any industry [...]'.

[73]Evolutionary theory and understanding of knowledge consider 'how to do' and 'how to choose' as being 'very similar' since actors (and organisations) face uncertainty at the time actors perform their skills or make an individual decisions or social choices (see Nelson and Winter, 1982 p. 52). Thus, actors learn about the valuable attributes of the species and learn, also, how to identify other attributes.

identification of the related attributes;[74] the basic information refers to the knowledge about storage and processing/cooking practices related to the species (or breed); and the ancillary information refers to the knowledge about reproducing the breed based on cultivation/husbandry, healthy breeding and variations in quality stemming from cultivation and breeding. These three types of information are interactive: It would be undesirable to define attributes that cannot be reproduced or to master reproduction of breeds with no positive value in use.

Novelty in nature can occur also as the result of unintentional circumstances (i.e., mutations and adaptation to the environment such as darker skin colour animals being better adapted to cooler environments). Although these unintentional circumstances also produce variation (e.g., ecotypes), [75] they imply a lack of control over the reproduction. Variation arises from selection and, in the case of biodiversity-based innovation, variation can be achieved by (intentional) invention or as the result of unintentional circumstances. This explanation derives from the contributions to the understanding of the evolution of species made by Charles Darwin in the middle of 19th century (Darwin, 1859).

The heuristic example includes the three elements introduced in Chapters 1 and 2: (i) the innovation process related to the species considered as the artefact (Bijker, 1995), from its definition to its introduction to the market; (ii) the institutions and organisations involved in the innovation process (Nelson and Winter, 1982; North, 1990); and (iii) the forms of governance over public and private goods and appropriation of benefits arising from these goods, which emerge from the shaping process. The analysis addresses the two questions introduced in Chapter 1, Section 1.5, for each of the elements. The following sections address the three elements introduced in Chapters 1 and 2 and the associated questions addressed in the analysis.

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[74] The defining information can include valuation and identification knowledge as basic as picking the species for consumption, to complex forms that include the codification of information of specific attributes (based on comparisons with other species) (i.e., taxonomy) or the sequencing of DNA (i.e., genomics).

[75] Hubbell (2001) explains these options for a species and the individuals in that species, in terms of neutrality, which means that at all organisms are treated identically in relation to their per capita probabilities of giving birth, dying, migrating, and speciating (i.e., evolving into a new species) (see Hubbell, 2001 pp. 5-6). Therefore, populations are subject to physical (e.g., land area available for reproduction or natural levels of radiation) and biotic interactions (including with humans as breeders or other *ecological guilds*), but also to *demographic stochasticity* (i.e., random mutations occurring in reproduction).

4.1 The Jersey cow innovation process

In this section, we analyse how defining the breed and learning the skills and the underlying knowledge related to its reproduction, involve a social practice. As argued in Chapter 2, Section 2.2, it is useful to view this social practice in the case of the Jersey dairy cow using a SCOT lens. Although its domestication and breeding began thousands of years ago, the analysis focuses on the period from the beginning of 18th century when some of the actors and practices relevant to the breed's broader commercialisation can be traced.

Long before the 18th century, humans tended to make efforts to mane and manage wild animals and focus on certain attributes, which resulted in the definition and domestication of aurochs,[76] the ancestors to modern domesticated cattle (Diamond, 2002 p. 701). There are three domestication events associated with each of the wild subspecies from which modern cattle emerged. These events resulted in the two subspecies: *Bos taurus indicus*, from India, and *Bos taurus taurus*, from the near East, middle East (i.e., Western Asia) and north Africa, which moved to Europe some few thousand years ago[77] (FAO, 2007a p. 7). Domestication enabled a better understanding of these animals' utility, from its material character (i.e., for consumption, similar to mineral resources), to an understanding of its identity and lineage.

Hence, domesticated animals, along their material character, carry information about their phenotype and genotype (i.e., deoxyribonucleic acid or DNA). We know that genotype and phenotype are two different forms of this information and that the genotype-phenotype relationship is not one to one. The genotype is reproducible generation after generation, while phenotypic reproduction can involve subtle changes

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[76] Some authors suggest that some of the attributes that led to the domestication of animals, such as aurochs (larger than modern cows) and then *Bos Taurus*, included a preference for smaller animals, which were easier to manage, reached puberty sooner and could be herded (see Hall, 2004 p. 9). Also, some animals satisfied human's demands (e.g., for meat or milk).

[77] The most recent domestication event occurred around 5,000 years ago in India and involved the *Bos primigenius namadicus*, and resulted in the subspecies *Bos taurus indicus* or zebu (see Chen *et al.*, 2010). The next most recent event occurred around 8,000 years ago in the Near and Middle East (Western Asia) and involved the *Bos primigenius primigenius.* The third event occurred around 9,500 years ago in north east Africa and involved the *Bos primigenius opisthonomous*. The latter two species produced the *Bos taurus taurus* (or *Bos taurus*),which are the modern taurine cattle (see FAO, 2007a).

due to the environment and post-transcriptional differences in the expression of the genotype.[78] Phenotype information (although perhaps described differently) has been known to users of biodiversity for many thousands of years because of its relationship to animal utility. Animal domestication is a process of understanding the defining information (i.e., those valuable attributes that recur), basic information (i.e., how to store, milk or cook the products and sub-products) and ancillary information (i.e., how the animal reproduces or breeds). However, we know little about human practices related to species changes in prehistoric times.

A subset of the ancestral diversity of cattle survived a process of mutation, genetic drift, and natural and human domestication. In the last millennium, domestic livestock were modified at the genotype and phenotype levels: 'reshuffling of genes at each generation, mutation, and cross-breeding or admixture of different gene pools has offered new opportunities for natural and human selection' (FAO, 2007a p. 18).

The multiple sources of cattle in Europe and their close relationships with humans resulted in many populations with distinctive attributes, referred to as breeds. A breed is a standardised animal phenotype obtained by applying breeding and husbandry techniques, where the 'standard' is defined by humans. Breeds more suited to meat production were valued by communities in regions outside north central Europe, which led to these communities following different weaning practices. 'Later-weaning' was best suited to meat production and encouraged calves to gain weight while early-weaning made more milk available for human consumption (Balasse and Tresset, 2002; Beja-Pereira *et al.*, 2003). Early weaning is applied to the calves from Jersey dairy cows.

Communities following early-weaning practices in order to produce dairy goods had several optional shaping options. Tracing the lactation history reveals the different paths of shaping available to Jersey cow breeders. It is a history full of 'mystery, myth and impassioned debate' (Valenze, 2011 p. 3). Some societies considered consumption of cow's milk to be dangerous and repulsive for several reasons, including that: (i) it denied

[78] Sholtis (2008 p. 41) mentions that 'alternative splicing and other mRNA editing, RNA interference, the formation of protein multimers, gene regulation and a host of other factors' complicate the relationship genotype-phenotype, which is rarely one to one. 'The many steps between DNA sequence and trait (e.g., regulatory control of expression, mRNA processing, translation, interaction with other genes or proteins and the environment, and chance) add variation to the genotype-phenotype relationship'.

young animals the nourishment of their mother's milk, which put the progeny at risk; (ii) it was repulsive to consider, 'eating cheese made of breast milk', or to drink any animal fluid, e.g. urine; (iii) milk was a forbidden food for Christians on fast days since it came from flesh; and (iv) milk consumers could become ill because of its perishability or due to a lactose intolerance (Valenze, 2011 pp. 3-4).

During the Renaissance, it was believed that health could be maintained or corrected by adding or subtracting one of the four elements that make up the body (including blood), and milk was considered akin to blood. Its consumption 'warms the brain, is good for the stomach and lungs, and increases fertility' (Platina, [1465] 1994 cited in Valenze 2011 p. 61). Platina gave instructions for enhancing the benefits of milk consumption and lists a hierarchy by source: Goat's milk was the best, following by sheep's milk, and finally cow's milk (Valenze, 2011 p. 61). Despite alternatives, in the 16th century, Dutch farmers used cow's milk to meet the demand from Holland's huge urban growth. The links between cities and the country side allowed sale and consumption of vast volumes of milk. Dairy cows were 'better suited to the lowland pasture than goats', and 'the same amount of butter and cheese as [produced by] ten sheep' could be produced by a single cow (Slicher van Bath, 1963 cited in Valenze 2011 p. 91).

In India and other Asian countries, milk production was based on the water buffalo. Water buffalo, although somewhat similar in size and shape to the cow, is a different species. It was existed in Europe in the 6th century, and its milk provided higher amounts of solid than cow's milk (Popenoe *et al.*, 1981; Scherf, 2001). Thus, there were several options in Europe for obtaining milk, from both in Jersey and around the world. Cattle were part of the valuation process (see Ch. 3 Section 3.1) carried out by humans, who after overcoming their fears, and the related myths, were milk consumers. This valuation process was applied also to goats, horses, asses, camels and sheep (Valenze, 2011 p. 21). Humans came to value cow's milk after identifying its benefits, learning specific practices[79] and comparing milk production to the alternatives available in the prevailing environmental conditions and institutional arrangements.

[79] Implicit in the Saint Exupéry' quote presented at the beginning of this thesis, both the (animal or plant) species and the human who use the species become adapted to (or tamed).

The following two sub-sections describe the process of shaping the Jersey cow as a provider of rich milk and the roles played by the decisions and choices made by the actors involved in the stabilising the meanings in this process.

4.1.1 The shaping of the Jersey cow as a biodiversity-based innovation and the social practice of tethering

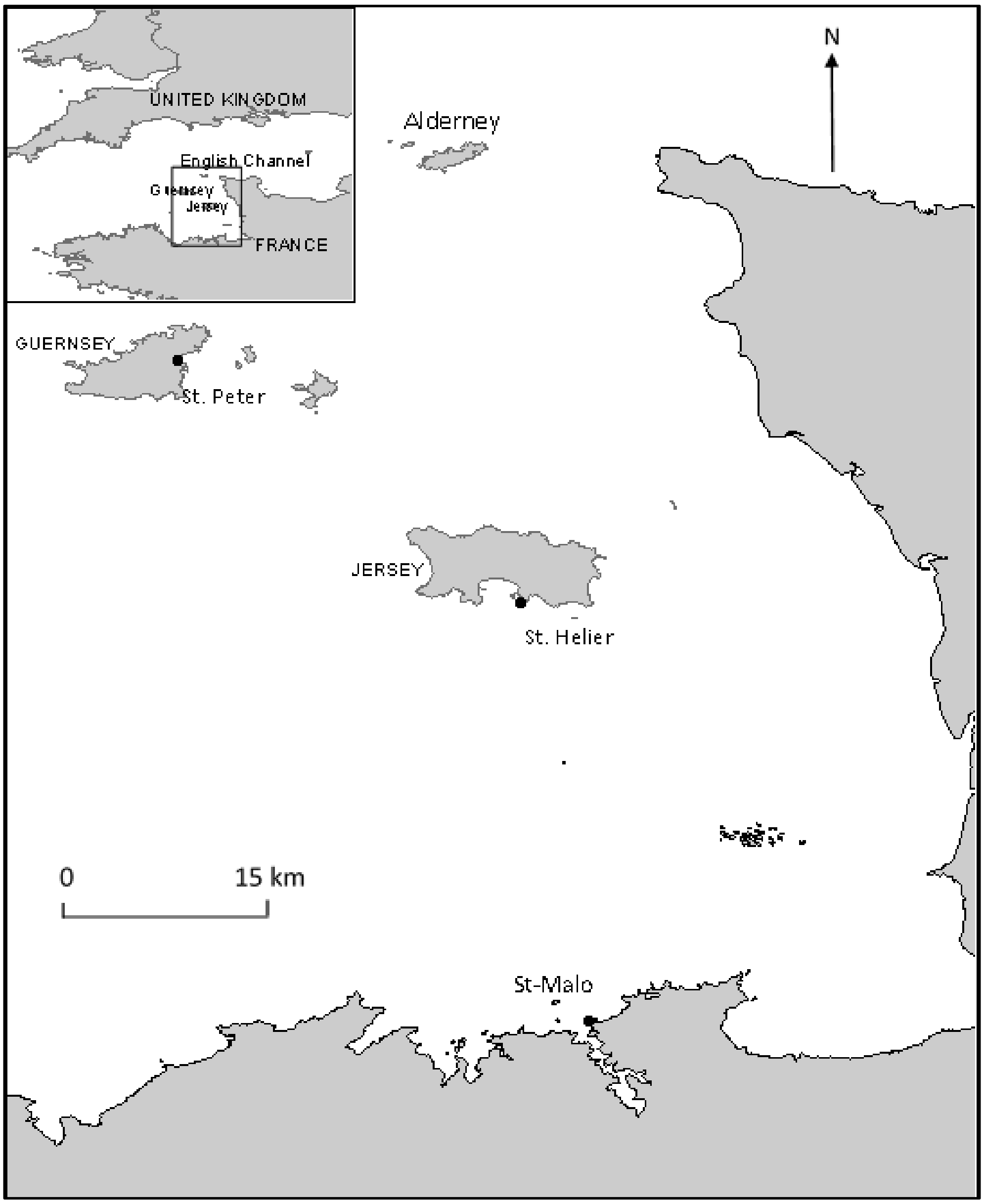
The island of Jersey is a self-governed United Kingdom Crown dependency and is part of the Channel Islands (see Map 1).[80] It is famous around the world for its dairy cows. Jersey farmers and other *social groups* (e.g., cattle dealers, who bought cows from Jersey for export to England), shaped the Jersey cow. The standardisation of phenotypes (certain attributes of the breed) of the Jersey dairy cow as a social construction is described in the sub-sections 4.1.1 and 4.1.2.

Jersey is a small island of 118.2km^2, located 161km from England and 22km from Normandy, in north-west France. Since the 13th century, Jersey has been self-governed and under the protection of the British Crown. Despite the obvious French cultural influence,[81] it is at a political distance from France, and more proximate to the United Kingdom. The British Government imposes no tariffs on Jersey's exports. Gow (1938) discusses how Jersey residents are known for their fishing skills and ability to moving from one industry to another as opportunities emerged. For instance, the 1700s, the small island registered exports of potatoes, tomatoes, tobacco, and woollen stockings and, in 1741, it's the first export of cows to Southampton (Gow, 1938 p. 21), in the south of England was recorded. Previously, the Jersey dairy cattle was locally produced and rarely commercialised (or was its use diffused).

[80] The maps in this thesis were produced using ArcMap 10.2.1 and data from DIVA-GIS (2016).

[81] Jèrriais, a derivative Norman French language, was spoken by farmers in Jersey until the beginning of 20th century, scarcely codified in the 18th century, and until that moment normally used in informal community and colloquial life (i.e., with family and friends), while French was the formal, official language used in religious services, politics and law. In the 19th century English become the dominant language (see Liddicoat, 1994).

Map 1. The Island of Jersey's location in the English Channel



Jersey farmers had more than one option for the selection of cow phenotypes to cultivate. They could choose to specialise in meat production or milk production or both. Until the 18th century, Jersey farmers, whose individual land holding were smaller than in other European regions, reared cows by tethering (securing the cow on a lead at a succession of locations), rather than herding. Tethering complemented early weaning,[82] and favoured cows for milk production. The milk was used mainly to produce butter rather than cheese (Le Cornu, 1900). Tethering allowed farmers to optimise their land use, which mostly was used to produce grains, mainly wheat, and rotated with horticultural products such as turnips, potatoes, carrots and parsnips for self-consumption (Le Cornu, 1900; [1859] 2000).

The land use issues peculiar to Jersey are related anecdotally and circumstantially to the social practice of tethering. Tethering could involve moving the cow as often as every two hours during the day. This practice was easier when the animals were smaller since it involved less risk and effort than in the case of fully grown beast. Tethering made it possible also to use pasture intensively, which reduced the amount of feed compared with other feeding practices. The Jersey cow produced smallish animals, the size of the cow allowed women, who would have found it difficult to manage large and less docile animals, to be responsible for tethering and milking (Le Cornu, 1900). This implies that a docile breed was valued. It was achieved through selection, slaughtering of larger less docile animals and allowing the most manageable to reproduce. Repetition of this selection led to a distinct breed of smallish size and docile nature. While a similar practice was applied to other species in order to domesticate them (e.g., dogs and pigs) and to achieve a desired size (e.g., ponies bred from horses), particular to the Jersey cow case was that led to a 'third' phenotypic attribute: The capability to produce high quality milk. This was the result of cows that produced higher quality milk producing and raising more and healthier offspring, or because of the preference for high fat milk to produce butter.

Tethering was described by an observer in the late 19th century, who associated the quality of the milk with restrictions placed on the cows which reduced their exertion:

> First - The cow not being allowed to roam at will and use her strength in needless exercise, her food, beyond the amount required for maintenance went to the development of milk, and that, too, a milk rich in butter-fat. Second- This lack of exercise also tended to produce the delicacy and fineness of form now so characteristic. Third -The system of tethering requiring the frequent removal of the cow from one place to another by somebody, made her familiar with man,

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[82] Given the small size of the landholding, only heifer calves raised to replace old milking cows and calves to become bulls were raised. See Section 4.3 on the relationship between land, feed and numbers of animals.

> produced the gentleness and docility which are such pleasing peculiarities of these animals. (Prof. Henry S. Redfield, in 1892, cited in Gow, 1938 pp. 42-3)

However, there is no evidence that the quality of the milk or docile nature of the cow was attributable to tethering but as early as 1734, observers concluded that the Jersey cow was superior to French cattle.[83] Dealers who transported cattle across the English Channel to England were paying high prices for the Jersey breed. In 1789, Jersey banned imports of French cattle to the island, arguing that the practice of re-exporting French cattle to England via Jersey was damaging to the reputation of the Jersey cow and reducing its price. The ban stabilised prices and allowed a more 'scientifically controlled programme of breeding' (Gow, 1938 p. 42).[84]

Until 1810, Jersey farmers were able to cross local animals with other types of cattle, especially the French Norman cattle, which were readily available and which were bigger and, therefore, produced higher carcass weights. However, most Jersey farmers continued to focus on production of milk and butter for domestic consumption.[85] This allowed the Jersey cow to succeed against the potential offered by Friesian-Holstein cattle from the Netherlands. Friesian-Holsteins were bigger animal and most of their dairy production was exported to England or Germany. Jersey farmers did not favour them because of the small size of farms in Jersey and the amount of pasture available. Also, tethering was more difficult when bigger animals were involved. The larger quantities of feed that would have been required would have competed with other crops. The price of hay and silage used as feed in the late 19th century was much higher compared to marginal pasture which could be utilised by tethering.

Jersey cattle attracted the attention of several people in England. Thornton ([1880] 2000)[86] cited Mr George Culley, the great Northumbrian authority on cattle, in his

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[83] In 1734, Rev. Philip Falle wrote that 'the cattle of this island are superior to the French;' and Thomas Quayle, in 1812, considered that 'the treasure highest in a Jerseyman's estimation was his cow' (cited by Thornton, [1880] 2000). It was fortunate that the milk quality coincides the Jersey cow's advantages (i.e. relatively small and docile animal).

[84] The ban remained mostly in force for over 200 years, despite the fact that around 1850 there was free trade between England and France and in the 1990s, free movement of cattle in the European Union was agreed.

[85] Meat consumption is widespread in northern Europe. Given the small size of the island, the preference for dairy products reduced the possibilities for meat production which required more land dedicated to production of pasture or feed. Jersey's meat demand was satisfied by imports from France.

[86] Thornton writings are available thanks to Hans Nørgaard, a leading historian on the Jersey breed. He built the webpage http://jersey-dk.dk, where he has compiled a large database of writings on the history of

'Observations on Live Stock' (1807). Culley's meaning for the Alderney cows (In England, Jersey cattle were described as Alderney cattle since this was the last port used to export them) was 'scarcely worth the trouble of naming at all, as he imagined them too delicate and tender ever to be much attended to by British farmers. […] were only to be met with at the seats of our nobility and gentry, upon account of their giving exceeding rich milk to support the luxury of the tea table' (cited by Thornton, [1880] 2000).

In 1811, Michael Fowler, as cattle dealer, representative of the Great West London Dairy (GWLD), toured the Channel Islands seeking cattle for export for his company. Fowler learned about the rich milk which Jersey cow gave and bought one of these 'curious' small cows as a gift for his new wife. His skill and routines of the dairy industry allowed him to appreciate the amounts of butter that could be produced from the milk of these small cows. He was surprised to find that, despite the high quality milk these cows produced, which was much valued in the form of butter in England, Jersey farmers did not provide the same care and high quality feed to their cattle as farmers in England provided their herds. He suggested that with some developments, the Jersey cows might become suited to English conditions and made some recommendations to this effect. In the 1830, some 20 years after Fowler's visit to Jersey, some of these recommendations were implemented by John Le Couteur, a Jersey leader and *aide-de-camp* for the British army, who encouraged other farmers to take up the breed.

The actors applied different meanings, based on their interpretative flexibility, to the phenotypic attributes of the Jersey cow. Tethering was the Jersey farmer's social practice, which, along with selective breeding, shaped the Jersey dairy cow. The shaping process was multilinear and involved several paths of shaping. Jersey farmers controlled and replicated husbandry skills focused on production of high fat content milk rather than large volumes of milk or meat, as discussed below.

Jersey cow. The original date of these writings is in square brackets (i.e., []) and a second date is the year reported of the publication in Nørgaard' webpage. Anne Perchard writings on Jersey cow are also in Nørgaard webpage. The writings have not numerated pages.

4.1.2 The role of voice, individual decisions and collective choice in the shaping and stabilisation of the Jersey cow breed

Jersey farmers and cattle dealers used their individual skills and organisational routines to select the Jersey cow. The versatility of cow's milk, its acceptability as a food ingredient and the role of the cattle dealers (Valenze, 2011 p. 3) help to explain its commercial expansion to other continents.

During the 18th century, the Jersey cow was not strongly differentiated from other breeds. For example, cattle dealers, who developed skills and routines to export cattle from the Channel Islands, chose animals bred in Alderney (the last port for exports to England), Guernsey and Jersey, with no clear distinction among them. This resulted in them all described as Alderney cattle. In Jersey, the farmers differentiated between cattle reared on the north and north-west coasts of the island, which had more pastures land, and those reared in the south-west of the island where the pasture was richer in nutrients and salt (Gow, 1938 pp. 34-35). Thus, there was lack of standardisation of the phenotypic attributes of the breed.

At the beginning of the 19th century, cattle dealers and farmers decided to cooperate to increase the benefits from the commercialisation of Jersey cattle. A group of cattle dealers selected two cows 'eminent for beauty and dairy qualities. One of them was considered to be perfect as to barrel and fore-quarters, the other as to hind quarters' (Gow, 1938 p. 51). The *interpretative flexibility* (Bijker, 1995 p. 13) of Jersey farmers and dealers gave different meanings to the cow. Before that time, Jersey farmers were not interested in how the cows looked and their meaning focused only on the cream content. However, cattle dealers gave meaning also to how the animals looked and their potential for commercialisation. The cow's 'beauty' was a subjective judgement. It increased the potential for commercialisation of the cattle and reduced the transaction costs associated with potential buyers' concerns about buying the animals. Milk quality is variable and depend in part on feeding practices; external attributes (when combined with other desirable attributes) provided a more 'objective' standard for the shaping towards commercialisation. They also promoted breeding aimed at distinguishable uniformity. The desirability of physical qualities was reinforced by cows being sold as heifers, at which point the milk quality that they would produce in the future is a matter of less risky speculation as the breed becomes more standardised.

Social groups are defined around a common meaning given by each group to the artefact. The meanings, in terms of the skills of and organisational routines performed by each actor, are distinguished by their meaning about the use of the species and actors' agency (Giddens, 1984 p. 9) in shaping the species. Their decisions can include: (i) using the species (i.e., farmers who reproduce it, dealers who buy the heifers, and consumers who decide on the goods emerging from the species reproduction and use) or articulating favourable messages about it, or problematising it (both 'using' and 'articulating messages' are forms of raising voice); or (ii) not using the species (i.e., farmers preferring other animal species to reproduce, or crops to cultivate, cattle dealers who do not buy the reproduced animals, or consumers who avoid consuming the goods emerging from the species). Both non-use of the species and lack of articulated messages about the species meaning are forms of not taking part in the shaping process, or exiting, (Hirschman, 1970 p. 3), and would result in the disappearance of the species since farmers would look for improved uses of species to account for 'slack' in the use of the breed.

At the same time, farmers' agency allowed variations in the species while cattle dealers' voices provided inputs to the farmers' attempts to gain benefits from commercialisation of a standardised breed cattle. Jersey farmers had the agency to act when they bred their Jersey cow. Cattle dealers had the agency to buy the Jersey cattle, but only if they anticipated there would be a demand for them. Although this negotiation between Jersey farmers and cattle dealers was uneven since only farmers could affect the physical condition of the cows through their breeding decisions, the relationship was dependent. Cattle dealers provided meaning, which served as an input to the shaping process, allowing the Jersey farmers with agency to use this input to bred their cow.

Jersey cattle underwent several changes between 1834 and 1850. Le Couteur (1850 (2000)) reports that the 'beauty' of Jersey cows was contested by cattle dealers. At the beginning of the 19th century, Jersey farmers did not consider it problematic to include 'ugly, ill-formed animal[s], with flat sides, wide between the ribs and hips, cat-hammed, narrow and high hips, with a hollow back'. Although some external attributes such as 'head of a fawn, a soft eye, elegant crumpled horns, small ears, yellow within, a clean neck and throat, fine bones, a fine tail, above all, a well-formed, capacious udder, with large swelling milk veins' were common (Le Couteur, [1850] 2000 p. 321), the rich milk was the attribute aimed at by Jersey farmers in their selective breeding. Some years after 1850, the breed achieved higher level of stabilisation to the extent that the meaning given by cattle dealers (i.e., external attributes as well as milk quality) was seen as inherent to the breed and cows offered for commercialisation began to conform to the profile valued by the cattle dealers.

Thus, cattle raising in Jersey was open to different options. Up to the beginning of the 19th century, Jersey farmers adopted a shaping aimed at milk production and milk quality. This was based on skills and routines prevailing at that time, the farmers did not believe other paths (i.e., other uses of the species) were feasible or at least worth attempting (Nelson and Winter, 1982 p. 258). The next section discusses how after the institutional and organisational arrangement allowed the cattle dealers to voice their preference for external attributes in addition to milk quality, the Jersey farmers included these attributes so that the breed was standardised in the breeding process. Stabilisation of the meaning given to the Jersey cow by the different actors allowed diffusion of use in the second half of the 19th century of a more standardised breed. Cattle dealers became translators for potential consumers, displacing Jersey farmers by prioritising what they (the dealers) considered relevant, which gave them a degree of control over the commercialisation of the cattle and the associated benefits.

4.2 International trade, Jèrriais and English languages and the role of the Royal Jersey Agricultural & Horticultural Society (RJA&HS) in the innovation process

At the beginning of the 19th century, the Jersey cow meant different things to the Jersey farmers and cattle dealers: While their meaning for Jersey farmers was milk quality, cattle dealers considered external attributes. This section discusses the standardisation of the Jersey cow. It shows that organisations and institutional arrangements facilitated cooperation between Jersey farmers and cattle dealers to achieve a breeding process and a stable meaning for the Jersey cow, and facilitated cattle commercialisation and diffusion of use worldwide. This thesis applies evolutionary and institutional economics to an analysis of organisations involved in the biodiversity-based innovation process.

Institutional arrangements provide a set of adaptable rules, loaded with intentionality and values, that facilitated the learning process (Nelson and Winter, 1982 p. 84). Farmers and cattle dealers operated under certain institutional arrangements, such as the political structure and the historic links between Jersey and the United Kingdom, and cooperated through organisations, including the Royal Jersey Agricultural and Horticultural Society (RJA&HS). Given these institutional arrangements, actors used the species, consumed the goods arising from their use and articulate (and even codify) messages about their meaning (raise their voice) (see Ch. 2 Section 2.3). Both organisational goals and institutional arrangements provide a context in which Jersey farmers and cattle dealers made decisions about the goods that emerged from the shaping of the Jersey cow.

The institutions associated with language played a key role in the shaping of the Jersey cow. Language can reduce the costs of coordination for the actors (North, 1990 p. 92). Also, some social groups are adept at codifying messages such that the costs of writing them are reduced.[87] Written language provides the conditions for articulating and codifying the meanings given to the species along its reshaping. Also, given that actors motivations include considerations of the costs of the skills or routines performed versus the pay-offs, freedom from sanctions and *ad hoc* rule-enforcement systems, low costs to accessing meanings facilitates satisfactions of individual needs and achievement of organisational goals. Articulated codified knowledge helped to communicate the meanings given by users of the cow.

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[87] See fn. 59. 'Initial codification activity involves creating the specialised dictionary. Models must be developed, as must the vocabulary with which to express those models. When models and a language have been developed, documents can be written. Clearly, early in the life of a discipline or technology, standardisation of the language (and of the models) will be an important part of the collective activity of codification' (Cowan *et al.*, 2000 p.225). It seems that cultures differ in their success at codifying knowledge and reducing the associated costs. Comparison is not straightforward since some cultures have developed what can be are considered benchmarking practices with the result that cultures with no such practices are assessed based on their lack; also these benchmarking practices allow articulation of what science is and maintain prestige and power. Halliday ([1995] 2006 p. 18) includes in these practices (i) evolution of grammar standards, transition from common sense knowledge to education knowledge and then technical (or disciplinary) knowledge, and (iii) generalisation (from 'proper' to 'common terms'), abstractness (from concrete to abstract elements) and use of metaphors (from congruent to methaphorical construals) (see Halliday, [1998] 2006a p. 27).

During the 19th century, the formation of nation states in Europe was accompanied by the growth of standardised languages shaped by national education systems, the presence of armies, and trade among countries. The transition from rural communities to urban conglomerates facilitated stabilisation of these institutions: More people received primary education and learned the national language(s), central markets were established in cities and facilitated international trade, trade communications vias improved and were controlled by the police and the armed forces. The institutions and organisations involved in standardisation of the Jersey dairy cow are analysed, with an emphasis on language as an institution.

4.2.1 How did institutions and organisations affect the shaping and standardisation of the biodiversity-based innovation?

For hundreds of years, Jersey farmers developed skills and cooperated, following routines that ensured their subsistence under the institutions and physical conditions prevailing on the island. Jersey had a feudal regime, but also the peculiarity of small farms that ensured an even distribution of land. Rather than following British law, which dictated that 'landed estate has to go intact to the oldest son, or next nearest of kin', Jersey residents adhered to the 'old and natural custom of dividing the land in equal parts among a man's children' (Gow, 1938 p. 38). This more even distribution of lands was accompanied by an egalitarian perspective: For centuries, Jersey's government was by democratic parliament elected by its administrative districts or parishes created around churches, and with special representation for the most populous districts. Institutions, such as the ancient form of distribution of land and the democratic decision making practices, affected the shaping of the Jersey cow.

In the 18th century, farmers were the majority of the population and they reserved most of their production for self-consumption: Horticulture was combined with raising livestock. Farmers' routines restricted cattle to the less fertile lands and the corridors separating crop fields, or the edges of paths. Farmers learned that tethering was a suitable practice to restrict their cattle to orchards and fields while also allowing them to benefit from the surrounding pasture and, after harvest, from the stubble and other left overs before the field was prepared for new planting. The effort of tethering was rewarded by the daily production of dairy products (Le Cornu, [1859] 2000).

When cattle dealer and British dairy expert, Michael Fowler, visited the island at the beginning of the 19th century, he offered some recommendations to enhance the benefits from the breed, based on British experience. Following Fowler's advice, the RJA&HS was created in 1833 to promote mechanisms for improving breeding, and shows were established to ensure animal quality. The RJA&HS was organised along the lines of the political structure of parishes to allow their representation. However, the RJA&HS considered external experts voice in its decisions making, including about the desirability of identifying a clear cow type for the whole of Jersey. The result otherwise could have been that each parish representative might have defended a different type of cow, which would have defeated the aim of creating a distinct Jersey breed (Nørgaard, 1983; Thornton, [1879] 2000).

Thus, in 1834, the cattle dealers, who in the democratic traditions of the RJA&HS, drew up an initial points scale to be used by judges at cattle shows. Two cows were chosen as models of 'beauty and dairy qualities' (Thornton, [1879] 2000) and thus helped to define the points scale. The points scale was approved by the RJA&HS (see Sub-section 4.2.2) and it became the basis for awarding prizes at cattle shows.

The institutional arrangements also affected the shaping process and the profits obtained from breeding. The land area limited the number of animals that farmers could keep to provide dairy products. While cows were valued because they provided milk almost year round, bulls were valued for ensuring reproduction and then, at three years old, being slaughtered for their meat. The birth of heifer calves ensured replacement of old milking cows. However, a farmer could only keep the number of animals that he or she could feed, with the result that they chose to export some heifers.

At the time the RJA&HS was created, it was in the interests of everyone involved – farmers and dealer and the RJA&HS, to choose a single breed for export, especially to England where a *pure breed* animal commanded a higher price. In the first half of the 19th century, advertisements offering animals from the Channel Islands used the terms 'selected' and 'from the choicest breeds' or 'the best breeds' or 'the finest breeds' (Parmalee Prentice, 1997-2000). Thus, there was lack of identity of a unique Jersey cow (see Sub-section 4.1.2 on the confusion between Alderney cows and the two different phenotypes from two areas of the island of Jersey). Hence, the RJA&HS's decision to listen to the cattle dealers' about what should be the *pure breed* model in terms of colour, size and conformity among the available in each area of Jersey.

The RJA&HS's goal of increasing the benefits from the breed was achieved by solving the problem of standardisation, in which cattle dealers had an interest. Closure was achieved by redefining the problem,[88] the decision to select a single breed was made when the cattle dealers considered standardisation of the beauty of the Jersey cattle as a path of shaping. A set of points was introduced for judging the cow's appearance at shows organised by the RJA&HS. One observer said that the increasingly rich gentry in England valued pure breeds and demanded Jersey cattle as:

> the most expensive animals because of their beauty (the Jersey has been known as the Arab of the dairy breeds) to graze their paddocks and provide thick cream and lovely deep yellow butter for their social life style as well as enjoy competing with their friends in the show ring. (Perchard, 1998)

Cows and bulls that stood out in the show ring received monetary prizes (see Sub-section 4.3.1 on bulls) and, most importantly, reputation and commitment to certain phenotypic attributes (see Sub-section 4.2.2 for definition of pedigree for bulls and cows) which were valued and attracted more money when the animals were commercialised.

By the 1850s Jersey cow had gained sufficient stability that Michael Fowler and some other cattle dealers began exports to England by using steamboats (Thornton, [1879] 2000), also then imitated this model to export the Jersey cattle to other countries. The United States of America (USA), was the first market, followed by exports, mostly via colonial expansion of the British Empire, to New Zealand (1962), Canada (1868), South Africa (1880) and Australia (1880). Other countries that imported Jersey cows were Denmark (1896), Brazil (1895 imported via Portugal), Kenya and former Southern Rhodesia, now Zimbabwe (Webster, 1996). Standardisation of the Jersey cow and other breeds helped the industrialisation of dairy production, which began in the USA and

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[88] Two ways to solve the problem are enabled by the SCOT approach. Rhetorical closure means that the problem disappears since a social group 'see the problem as being solved'; closure is achieved by redefining the problem such that, once a solution for one social group is identified, it is 'translated to constitute a solution to another problem' for a second social group. Therefore, for at least two social groups, the reshaped version has the meaning of a solution (see Bijker *et al.*, [1989] 2012).

Europe. The boom in Jersey cattle lasted from the middle of the 19th century to the beginning of the WWI; it then stagnated till the end of the WWII. However, dairy production maintained its performance based on the Holstein-Friesian breed, which was valued by milk dealers because of its high productivity (volume of milk) compared to the Jersey breed. From the 1970s to the 2000s, the problem of low yield from Jersey cows was solved by cheese dealers by rhetorical closure (Bijker and Pinch, [1989] 2012 p. 37): Milk with high solids content is important for cheese production since the costs of separating the solids during processing are lower (Perchard, 1998).

The Jersey cow passed from being used locally in Jersey to its cattle being internationally commercialised. Institutional arrangements, such as international trade, parish representation and the heritage law, affected the shaping process, while organisations such as the RJA&HS provided direction and increased the pace of standardisation of the breed. The shaping process was one of variation and selection, in which Jersey farmers and cattle dealers made decisions. The expected benefits drive actors' decisions about different pathways. In Sub-section 4.2.2 we discuss the codification of the knowledge regarding the shaping process.

4.2.2 The role of knowledge codification in shaping the technology

Certain users can articulate and codify information borne in the species. Language, as an institution, helps to reduce the costs of actors' cooperation to address individual needs and pursue organisational goals. Actors articulated and codified the information for different reasons. These included building confidence among actors (i.e., reducing uncertainty and stabilising individual expectations), building trust in the accuracy of information derived from direct experience under particular circumstances, and building reputation of the artefact via standardisation, which offered unambiguous commitment to those delivering and those receiving the product (David and Greenstein, 1990 p. 4; Lazaric and Lorenz, 1998 pp. 1-18).

The English language was used in the shaping of the Jersey cow to reduce the cost of cooperation between Jersey farmers and cattle dealers and to enhance the chances of pursuing the RJA&HS's goals. Knowledge codification required skills and routines based on some actors access to knowledge about the Jersey cow, and also skills and routines related to writing and reading the written information or, more generally, knowledge of the language and models for receiving messages on and how to use them[89]. Export of heifers to England required Jersey farmers to maintain the qualities of the herd (i.e., the Jersey pure breed) and, hence, obtain higher prices. Each individual farmer had an incentive to produce more heifers for export, but also to 'free ride' on the general reputation of cows from Jersey. To preserve the reputation, it was necessary to reinforce the standardisation of the animal, which involved use of English as codification language.

Language was an institution that evolved together with technological changes and other institutional arrangements. The Jèrriais and French languages were predominant in Jersey until the 18th century. Although Britain had maintained a military presence in the Channel Islands since the middle ages, the differences between Britain and France at the end of the 18th century, which were resolved only by the Napoleonic wars, meant that a permanent garrison of British troops was established in Jersey and, particularly, in the town of St Helier. St Helier became the main port for trade with England and, after the Napoleonic Wars (1803-1815), Jersey was seen by former serving officers as an economically advantageous place to retire to (Liddicoat, 1994 pp. 4-6). In 1824, a regular steamboat service between England and the Channel islands was established, which increased the opportunities for trade and tourism (Ramisch, 2007 p. 178).

Jersey residents spoke predominantly Jèrriais until the 18th century, when they began to speak English. Before that time, expectations about the use of Jersey cows were stabilised by the repetitive routines of Jersey farmers. The lack of written documents is evidence that Jersey farmers had internalised knowledge about the Jersey cow to the extent that they did not need to refer to it when communicating with each other, or they has a collective memory of uncodified but stable skills and routines for using the Jersey cow, and conventions for referring to the quality of the animal and its milk (Cowan *et al.*,

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[89] European and other world languages have enabled the development of technical knowledge. Rural languages, including some in 'Italy, England or Germany did not evolve these elaborated grammatical metaphors – they were not, after all, expected to serve in the contexts of advanced education and science' (Halliday, [1998] 2006b p.96). Jèrriais was one such rural languages, the English language was used for experimental scientific discourse. Its evolution included: '(i) expanding the noun as a taxonomic resource, … [as took place] in the 1600s; (ii) transcategorizing processes and qualities into nouns, relators into verbs etc., with resulting semantic junction; (iii) compacting pieces of the argument to function in an "information flow" of logical reasoning; (iv) distilling the outcomes of (ii) and (iii) to create technical taxonomies of abstract, visual entities; and (v) theorizing: Constructing a scientific theory through the reconstructing of experience' (Halliday, [1998] 2006b p.94-5).

2000). Although Jèrriais could be written, knowledge about the Jersey cow was not generally codified or articulated. English became a second language and, especially, for business overtaking French as the most common written language in Jersey. The English language became the norm for commercial purposes (Liddicoat, 1994 p. 8), at least in St Helier, and it facilitated showing and judging cattle based on the points scale (see Sub-section 4.2.1) used in England. So, codification of knowledge about the Jersey cow in the 19th century was in the English language.

Each language (Jèrriais, French and English) implied different things in terms of whether or not to codify, and what to codify. These decisions had different costs that could be offset by the benefits obtained from the institutional arrangements. Codified and articulated knowledge (i.e., meanings) in English were convenient for those involved in the shaping of the Jersey cow. For example, it simplified to an informational character the meaning given by cattle dealers (see Sub-section 4.1.2), which was an input that Jersey farmers considered in the breeding process. Only farmers had the agency to shape the cattle and, therefore, to control the husbandry and breeding, to replicate or imitate these techniques and, eventually, to become inventors/innovators. Later, the cattle dealers could check whether the meaning given by them to external attributes (e.g., beauty) had been considered in the breeding process. The Jersey farmers' motivations were related to the benefits obtained from selling the breed animals to the cattle dealers as heifers or bulls.

Codification of the informational character of the animal was implemented in three tiers in Jersey. The first tier consisted of establishing the points scale in 1834; the second tier was implementation of the herd book in 1866; the third tier was marked by the introduction of production performance in 1893.

First tier. The scale of points

The first points scale allowed cattle dealers and farmers to codify how perfect Jersey cow and Jersey bull were defined. Tables 2 and 3 present the articles used to codify the perfect bull and the perfect cow (or heifer).

TABLE 2. ISLAND POINTS SCALE FOR BULLS, 1834

Articles	Description	Maximum Points
1	Purity of breed on male and female sides, reputed for having produced rich and yellow butter	4
2	Head fine and tapering; cheek small; muzzle fine, and encircled with white; nostrils high and open; horns polished, crumpled, not too thick at the base and tapering, and tipped with black; ears small, of an orange colour within; eye full and lively	8
3	Neck fine and highly placed on the shoulders; chest broad, barrel hooped and deep, well ribbed home to the hips	3
4	Back straight from the withers to the setting on the tail, at right angles to the tail; tail fine, hanging two inches below the hock	3
5	Hide thin and movable, mellow, well covered with soft and fine hair of a good colour	3
6	Forearm large and powerful; legs short and straight, swelling and full above the knee, and fine below it	2
7	Hind quarters, from the huckle to the point of the rump, long and well filled up; the legs not to cross behind in walking	2
	Perfection	25

Note: No prize shall be awarded to a bull having less than 20 points. Source: Gow (1938 p. 53)

TABLE 3. ISLAND POINTS SCALE FOR COWS AND HEIFERS, 1834

Articles	Description	Maximum Points
1	Breed on male and female sides reputed for producing rich and yellow butter	4
2	Head small, fine, and tapering; eye full and lively; muzzle fine and encircled with white; horns polished and a little crumpled, tipped with black; ears small, of an orange colour within	8
3	Back straight from the withers to the setting-on of the tail; chest deep, and nearly of a line with the belly	4
4	Hide thin, movable, but not too loose, well covered with fine and soft hair of good colour	2
5	Barrel hooped, and deep, well ribbed home, having but little space between the ribs and hips; tail fine, hanging two inches below the hock	3
6	Fore legs straight and fine; thighs full and long, close together when viewed from behind; hind legs short, and bones rather fine; hoofs small; hind legs not to cross in walking	2
7	Udder full, well up behind; teats large and squarely placed, being wide apart; milk-veins large and swelling	4
	Perfection for Cows	27

Note. Two points shall be deducted from the number required for perfection in heifers, as their udder and milk-veins cannot be fully developed. A Heifer will therefore be considered perfect at 25 points. No prizes shall be awarded to Cows or Heifers having less than 24 points. Source: Gow (1938 p. 53)

The scales changed over time with the addition of more items or more points for existing items. For example, a scale from 1850s included 31 articles for bulls and 31 points and 34 articles for cows and 34 points. These points scale allowed farmers and dealers to codify the defining information borne by the breed. The codification focussed mainly on those aspects that were more easily identified for commercialisation by those familiar with breed types, constitution, capacity, masculinity (in the case of bulls), and mammary development and dairy temperament (in the case of cows) (Gow, 1938 p. 57).

There was some dispute over one article: 'Purity of breed on male and female sides, reputed for having produced rich and yellow butter', or *points de race*. Between 1834 and 1866 the number of points decreased from four to two, when John Vaudin suggested 'that the *points de race* be deleted from the scales, as they operated harmfully to the interest of the breed' (Gow, 1938 p. 52). He based his claim on the frequent complaints about misrepresentations among animals competing in the shows, which could not be checked because it was impossible to check the claims made about pedigree.

Second tier. The herd book

The second tier of codification was implementation of the herd book in 1866, which solved problems of misrepresentation by requiring registration of pedigree for cattle from Jersey. Some considered this unnecessary since there was only one breed in Jersey, but the herd book was defended as allowing the pedigree of animals at shows to be checked. Inclusion in the herd book involved 'a preliminary registration at birth and a qualification later, before admission to the herd book' (Gow, 1938 p. 58).

Hence, the herd book was a mechanism for codifying further information (i.e., ancillary data, and cattle reproduction milestones) that was not available to show judges, but enhanced confidence among Jersey breeders. Detailed rules for registration and the qualification of animals ensured that the herd book information was accurate. The most important information included:

- Foundation stock - animals registered and admitted in the first seven years after establishment of the herd book, between 1866 and 1873;
- Registration to obtain an entry number in the herd book following qualification. Not all registered animals were assigned a herd book number; in principle, only 'progeny

of qualified stock, sired after qualification, [were] entitled to registration'. Once a 'qualified cow drops a calf the birth must be attested, within twenty-four hours, by a member of the Agricultural Department, who signs a certificate proving that the calf is the offspring of such cow. This calf must be registered within eight days from birth. The owner is given a certificate bearing a "folio" number, but at this stage the animal is not given any entry number in the herd book, and may be finally rejected';

- Qualification was the second step towards obtaining an entry number in the herd book: 'qualification requires a public examination of the animal by a panel of five judges (this panel is usually two or three judges) at a stated time and place. … The animals if passed by the judges, are graded as "commended" (average) or "highly commended" (above the average). The Secretary of the Island herd book is then authorised to assign a herd book number, with the grade designation C (commended) or H.C. (highly commended)'. The judges did not have a scale on which to judge, but worked according to consensus (Gow, 1938 p. 60).

In judgements, both in shows and for qualification, colour was mostly avoided as a condition for judgement; however, a 'solid colour' was considered important by many cattle dealers. These kinds of 'fancy' criteria were rejected energetically by the Jersey farmers who insisted on the 'large yield of rich milk' as the most important criterion (Gow, 1938 p. 59).

Third tier: The 24-hour butter test

The third tier of codification for production performance (ancillary information, variation in quality) was introduced by the English Jersey Cattle Society in 1893 in the form of the 24-hour butter test and reinforced in 1912 by the RJA&HS. This was considered a reliable means of ensuring authentic information about the dairy ability of cattle offered for sale to foreign buyers. It discriminated between good and less good performance and acted as a benchmark for the quality of milk being commercialised; there had been cases of 'poor milk' or watered down milk. Codification of the milk production was expected to support the Jersey cow's reputation, the description of the milk quality delivered by the Jersey cow via the farmer, the cattle dealer and the milk processor.

The 24-hour butter-test required an inspector to be assigned to a district that included a dozen or so herds. The inspector visited each herd once in a period of 14 days, without prior notice to the herd's owner. The inspector weighed the milk and took 2 ounce samples from two consecutive milkings (or 3 milkings in the case cows milked 3 times a day). The samples were sent to the RJA&HS's headquarters where the Gerber test[90] for butter-fat was applied (Gow, 1938 p. 63).

The information on the cows allowed farmers and dealers to compare the yields of milk and fat in a given period, the average fat level, the number of lactation days and the calving period. The RJA&HS awarded certificates of merit based on those numbers in three categories:

> A Cows - which exceeded 14 months between calving dates
>
> AA Cows - which did not exceed 14 months between calving dates
>
> AAA Cows – that produced the amount of fat required by Rule 18 in a test not exceeding 305 consecutive days, and not exceeding 14 months between calving dates. Rule 18 required a butter-fat level of 250.5 lbs in a test begun at or before the animal was aged 24 months, adding one-tenth of a pound to this amount for each day older than 24 months, up to the age of five years or over, when the requirement became 360 lbs of butter-fat. All records were calculated in butter-fat, the equivalent amount in butter being ascertained by adding 15% to the total fat. (Gow, 1938 p. 64)

These three tiers of codification occurred under institutional arrangements that evolved over time. The codification of information reduced the costs of cooperation between Jersey farmers and cattle dealers since it simplified the inputs from cattle dealers about their expectations. Both the shaping process, which led to a more standardised Jersey cow, and the codification were sufficiently flexible to cope with the obduracy of the cow (i.e., limitations on variation compared to manufacturing products). They were flexible enough to meet the limited agency of farmers to modify the cow, and to adjust the farmers' and dealers' skills and the organisational routines (i.e., shows) of the RJA&HS and the English Jersey Cattle Society. Progressive codification of the phenotypic information recorded systematically through devices such as the herd book, gave more certainty about the Jersey cow phenotype. Finally, the standardisation involved the commitment of Jersey farmers to provide (and of cattle dealers to receive)

[90] The Gerber test combined a chemical reaction (i.e., separation of milk fat from proteins by adding sulphuric acid) and a physical process (centrifugation). It was patented in 1891 under the name 'Acid-Butyrometrie'. The method is 'still used because it is simple, fast, low-cost and suitable for a relatively high sample throughput' (Badertscher *et al.*, 2007 p. 20). Application of the test requires training in the use and quality of inputs (e.g., acid concentration) and tools (e.g., centrifuges and tubes) used for the test.

the Jersey cow under the institutional arrangements, of the points scale, the herd book and the 24-hour butter test.

Codification of the underlying knowledge of the Jersey cow allowed farmers to commercialise their animals at a higher price. Many countries that imported animals from Jersey implemented similar codification tools (i.e., shows, herd books, milk quality tests) (Gridley and Barnes, 1869). Other users, including university and research centre' researchers, introduced new codification processes such as writing articles (Girardin and Morière, 1857), conducting studies, publishing books and compiling databases. The meanings given by researchers were considered by farmers with the agency for further shaping of the breed. Goods (public or private) that emerged from the shaping process, and their forms of governance and appropriation of benefits, are related to the institutional arrangements discussed in section 4.3.

The types of information that were codified increased to include artificial insemination, embryo transplantation and cloning techniques alongside codification of phenotypic and genotypic information.[91] Different forms of codification were used to codify new and more complex knowledge about the Jersey cow.

As well as identifying the Jersey cow and its milk quality, codification also helped farmers' decisions about which animals to slaughter. The Jersey cow is not a high milk yield breed like the Friesian-Holstein. Jersey farmers had agency to shape the cow and used codified meaning from cattle dealers as an input for decisions about breeding based on milk quality.

Use of English as the written language in Jersey facilitated the implementation of the points scale, the herd book and the 24-hour butter test, which directed the shaping of the Jersey cow. Organisations such as the RJA&HS established routines, such as the

[91] Artificial insemination of cattle began in the 1930s (see Landauer, 1933)). Heritage studies of Jersey cows expanded from phenotypic attributes (see Gowen, 1933) to predictions about breeding efficiency based on artificial insemination (see Trimberger and Davis, 1945). Prediction were based on identification by family (i.e. cow line) of different levels of fertility, rather than by climatic conditions or season of the year. In the 1950s, basic techniques were introduced to characterise cattle genotypes, such as mineral content (see Washburn *et al.*, 1955) and later DNA weight (see Trenkle *et al.*, 1978). In the 1950s embryo transplantation in cattle began, but only in the 1980s most of the modern techniques of reproduction became widespread (see Petac, 1987; Selk, 2002), and few years later cloning techniques (see Marx, 1988). These techniques maximised the cattle genotypification (see de Boer and van Arendonk, 1991; Hasler, 1992).

organisation of shows and cattle judging, which also determined the rate of the shaping process.

4.3 Towards privatisation as a form of goods governance and appropriation of benefits

This section discusses forms of governance over the public and private goods that emerged from the shaping of the Jersey cow, and how actors and organisations appropriated the benefits from those goods. The public and private form of governance over the goods emerging from the shaping process is explained by the technological attributes of the species (i.e., subtractability) and the institutional arrangements (i.e., excludability) in which the shaping process of these goods took place. The appropriation of benefits by actors and organisations related to public and private goods is explained by their roles in the shaping process (i.e., by agency, raising voice or exiting), their relative bargaining power over the complementary means (Ribot and Peluso, 2003) that constrained or enhanced the capability to appropriate those benefits, and the use of their bargaining power to define (and enforce) institutional arrangements to govern commercialisation and control or ownership of the benefits.

At the beginning of the 19th century, European communities were mostly located in rural areas, but several cities grew throughout the century. The growth of existing cities and the establishment of new ones come together with changes of the social structure and the skills and organisational routines. Cities, such as London in England, the largest city in the world between 1825 to 1925 (Chandler, 1987), and New York in the USA, the largest city in that country since 1790 (Gibson, 1998), enabled merchants to adjust the technological and institutional arrangements for satisfying demands for food. Farmers in proximate were encouraged to cultivate products to satisfy the growing demand for staples, vegetables, meat and other animal based produce.

The multidimensional character of actors, such as farmers and consumers, allowed them to cooperate within different organisations, and to consider complementary institutional arrangements. Institutions, such as the nation state, the education system, markets and language, built on previous institutions in which actors and organisations participated to achieve their individual needs and organisational goals.

The forms of governance are described with a focus on forms related to the material character of the species and the underlying codified knowledge. The analysis emphasises how these factors affected commercialisation of the Jersey cow. It examines the intertwining among the actors and organisations involved in the shaping process and the form of governance over *public and private goods*, and investigate the appropriation of benefits for actors. In depth analysis of how the benefits from commercialisation were distributed among actors (or organisations) and the levels of welfare of different actors (or social groups) is beyond the scope of this doctoral research.

4.3.1 How did public and private goods emerge from the governance of the Jersey cow shaping process?

Analysis of the forms of governance over the goods available for consumption refers to their subtractability and excludability. The focus is on the goods that emerged from use of the species. We study four goods: (i) dairy products and meat; (ii) the animals (cows and/or bulls) used for reproduction; (iii) the underlying codified knowledge; and (iv) the foundation stock. We also analyse reproducibility of the species (i.e., the expansible nature of information (Cleveland, 1982)), which reduced its subtractability, and the conditions required for reproduction (i.e., viable population).

Good (i): In the case of *dairy products and meat*, each Jersey farmer appropriated the benefits from use by self-consumption: Cows were milked and dairy products were consumed or sold locally, and animals (mainly male calves, old cows or bulls aged more than 3 years) were slaughtered and the meat was consumed or sold. Whatever the process, once the milk or meat was consumed it could not be consumed again. *Privatisation* is the form of governance over such goods and allowed the owners of the cattle to prevent others from consuming some of the dairy products or meat (excludability), while the subtractability of milk and meat made it impossible for others to consume such products (rivalry or depletion) (Hess and Ostrom, 2007 p. 9).

Good (ii): The cows and bulls used for reproduction. The farmer could sell his or her *cows and bulls*. However, this meant selling the animal's capability to reproduce, the capability of cows to calf and bulls to sire. If the farmer chose to keep his cows and bulls, they could be used to reproduce (i.e., to spread the genotypic information) and the resulting calves, in principle, could be governed privately and would provide further benefits.

Given the small land area of most farms, most farmers kept only herds of cows, since bulls were required only when the cows were in season, which was once a year. Most farmers borrowed a bull for stud services to avoid the expense and risk involved in keeping one themselves. Care was taken to avoid inbreeding (a fairly high risk given the small size of the island and the value put on best bulls). Thus, the breeding process was in the collective interest. (Thornton, [1880] 2000) reports that:

> In Jersey, bulls were looked upon (sic) as expensive animals to keep; for they are kept generally in very high condition, and the prize bull of a parish becomes in truth a parish bull. It is no uncommon, thing for a first prize animal to serve upwards of 300 cows during the season; consequently they are rarely kept over three years old. By some this is attributed to the viciousness of the animal increasing with age, but undoubtedly the true reason is unfruitfulness.

Governance of the siring service involved collective action on the part of both the bull’s and the cows/heifers’ owner. The possibility that bull’s owner could refuse to cooperate was reduced by the RJA&HS declaring that a prize winning Jersey bull from the island (see Sub-section 4.2.1), *must* make the animal available for siring services for a minimum of 12 months (Gow, 1938 p. 65). This reduced the excludability of the service since there was a disincentive to exclude neighbouring farmers. If the owner of a bull did not comply, the prize money had to be refunded to the RJA&HS. No compliance was based on the pay-off from an alternative use such as selling for export. The price received for exporting prize winning bulls was very high at the end of the 19th century, and much higher than the monetary amounts of the show prizes. However, the owner of a bull charged per service, which made the siring service excludable, and the cow’s owner paid an additional charge for every cow ‘that shall be in calf by such bull’ (Thornton, [1879] 2000).

Although a single bull could serve many heifers and cows, the herd book shows that most bulls were sold after one year. This avoided inbreeding or the pre-eminence of a single bull and its progeny (Blampied, [1965] 1979). Nevertheless, bulls serviced the cows of more than one owner. Thus, governance of the siring service implied a lower level of subtractability than consumption of meat or milk. However, the bull’s owner made an agreement with the cow’s owner in relation to the siring service, and this included conditions for providing such service and excluded those who did not comply with these conditions. Limits to the number of actors who could access the service (i.e., easy excludability) combined with a service with a low level of subtractability than in the case of meat or milk consumption, resembles governance of *toll or club goods*.

Good (iii): When Jersey farmers decided to aim for a 'pure breed', the RJA&HS implemented shows, its points scale, the herd-book, and the 24-hour butter-test. The farmers *codified certain levels of defining and ancillary information* related to their animals. This codified information included the ways in which the Jersey cow differed from other breeds, which cows and bulls were registered in the herd book, which had won show prizes and which produced the most butter-fat in their milk and had been awarded an AAA certificate. Once this defining information on the Jersey cow became available, it was difficult to exclude those involved in the provision of the information; information could be accessed without its being exhausted (i.e., it was available in the published herd book[92] or was diffused by word of mouth). In principle, this information was a public good because there are not restrictions on its provision or its access by actors (i.e., non-excludable and non-subtractable).

When the dominant language was Jèrriais (Section 4.2.2 First Tier), few records of defining or ancillary information (i.e., 'what the Jersey cow was for farmers' and 'how farmers used it') were available. The Jèrriais spoken by farmers in Jersey was scarcely codified in the 18th century, and only used in informal community and colloquial life (i.e., with family and friends). Codification began after new institutional arrangements evolved, such as the RJA&HS organisational routines of writing down 'what to sell/buy' and 'how to measure' it (i.e., scale of points), and consolidation of cattle trade between Jersey and England. Herd books were already available in England. In 1838, Col. C.P. Le Cornu, following the introduction of points scale, implemented the registration of animals in a herd book.

Similar to the case of the siring service, which generally was limited to farms proximate to the bull owner, the codification of knowledge in English required also of proximity, in this case not special, but in terms of language. The codification of knowledge

[92] The first volume of the herd book was published in l873; the second volume was published in l874 (see Thornton, [1880] 2000).

in English required someone familiar with: (i) the English language and the models for delivering messages; and (ii) the skills needed to benefit from the codified information.[93] In the 19th century in Jersey, English become the dominant language for commerce and social life on the island (Liddicoat, 1994). However, codifying and articulating in English and benefiting from the codified information do not seem to have been straightforward. French was the official formal language for religious services, politics and law.[94] The introduction in children's education of English teaching in the first decades of the 19th century and the establishment in St Helier of Victoria College in 1852, implied that not all Jersey residents were able to access the points scale and the herd book. This provided an incentive to promote English as the predominant language to reduce the costs of codification and articulation of knowledge and allow access to this codified information.

The versions of the herd book were published in English and most information was aimed at England, then the USA and later other colonial territories where English had become the language of business. Since the second half of the 19th century herd books for the Jersey breed have been published in English, including Bristol, Connecticut, in the USA (1869), by the Pacific Coast Jersey Cattle Club in San Francisco (1886), in England (1892), in Australia (1901), in Queensland, Australia (1914), in New Zealand (1903), and in South Africa (1928).

Thus, codification and articulation was for and by English speakers rather than French, Jèrriais or other language users, for those involved in the cattle business. This included the RJA&HS, which established rules for the codification of information on cattle and issued certificates of pedigree under the Herd Book Society's seal (Thornton, [1879] 2000). Hence, governance over good iii (*codified defining and ancillary information)* was contextual rather than absolute, and dependent on the skills of every potential user or the routines of the organisations in which users cooperated.[95]

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[93] This applies also to decoding the knowledge, which requires knowledge of the language and the message models.

[94] Most of the laws were written in French, which included those related to levies on the trade of cattle, since those Jersey-men with access to education studied in France until the end of the 18th century. The emerging newspapers, after the introduction of printing in Jersey at the end of the 18th century, were in French and included writings in Jèrriais.

[95] Cohendet and Steinmueller (2000) discuss context dependent information interpreting it as being related first to the cost and complexity of creating conditional statements or as effective means of 'codifying' knowledge as information, or as ability to recognise codified information (i.e., conditional statement), the

Other ancillary information, not referred to at the time Jersey farmers communicated with each other, held in the collective memories of farmers, uncodified but stable skills and routines, were costlier to access and difficult to codify. There are few records of management of Jersey cows before 1868, with the exception of a short book published in the USA on phenotypic attributes or values the in use of the Jersey cow (Parson Fowler, 1855). If the governance of information involves actors with specialised skills, for example, specific knowledge (i.e., climate or facilities) about a certain place or language,[96] this governance concerns *local* public good. It provided information about tethering, and herbal remedies for breeding cows' digestive problems. Governance over less specialised skills is *broadly public*, such as details on differences in the solids content in Jersey cow milk versus milk from other breeds of cows, and how to boil Jersey cow milk.

Good (iv): The *foundational stock*, which was the set of animals registered and admitted in the first seven years of the herd book, between 1866 and 1873, allowed the Jersey dairy cow to be described as a 'pure breed', from which 'pedigree stock' was obtained. Governance over this type of goods is over a *common-pool resource* (see Ch.2 Section 2.3), which was managed and owned by individual Jersey farmers. Every farmer owner of a cow (or bull) that was part of the 'foundation stock' was reputed to contribute to the pure breed (i.e., excludability of the cows' owners); subtractability levels were high since judging of the animals at shows served as a mechanism to limit the common-pool resource, to exclude others (e.g., foreigners) from benefiting from the Jersey cow's reputation.

The farmers learned how to benefit from maintaining the purity of the breed. However, its sustainability and the collective interest in it being maintained required further institutional arrangements:

> In order to encourage breeding from superior animals, new rules were enacted, to the effect that any person withholding the service of a prize bull from the public

creator 'must take into account not only the context of the information, but also the identity and capabilities of the 'receiver' of the statement (see Cohendet and Edward Steinmueller, 2000 p. 196).

[96] Codified information such as amount of fat or amount of butter from a certain volume of milk, and surveys of how to manage the breed or its production, began to emerge at the end of the 19th century. The spread of the Jersey cow and the intensification of its production was accompanied by new milking technics and reports of the presence and study of and cures for diseases. Most of this research was published in English, but the establishment of herds in the Scandinavian countries (Denmark, Norway and Sweden), meant that some was in other languages (see fn. 91). This reduced the accessibility of the information and the benefits.

> should forfeit the premium; that no person should receive a prize for bull, stallion, or boar until the animal had remained in the Island at least one whole season after the prize had been awarded; and that all heifers having had premiums adjudged to them should be kept on the Island until they had dropped their first calf; if previously sold for exportation, they should forfeit the premium. These rules became necessary, for prices began to increase. (Thornton, [1880] 2000)

The value of prize money became marginal as the prices for cows and bulls in the market increased. The RJH&AS tried to ensure that prize winning animals remained on the island for a certain time in order that the foundation stock would not be reduced. The risk of free riding emerged if Jersey farmers (or farmers from other of the Channel Islands) avoided using shows as a mechanism to ensure the purity of the breed and quality of the animals, but still benefited from its reputation. This reduced the trust of cattle dealers. Arrangements such as certificates of pedigree with the Herd Book Society's seal resolved this problem.

The routine of sharing the cow' defining and ancillary information among Jersey farmers, allowed to identify Jersey cow as a rich milk animal. Institutions, such inheritance and division of land, and forms of organisation, such as the family, a farm-based economy within the parish and the RJA&HS, allowed the uniqueness of the breed and the governance over the foundation stock to be a local *common-pool resource*. These institutional arrangements also ensured the private condition of the animals and their benefits to their owners.

4.3.2 How do actors and organisations give meanings (values in use) to emerging goods and appropriate the benefits from biodiversity-based innovation?

Section 4.3.1 discussed how the governance over public or private goods is not absolute, but contextual. The forms of governance vary based on the individual skills and the organisational routines of the user. This section discussed how actors and organisations appropriate the benefits from the use of biodiversity and provides evidence on the complementary means that constrain or enhance the capability to appropriate benefits. The section is organised around actors and organisations involved in the emerging goods analysed in section 4.3.1: (i) the Jersey farmer - actor; (ii) the bull's owner

- actor; (iii) the cattle dealer - actor; (iv) the RJA&HS - organisation; and (v) the set of Jersey farmers who owned the foundation stock - organisation.

Actors 'engage in purposive activities' and play the role of agents driving the institutions and how they change (North, 1990 p. 73). The multidimensional character of the actors means that they are involved in the subsistence of themselves and others. Procuring food (i.e., dairy products and meat) for subsistence satisfies these needs and promotes health, and reduces idleness. Failures to address certain needs may involve a *trade-off* (Max-Neef *et al.*, 1991 p. 17) with other needs. The actors' institutional context reduces the risk of failing in addressing their needs.

Benefits can be explained as the 'values in use' given by actors to the goods emerging from use of biodiversity. Benefits are derived from the meanings actors give to the use of the breed. The appropriation of benefits is based on the actors' skills (and organisational routines) in addressing their needs (and pursuing the organisational goals). So, 'some sort of stable accommodation between the requirements of organisational functioning and the motivations of all organisation members is a necessary concomitant of routine operation' (Nelson and Winter, 1982 p. 108). Each actor's (or organisation's) appropriation of benefits is analysed.

Actor (i): If the cost of *Jersey farmer's* skills (and organisational routines) is higher than the benefits expected from their consumption or sale (i.e., income), the farmer will decide to use his skills to cultivate grains and vegetables (e.g., wheat and potatoes), or to keep other animals (e.g., goats or sheep). However, if the costs are lower than the expected benefits, then the farmer will continue to use his skills and routines to produce dairy products.

When 'it is possible to measure individual member (or actor) "output" reasonably well; reward (or freedom from sanction) can then be conditioned on achievement of a satisfactory output level' (Nelson and Winter, 1982 p. 110). However, there are other benefits that are more difficult to consider since they involve long term expectations, cultural attitudes to responsibilities and rewards, etc.

In the Jersey cow case, *the Jersey farmers* received additional benefits to access to dairy products or meat. Both dairy products and meat are output goods that can be measured reasonably well, and result in an income based on levels of production.[97] However, Jersey farmers also considered other benefits such as lower risk of diseases related to consumption of dairy products or meat, social acceptance of such consumption (e.g., ethical or religious considerations), and aesthetic and hedonic preferences[98], which are more difficult to measure.

Knowledge is a complementary means that enhances the capability to appropriate benefits from the Jersey cow. Farmers, based on their husbandry knowledge, maintained a balance between the size of the herd that produced their dairy products and meat, and the available land area. An unbalanced number of animals could affect the availability of food: A large number of cows could reduce the availability of land for horticulture to grow staples foods for the family (i.e., wheat and potatoes) or animal feed, which would affect the dairy herd, and availability of dairy products and meat, while a too small number of cows would affect the availability of animal food and result in unused pasture land. An infelicitous balance would affect benefits to the farmer.

Property of the land and the cattle ensured the farmers' rights to use the cows and their production. 'Rights-based means' involve a community, state or government enforcing the entitled claimants claim based on ownership of a title, property deed or permit in the case of a dispute (Ribot and Peluso, 2003 p. 162). 'Structural means', such as fences, are technologies for enclosing the farmer's land and are symbols of restricted access by others. Such 'means' enhanced the appropriation of benefits to the extent that they ensured feed for the farmer's own animals and provided certainty (i.e., reduce conflicts) in interactions with neighbouring farmers.

Actor (ii): The owners of bulls provided value by using the bulls to sire calves or as meat. The owner of a prize winning bull at a show could choose between offering it to

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[97] Factors that complicate the measure of income include differences in frequency between dairy products (based on a daily production), and meat, which happens once for each animal. It is necessary also to consider the quality of both meat and dairy products, which is associated with several conditions, and the costs of their production. Risks associated with potential damages or injuries, such as the danger to handle a bull can offset the expected benefits. There is no information on cases of rejection for the consumption of meat or milk in Jersey, but several authors refer to diseases related to consumption of these products (see McMichael *et al.*, 2007), and social reasons such as veganism for moral or religious (e.g. Jainism, Hinduism, Buddhism) (see Spencer, 1996; Dundas, 2002), or individual preferences (e.g., food phobias or fussy eating) (see Dovey *et al.*, 2008).

[98] The introductory section Chapter 4 explains how milk consumption evolved overtime from being rejected in Europe, for example because it was not mentioned in the bible, to become accepted (see Valenze, 2011).

service cows in the parish for a payment or selling or exporting the animal at a price based on its reputation (Nørgaard, 1983).Keeping rather than selling a bull involved more expense and was more dangerous. Owners using their animals for siring service also did not use them to pull ploughs, etc. Steers after castration were less aggressive, put on weight more quickly (i.e., produced more meat in a shorter time), and could be kept in herds; bulls had to be isolated to avoid fights for dominance among them.

Keeping a bull to service cows required a viable population of at least one cow to ensure viability (i.e., conditions for expansion). A bull owner that tried to take all the benefits of a siring service needed cows that required servicing. This differentiates it from use of bulls as work animals (e.g., for ploughing). To enhance the appropriation of benefits required both the bull and cows, all of which required feed in the form of pasture, hay or silage. This involved a combination of structural and relational means including inherited land or capital to buy (or rent) land, and labour skilled in animal husbandry. The small size of Jersey farms restricted the number of bulls, heifers or cows that could be kept and the amount of land reserved for growing crops and animal feed. This bounded the appropriation of benefits.

Actor (iii): Cattle dealers valued cattle raised in Jersey as merchandise. Cattle dealers' benefits were the income derived from buying Jersey heifers, cows and bulls from Jersey, the place of production, and selling them to other farmers in England and then in the USA and Australia. The purchasing farmers were able to produce Jersey milk in other places, close to cities, or regions where demand for high quality milk was valued. Cattle dealers had links also to the market and structural and relational means such as steamboats.

Organisation (iv): The RJA&HS gave the meaning 'pure breed' to prize winning animals judged according to the points scale. The RJA&HS received income from organising the shows (i.e., entry fees and royal patronage from the British monarchs), which was used to fund the prizes. When the herd book was established, the RJA&HS received income from their sale and applying the Herd Book Society's seal to the certificates of pedigree (Thornton, [1879] 2000).

The mechanisms used by the RJA&HS to codify the underlying knowledge (i.e., points scale, herd book and butter test) were applied to reject animals that did not fulfil the requirements. These animals went for slaughter, which resulted in loss of the physical animal and its reproductive capability (i.e., siring in the case of bulls or producing calves in the case of heifers and cows). Jersey farmers were initially opposed to these mechanisms, but then realised that they also allowed a higher pay-off for exports of prized winning heifers and bulls. Once these mechanisms were implemented, Jersey farmers accepted them, despite their requiring costly procedures. For example, to avoid conflicts of interest, show judges were not allowed to associate an animal with its owner or breeder (Thornton, [1880] 2000) which ofter meant using foreign judges.

The decision to use the English language to codify knowledge was the result of a social learning process among English speakers since the 17th century. English was used for codification and a grammar was developed to write generalisations and theories, and text that could be understood based on a set of learned rules and standards. Although the French language had followed a similar learning process, the bargaining power of the United Kingdom over Jersey resulted in English becoming dominant. This ruled out use of Jèrriais, which, although its use would have implied lower costs to the population of Jersey, would have restricted communication to other areas.

The RJA&HS issued and implemented regulations in collaboration with the relevant authorities. This included establishing the points scale used in shows to award prizes and the imposition of levies on foreign cattle and offences related to imports of foreign butter (Le Cornu, 1900)). These routines were a relational means to enhance the RJA&HS's benefits.

Organisation (v): The farmers in Jersey maintained the *foundation stock* and received value in use from a set of animals with the capability to reproduce pedigree stock. All of Jersey's cattle farmers received benefits based on their skills and institutional routines. There are limits to common-pool resources; the foundation or pedigree stock could have diminished over time due to animal aging and declining fertility. Also, since up to 20% of the Jersey cattle on the island might be exported in the space of 12 months, there was a risk that the best animals would be sold. This would mean loss of the breed or loss of control over the foundation or pedigree stock.

In the latter part of the 19th century and during the 20th century, farmers in other countries maintained several pedigree animals exported from Jersey, which became the foundation stocks for farmers abroad. This demonstrated that concerns over losing control over the 'artefact' were real. In the 18th century, farmers had voice and agency to shape the technology and benefited from local production and commercialisation. During the 19th and 20th centuries, Jersey farmers benefited because cattle dealers exported cattle and paid high prices for heifers and bulls considered 'pure breeds'. Although this increased the Jersey farmers' economic benefits, it was the first step in loss of control of the breed by Jersey farmers: Jersey cows could be reproduced everywhere.[99] Currently, Jersey farmers do not raise cattle commercially: in a six hour walk across the island in 2015 'from the airport eastwards, then up to the north coast, [Bullough] saw just one dairy herd … and not much sign of anything but fallow fields' (Bullough, 2015 n.p.).

Since the early decades of the 20th century, the price of Jersey bulls has fallen and the cost of transporting animals from Jersey has increased. The Jersey farmers' cows and bulls have been displaced (or become an alternative rather than a monopoly) by cows and bulls dispersed worldwide, while the foundation stock is available *in vivo* and as semen straws or fertilised eggs. Jersey cattle in other latitudes adapt to the local conditions (in a further shaping process) and can thrive in other developing economies. In the last decades of the 20th century, commercialisation of cattle, semen and embryos involved Brazil, Central America, China and India: 'Jerseys do much better in tropical countries than other exotic breeds - they can withstand heat much better, they mature earlier, they calve very easily and are probably closer in their genetic make-up to the animals of these hot and humid countries, with their colour and quick adaptability to heat and altitude' (Perchard, 1998 n.p.).

In the purposive exercise of skills and routines, different actors gave value in use to the Jersey cow and appropriated the benefits from the goods and services that emerged from the shaping of the cattle. These benefits were affected by complementary means such as access to land, markets, labour or technologies.

[99] The development of artificial insemination techniques gave agency to veterinarians to obtain Jersey cow reproductive material independent of the Jersey farmers. Artificial insemination affected the appropriation of benefits making the pedigree available anywhere at low cost.

4.4 Summary and reformulated research questions

This chapter presented the proposed framework of analysis to explain the biodiversity-based innovation process related to the Jersey dairy cow. The Jersey cow passed from being locally produced in the island of Jersey in the 18th century, to its use being diffused and the breed and its products commercialised worldwide in the 19th and 20th centuries. The theoretical approach fits with the shaping process of the Jersey cow which was used locally until it became an innovation in the international market. Some of the uses of the Jersey cow were innovation activities supporting the export of heifers and bulls and diffusion of the use of the bred around the world.

The SCOT approach was extended by evolutionary and institutional approaches. This allowed a broader analysis of the non-linear perspective of innovation. Thus, the micro-level perspective of Jersey farmers was complemented by both meso (i.e., institutions affecting the breeding process) and macro (i.e., organisations and cumulative community learning process) analysis.

The theoretical approach focussed on how the shaping process occurred and, for that purpose, followed the concepts of actors with skills to use the species and give it meaning. These actors' meanings include favour and against. For instance, cattle dealers considered the external attributes of the Jersey cattle problematic for its commercialisation. Farmers with agency to shape the species, were interested in meanings as inputs to the breeding process in order to gain additional benefits.

Farmers and cattle dealers cooperated with each other around organisations, such as the RJA&HS, to address their needs, and achieve organisational goals, such as benefits from the export of pure bred cattle. Farmers and dealers cooperated under institutional arrangements (i.e., rules) that reduced the costs and uncertainties of their cooperation.

Articulation and codification of knowledge is convenient for the shaping process since it reduces the meaning to information. The process of sharing meaning and shaping the species continued over many years. At a certain point the Jersey cow reached a level of stability, which allowed the artefact to be used broadly. Standardisation was enabled because codification facilitated the building of confidence among actors, trust in the accuracy of the information and reputation of the Jersey cow. For historical and political reason, codification was in English, one of the European languages that evolved for the building of modern science. Codification in the English language overcame the use of the spoken Jèrriais.

Public and private goods emerged from the shaping process. Four goods were analysed in terms of the forms of governance and how actors or organisations gained benefits from them. The form of governance over the public or private goods derives from the technological attributes of those goods and the institutional arrangements. Jersey farmers considered those arrangements in the shaping process. Jersey farmers and cattle dealers gained benefits from the value in use that they gave to the goods that emerged from the use of the species. The benefits came from the purposive performance of their skills in addressing their individual needs and maintenance of the routines to pursue organisational goals. The benefits from participating in the shaping process were uncertain.

Similar to manufacturing, the shaping process is not linear since there is variability in the origin of selection. Unlike manufactured goods, the Jersey cow showed certain obduracy in the shaping process; the cow 'maintained' its attributes and performance, such as the low yield compared to the Friesian-Holstein breed, which the actors fail to change. From the actors' perspective, their capability to modify the species was limited.[100] Also, the shaping process was affected by unintended consequences and unintentional circumstances beyond the control of those with agency.

Although there are no actors that were indirectly affected by the innovation in the Jersey cow case, the framework of analysis opens the possibility of including in the analysis those not involved in redesigning the artefact, but who may be affected by the commercialisation of the product. Thus, use of the artefact is broad and flexible and allows several actors to give different meanings to the artefact. The meaning allows the actor: (i) to raise voice by (i.a) using it or the goods emerging from its use, (i.b) to articulate a message (for or against) or (ii) to exit the artefact.

[100] In the 20th century, the capability to modify species increased greatly with the application of scientific genetic techniques. However, some modifications are considered problematic (e.g., unethical or unsafe) for some users. This applies to consumption of LMOs.

The inclusion of the evolutionary and institutional perspective helped to explain the forms of governance over the good and how actors benefited from its use. Despite the easy excludability of the material character of the species and slack in the use of the breed that allowed the actors to consume the dairy products and meat and avoid exports of the animals, Jersey cattle became commercialised at the international level. The technological attributes (i.e., reproducibility) of the species and the institutional arrangements drove farmers and breeders to make it difficult to exclude others from appropriating the benefits.

This theoretical approach includes a set of concepts and methods that can be used by policy-makers to promote biodiversity-based innovation to enlarge the benefits for biodiverse developing countries and achieve an equitable sharing of these benefits.

The refined framework of analysis has led to a re-formulation of the research questions. The first question about the process becomes: How is biodiversity-based innovation shaped by the social practices of actors and organisations in an institutional context? The second question becomes: How do the forms of governance over public and private goods emerging from the shaping of biodiversity-based innovation affect the appropriation of benefits? Thus, a wording coherent with the theoretical framework and with the scope presented in the historical case study is used in the research questions. Also, coherent with the theoretical framework, in the second research question, the emphasis is on how the appropriation of benefits takes place, rather than on what forms of governance affect the appropriation of benefits.

5 The two Andean case studies (extending and deepening the research design)

Chapter 4 developed an heuristic example using the theoretical approach from earlier chapters. This chapter introduces the two case studies that are the focus of the empirical research (maca and quinua) and extends the research design. Chapters 6 and 7 adopt the analytical template which begins with the heuristic example and is extended in this chapter, and apply it to each of the two cases. The case studies provide evidence for policy-makers interested in biodiversity-based innovation, with a focus on how the shaping process and the appropriation of benefits arising from the use of biodiversity occur. This evidence should allow a critical perspective on the possibilities for pursuing the Nagoya Protocol's aim of appropriating greater benefits for biodiverse countries from biodiversity-based innovations, and more equitable sharing of these benefits.

This chapter is based on the research design applied to the heuristic example (based on species and introduced in Ch. 3), and extends (and deepens) the research design so it can be operationalised to analyse the two contemporary case studies. It is extended to include different forms of biological reproduction (sub-section 5.1.1), patterns of social structure (sub-section 5.2.1), and a historical (Section 5.2) and simultaneously contemporaneous background (sub-sections 5.2.2 and 5.3.2). The two case studies have some commonalities including that they are both Andean species that have been used by indigenous communities since pre-colonial times. For this reason, some common historical background information is provided (sub-section 5.1.2 and section 5.2) on the learned skills of indigenous Andean people that were likely used for the shaping process, and the organisations and institutional arrangements involved in the actors' decision-making.[101]

[101] As mentioned in the Jersey cow case study, the historical background to the domestication and use of the species emphasises the species' long history, clarifies the relationship between species and biodiversity in a territory, shows the pathways that traditional communities could have followed, and the unintentional circumstances and unintended consequences along the shaping process.

The chapter is organised in three sections following the template adopted in the theoretical approach (see Ch.2 Section 2.2) and the research design (see Ch.3 Section 3.3). Each section provides a context to facilitate reading and understanding the case studies, especially for those readers unfamiliar with the topic of biodiversity or the institutional arrangements in Latin America.

5.1 The artefact and the users

As in the heuristic example, each of the two Andean species is an artefact that can be used by actors (Section 4.1). Therefore, this section covers two aspects. The first sub-section presents the species as part of a broader conception of biodiversity, addressing the choice of the selected Andean species for this doctoral research. The second sub-section presents the actors and how they voiced (or not) their contributions to avoid deterioration of the artefact or to shape it. The first sub-section introduces the species, with an emphasis on those aspects of it that affected its flow between regions and its use, the second section discusses actors' agency and voice in influencing the shaping of the species and the appropriation of benefits.

5.1.1 Biodiversity and food species

Biodiversity includes all the variability in life forms within a specific group in a territory. The group can be at the level of genome, species, ecosystem or biome. A common way to refer to and measure biodiversity is at the level of the species (Gotelli and Colwell, 2001 p. 379).

Thus, biodiversity can be seen as an aggregation of species (richness) or as the density of a species in an ecosystem (Gotelli and Colwell, 2001).[102] Humankind passed from hunting/gathering, benefiting from that aggregate understanding about which species in the territory could be chosen and used, to a form of appropriation of benefits

[102] Gotelli and Colwell (2001) explain that although the more common and easiest way to measure biodiversity is to count species, quantification of biodiversity includes several options related to species richness and density (see Gotelli and Colwell, 2001).

based on cultivation or husbandry, in which humans selected species to increase their density within an ecosystem.

This thesis focuses on biodiversity as a source of food, where the concept of species is relevant since social identification of species (and the goods derived from them) determined diet. De Boer *et al.* (2006) indicate that dietary patterns or alimentation are explained by several aspects: i) ecological factors (e.g., ecologically induced differences between Mediterranean, Germanic and Celtic cultures – the former includes more vegetables and the latter more meat; in both cases these diets were the source respectively of many of the vegetables and meats in contemporary western diets), ii) economic factors (i.e., the 'natural rhythm' of an agricultural society where local production provides food needs, vs. 'global supermarket', where diet is based on what is available to buy); and iii) cultural factors (i.e., 'path dependence' according to what is available to what is available to buy vs. cultural categorizations and rules about what is allowed to be eaten and when' in subnational regions) (de Boer *et al.*, 2006 p. 268). Therefore, in the contemporary world the presence or not of species cultivated in a territory is part of the reason for its use or not for food, with other social practices and institutional arrangements also important.

Scientists have proposed standard names and classifications for species to understand their role in human diets and other human uses. Local, vernacular or common names can be confusing with different names for the same species or the same name referring to different species. This motivated the construction of detailed classifications to characterise species biodiversity. These include the International Code of Zoological Nomenclature (ICZN), and the International Code of Nomenclature for algae, fungi, and plants (ICN).[103] These systems identify species common in the human diet (at the level of regions or cultures), how they evolved through time and centres of origin, dispersion or domestication around the world that are (or were) particularly rich in species that form part of the human diet.

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[103] Biodiversity includes other groups than plants and animals such as bacteria, protozoa, fungi, chromista (including algae) and viruses which need a host in order to reproduce. Although many of these are of economic and social importance despite some not having been ultimately identified and registered, the emphasis on this dissertation is on plants and animals.

In addition to the scientific classification, the existence of breeds in animals, a subset of the biological classification group of species, contributes to biodiversity at the level of individual species. Breeds a more minor aspect of biodiversity-related science (e.g., conservation biology); they have different evolutionary time, they are relatively ephemeral since inter-breeding remixes their defining attributes. However, breeds created by human intervention are important for the agricultural economy and some cultures have been especially active in managing the outcomes of selective breeding. Breed management includes identification of valuable attributes, and mechanisms to articulate and codify those attributes, such as meetings and shows to ensure their presence and registration in pedigree or herd books, all of which mechanisms (including the points scale discussed in Ch. 4 Sub-section 4.2.2) build reputation. For example, the species *Bos Taurus* includes two subspecies: *Bos Taurus indicus* or zebu, and *Bos taurus taurus* or known *Bos Taurus*, and modern taurine cattle. This last subspecies includes hundreds of breeds including the Friesian Holstein and the Jersey famous for their dairy production, the Simmental and the Brown Swiss which are dual-purpose animals, and the Charolais famous for its beef (FAO, 2007a p. 58).

Plants are categorised in varieties rather than breeds.[104] Varieties are selected based on some valuable attributes and only a few varieties are important in world agricultural production. Plants varieties are registered with International Code of Nomenclature for Cultivated Plants (ICNCP), and the Union Internationale pour la Protection des Obtentions Végétales (UPOV or International Union for the Protection of New Varieties of Plants) , which were set up to support the appropriation of benefits for plant breeders.

Maize was ranked top for production (in tonnes) in 2014, according to the Food and Agriculture Organization (FAO) (2017) and is a good example to analyse both species and variety. The botanical classification of the species *Zea mays* includes four subspecies: *Zea*

[104] This definition of variety is based on variability within the same species. Variability can be based on the relationship between the plant and the environment where species sub-units are name 'ecotypes'. Complexities are introduced by (i) human intervention to reproduce preferred plants or avoid reproduction of undesired plants based on their phenotypic attributes; (ii) the microenvironment; and (iii) changes made in the past using different techniques. These factors make the sub-classification of species more complex than consideration of variability or the relationship between the plant and the environment, aspects that are not fully standardised in use in the literature, e.gl, they can be described as taxons, ecotypes, landraces, races, or subspecies.

mays subspecies huehuetenangensis, Zea mays subspecies mexicana, Zea mays subspecies parviglumis and *Zea mays subspecies mays*. This last is commercial maize. The agronomic classification describes maize as *Zea mays*. There are hundreds of varieties of maize, including dent corn (*Zea mays var. indentata*), flour corn (*Zea mays var. amylacea*), popcorn (*Zea mays var. everta*) and sweet corn (*Zea mays var. saccharata* and *Zea mays var. rugosa*). Dent corn is the most widely produced maize variety and has been subject to much 'shaping' (in the language of the theoretical approach introduced in Ch. 3) to produce 'new varieties'. These 'new varieties' are protected by UPOV (i.e., PBR) and other institutional arrangements (e.g., patents) in several countries around the world (see Ch.1 Section 1.4 on forms of appropriating benefits from the use of biodiversity).

Biodiversity around the globe is unevenly distributed: Most species have a very restricted geographical range of dispersion while only a few species - including *Homo sapiens* - are considered cosmopolitan since they are distributed over all continents and over a wide range of environmental conditions (Brown and Lomolino, 1998). [105] Biodiversity depends mainly on environmental conditions, such as latitude (e.g., the higher number of species between the tropics of Capricorn and Cancer), energy availability and the conditions allowing species to flow from one territory to another and to disperse within a territory (Gaston, 2000). In this last case, for some species, humans cooperating in indigenous communities have provided the conditions for moving and adapting animal and plant species over thousands of years. The conditions that favour continuing high biodiversity can be found in some 34 hotspots (Mittermeier, 2004) where there is a concentration or a large number of plants and of terrestrial vertebrate animals (see Ch.3 Section 3.1).

These hotspots are the source of seeds to produce food to feed human population. Based on what Vavilov (1930) called 'centres of genetic diversity', Kloppenburg (2014) identifies West Central Asiatic and Latin American regions as sources of some two thirds

[105] Biodiversity, as the aggregation of animal, plants and other species types refers to a few million (known and unknown) species. From the approximately 1.4m known species in the world, 86% occur on land earth and the remaining 14% are found in oceans (see Mora *et al.*, 2011 p. 5). Animalia is the biggest kingdom in terms of number of species, constituted mainly of 0.9m known terrestrial species of insects. The second biggest is the plantae kingdom, with 0.2m species. Only a very small percentage of species from biodiversity is edible, used, and dispersed by human beings: Some 35 animal species have been domesticated and 7,000 plant species are cultivated (see FAO, 2016).

of global food crop production (in metric tonnes) in 1988. Latin America is the centre of origin of maize, potatoes, cassava and sweet potatoes; Chino-Japan, Indo-China and Hindustan are the centres of origin of rice; and west central Asia is the centre of origin for wheat and barley (Kloppenburg, 2004 p. 181). In terms of animals, the FAO reports that west south Asia (including the Fertile Crescent which extends from the Persian Gulf, through modern-day southern Iraq, Syria, Lebanon, Jordan, Israel and northern Egypt) is the primary centre of origin and domestication for cattle, pigs, goats and sheep; the Indus valley is the main centre of origin for cattle, goats and chickens; and Latin America is the centre of origin of turkeys, guinea pigs, llamas and alpacas (FAO, 2007a p. 10).

Breeds and varieties follow a different geographic distribution from that of the species' centre of origin. The number of reported animal breeds in the Global Databank for Animal Genetic Resources[106] was 8,774 in 2014, 88% of which are present in only one country (i.e., local breeds) and the remainder are present in more than one region[107] or worldwide (FAO *et al.*, 2015 pp. 25-30). Europe and the Caucasus are the world regions hosting the highest number of breeds in part because breeds are considered 'separate entities even when they are closely related genetically', and because the institutions behind the inventory and characterisation of breeds historically were located in Europe; this coincide with an 'advanced state of breed inventory and characterization' (FAO, 2007b p. 14). The Holstein-Friesian black and white dairy cow can be found in 128 countries (FAO, 2007a p. 56).

Similarly, in the case of plant varieties, Europe host the largest number of reported new varieties. The PBR system is applied differentially to types of plants. It is used to some cereals and grains, such as maize, wheat, barley, soybean, sorghum and quinua, but it is applied much less to roots and tubers, such as potatoes. Therefore, although the explanation for the differences among countries and regions is similar to the case of animal breeds, technological attributes such as type of plant (and form of reproduction) are also important. For example, maize is produced in 168 countries around the world

[106] The Global Databank for Animal Genetic Resources is the backbone of the Domestic Animal Diversity Information System (DAD-IS) hosted by FAO. It is used to monitor the status of and trends in animal genetic resources on a world scale (see FAO *et al.*, 2015 p. 25). The DAD-IS can be accessed at http://dad.fao.org/

[107] The countries are grouped into 7 regions: (i) Africa, (ii) Asia, (iii) Europe and the Caucasus, (iv) Latin America and the Caribbean, (v) the Near and Middle East, (vi) North America and (vii) Southwest Pacific.

(FAO, 2017), but European countries have a concentration of 61% of the PBR records for this species in UPOV's Plant Variety Database. The top 35 countries for maize PBR registrations include the USA, South Africa, the Russian Federation, Argentina, and the 27 European Union countries, with between 500 and over 8,500 new varieties recorded. By comparison, Mexico, centre of origin of this species, reports only 407 new varieties (UPOV, 2016). For quinua, the Netherlands reports 17 PBR records, Denmark 7, and the remaining European Union 25 countries 3 or 4 each[108]; Peru, one of the centres of origin of quinua, register 1. Potatoes are produced in 162 countries and are an exception among roots and tubers with quite large numbers of records, mostly in European countries (between 300 and 4,000 records per country). Among Andean countries, Chile reports only 71 records for potatoes in the PBR (UPOV, 2016).

PBR are a common form of appropriation of benefits when commercialising seed of 'new varieties' (see Annex A Section A.1), and this often mean that seeds need to be bought more regularly as in grains such as quinua. The motivation for investing in new varieties is based on the expected costs and benefits to both breeders and farmers (Tripp *et al.*, 2007 p. 356). Form of reproduction is one of the attributes influencing these costs and benefits. In the case of roots or tubers, most plants reproduce through cloning, and the PBR system cannot easily ensure the appropriation of benefits for breeders since many farmers save some part of the harvest for use as seed the following season. European and USA companies have registered the highest number of new varieties under PBR, due to their advantages in the development of reproductive techniques such as hybridisation. Hybridisation requires the farmer to buy new seed each years since second generation seed loses 'its yield potential and its uniformity', and 'inbred parents are a form of trade secret [that] keeps competing companies from producing the same variety' (Tripp *et al.*, 2007 p. 357).

The difference between the centre of origin of a species and the region in which breeds and new varieties are reported shows, first, how species that have occurred for centuries, flow, and, second, the role of the institutions and organisations created since the early 1800s to appropriate the benefits of biodiversity. Although indigenous communities, such as those in Mesoamerica and the Andean region, have shaped several

[108] This situation is explained because the registration can be done for all the European Union countries.

varieties from ecotypes, races or landraces[109] through cultivation, the institutional arrangements did not enable the appropriation of benefits.

In this thesis, we use the term 'new varieties' to refer to varieties protected under the PBR system, while 'varieties' is used to refer to any subgroup of a plant species adapted to specific environmental conditions (i.e., ecotypes), and that have been exchanged among users under institutional arrangements (see Section 5.3.2).

Prior to the establishment of PBR (including in pre-colonial times), it has been suggested dozens (even hundreds) of varieties of maize (Benz and Staller, 2009; Doolittle and Mabry, 2009), potatoes (Salaman *et al.*, 1985 p. 159; Morales Garzón, 2007) and quinua (Tapia *et al.*, 1979; Tapia *et al.*, 2014) likely existed. The continual seeding of these varieties in an environment suggests that (i) these seeds have not resulted in catastrophic crop failure over multiple generations in a way that discouraged farmers from using them, and (ii) the yield of these varieties is not conspicuously inferior to the yields of immediate neighbours (yield variances with more distant farmers could have been explained by different growing conditions). The result was availability of several varieties in the same territory.

Species flow from region to region (i.e., species borrowed from rich biodiverse regions to poor regions and *vice versa*) should provide advantages to the recipients by increasing local biodiversity and the options of what to rear or plant. Since only a few of the hundreds of thousands of animal and plant species are edible and, therefore, worth hunting or gathering, the flow of edible species and identification of locations favouring outstanding yields, are relevant for human welfare (Diamond, 1997 p. 88).

However, since 1900s the successful introduction of sets of breeds and varieties has reduced the diversity of the plants and animals used in agriculture and affected human welfare.[110] In animals, 'the development and expansion of intensive livestock

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[109] As already noted, taxonomy and classification of units of biodiversity are complex since they involve factors that affect biodiversity such as human intervention, the environment, time when changes have taken place, and so on. See fn. 104.

[110] Modern agriculture has enabled the amount of food produced and yield to increase; however, 'it has also been responsible for considerable damage to biodiversity, primarily through land-use conversion […], but also through overexploitation, intensification of agricultural production systems, excessive chemical and water use, nutrient loading, pollution and introduction of alien species' (CBD, 1992). Several patterns of social structure and associated technological and institutional changes have resulted in increased yield, but also loss of biodiversity and, in many cases, less varied diets. These patterns include: Population growth

production and the export of entire production system have led to a reduction in diversity through the large-scale replacement of local breeds with a small number of globally successful breeds' (FAO, 2007a p. 71). In the case of plants, some species have become dominant worldwide. Maize, rice, wheat, potatoes, soybeans and cassava were the most produced staples by weight worldwide in 2014 (FAO, 2017). In colonial time, wheat and barley were introduced to Latin America, and their expansion and commercialisation is related to reduced production of quinua (Tapia, 2015), which was one of the three most important staples, together with maize and potatoes in pre-Hispanic times.

Species flow occurs by the intentional introduction of species (as in the case of staples such as wheat or maize), and by unintended consequences (e.g., movement by air, water or animals). It is influenced by unintentional circumstances (e.g., weather requirements which constrains growth and yield in some areas and minimal conditions for the plant to survive).[111] For example, for centuries maca remained marginal in the Peruvian wet *puna*, where no other crops were able to survive. Cold temperatures and low levels of oxygen were conducive to maca whose nutrients reservoir root was used for human consumption. Other species reproduced readily without human intervention and can develop into invasive weeds[112] in certain environments. The agency of humans and popularity of certain species resulted in their movement across different geographic territories.

While communities around the world have produced staples such as cereals (such as quinua), legumes, roots (such as maca) and tubers, intensively, fruit and vegetables have been subject to less intensive cultivation. Starchy products were favoured for their energy content. Although, in the last three decades, consumption of fruits and

beyond subsistence agriculture; the push to become specialised in manufacturing activities and services and obtain wages and monetary rewards; achievement of economies of scale in the production of certain types of foodstuffs, which makes these items relatively cheaper, and results in the unequal distribution of benefits. In the last three decades, diet in many regions in the world (i.e., countries in Latin America, North Africa/Middle East, Sub-Saharan Africa, Asia), have faced a nutrition transition including the fact that food production now relies on a limited number of energy-rich foods (see Popkin, 2002; Galluzzi *et al.*, 2011 p. 18). This has coincided with a rise in obesity and, paradoxically, undernourishment, even within the same family or community (see Galluzzi *et al.*, 2011 p. 19).

[111] Following the Holocene, weather conditions stabilised and new species emerged.

[112] Weeds are defined by their ability to restrict the growth of other species. Weeds are mostly rejected by humans, although they may be encouraged or allowed to survive to achieve certain organisational goals.

vegetables[113] (Trichopoulou and Lagiou, 1997; Cordain, 2007; Reiss *et al.*, 2012) has increased, consumption of these items varies by socio-economic status (Drewnowski and Specter, 2004), culture (ethnicity), gender, type of food, aesthetic perception, etc. (Kearney, 2010). Large-scale production of staple foods has increased more rapidly than population growth, which should reduce malnutrition around the world.[114] This has also resulted in a reduction in the prices of staples,[115] allowing higher earners to spend more money on other foods, such as fruit and vegetables. Two species recently introduced into the international market are maca, a root, and quinua, a grain, both of which are purchased increasingly by high-income consumers. These species are of particular interest to the extent that they derive from biodiversity hotspots and their recent entry to the international market makes it possible to trace the shaping process of these species.

This section highlighted several factors involved in the diversification and flow of a species and diffusion of its use as a crop. These factors include actors' decisions to use the crop, performance of the set of skills and routines required for its reproduction and the forms of biological reproduction of the species.

The two main forms to appropriate benefits are by hunting/gathering and cultivation/husbandry (see Ch.1 Section 1.4), each of which involves a pattern of social structure (Wittfogel, 1957 p. iii). Maca and quinua have become cultivated species. The next section explores the changing social structural patterns from hunting/gathering to cultivation/husbandry, and the changes that occurred in these patterns in the Andean region with the onset of colonialism, which resulted in new organisations and institutions. These organisations and institutional frameworks were the context for the shaping process of these two Andean species.

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[113] From a contemporary nutrition perspective, fruits and vegetables are important for providing micronutrients that lower the risks of certain diseases. High socio-economic status and culture are associated with higher consumption of fruit and vegetables (see Irala-Estevez *et al.*, 2000; Cooke *et al.*, 2004; Kimmons *et al.*, 2009; Restrepo B *et al.*, 2014). Also, the perception of benefits related to the consumption of certain products (see Redkar and Jolly, 2003; Reiss *et al.*, 2012) increases the chance of their consumption, especially for high income privileged citizens (see Popkin, 2002).

[114] However, other factors that price and availability of staple foods constrain the reduction of hunger across the world. High and volatile food prices derived from disincentives to invest (financial crises), use of food for biofuel or animal fodder (see FAO, 2011 p. 2), political instability and climate change all reduce availability of food for human consumption. Despite global efforts, poverty and undernourishment are especially critical in developing regions such as Central Africa and Western Asia (see FAO, 2015b).

[115] 'Apart from a peak in the early 1970s, the cost of food declined from the early 1960s until 2002, since when it … started an upward trend' to the levels of 1980s (FAO, 2011 p. 11).

5.1.2 Spaniards, indigenous Andean people and dealers: Agency and voice in the exchange of species.

This section focusses on how different actors (following the concepts of the theoretical approach) exerted agency or raised their voices to shape the Andean species maca and quinua before 1950. It emphasises the long history of their use by indigenous people and the intentional movement of these species from region to region. It shows that their diffusion of use as crops was not linear and relied on both ecological factors and human agency and voice.

It is interesting that the diffusion of the potato as a crop in Europe in the 17th and 18th centuries did not occur in the case of other introduced Andean species. Reports of Spanish chroniclers include implicit or explicit references to the diffusion of the use of Andean species in Europe. In the case of quinua (see section 5.2.2 and Ch. 7), there are reports of this species being available in some regions of Europe at the beginning of the 19th century, but its use was not diffused and it disappeared from some places where it had been introduced.

Although similar in terms of their Andean region origin, among the roots, tubers and grains grown in the highlands, maca and quinua differ in several ways. These differences allow a better understanding of the progress in or constrains on the innovation process. In the case of maca, it failed to be introduced to Europe in Colonial times, but after 1990 the maca flour became widely commercialised in Europe. In the case of quinua, the conditions were favourable for its diffusion as a crop and commercialisation as a grain in Europe, but it did not become popular, before the 1960s. This section discusses how actors learned and exerted agency over species flows after the arrival of Spaniards in America at the end of the 15th century and before 1960s. Chapter 6 and 7 focus on the history after 1960s.

Cultivation is based on learned individual skills and organisational routines, one of which involves knowledge about the types of weather conditions conducive to the seed. In the case of many cereals (such as quinua grain)[116] and legumes, a single seed produces

[116] Hunziker (1952) referred to quinua grain as a pseudo-cereal (Hunziker, 1952). However, it is not clear why to do so since cereals is a broad category. Interviewee DA believes it was a mechanism to differentiate

a plant that yields grains (or pods). The fruits of these species can be used as seed for the following season, given the predictable 'Mediterranean climatic'[117] type cycle (Hobbs *et al.*, 1995; Diamond, 1997 p. 136). Maize, wheat, barley, rice, beans and Andean grains such as quinua, kiwicha (*Amaranthus caudatus*) and cañihua (*Chenopodium pallidicaule)* follow these annual cycles, with variations depending on latitude, altitude, precipitation, etc. Likewise, in most tubers, a single tuber can be used as the seed for the next season. The tuber' plant reacts to reducing temperatures by accumulating carbohydrates which are stored over the cold season and the rest of the plant dries out. The most common tubers are potato, oca (*Oxalis tuberosa*), olluco (*Ullucus tuberosus*) and mashua (*Tropaeolum tuberosum*). Maca (Lepidium meyenii), despite having accumulated carbohydrates for the cold season, has certain distinctive features, which are discussed in Chapter 6. There are forms of biological reproduction (e.g., clonal and sexual),[118] forms of reproduction in grains, roots and tubers are discussed because they are related to the species under study.

When the Spaniards invaded America at the end of the 15th century, there were both differences and similarities in their methods of cultivation/husbandry (to appropriate benefits). In Europe and America, cultivated staples and animal proteins were consumed. Europe was in a privileged position since it received a flow of species from the macro continent of Eurasia and from Africa. Despite Europe's paucity of original biodiversity, the flow of species allowed some European kingdoms to identify several species that could be adapted to local conditions. These included staples, such as wheat

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the 'European introduced grains' from the rest, and in this way to refer to it as 'less' than the European grains.

[117] 'Mediterranean climate' type is 'characterized by mild, wet winters and long, hot, dry summers. That climate selects for plant species able to survive the long dry season and to resume growth rapidly upon the return of the rains. … Cereals and pulses, have adapted in a way that renders them useful to humans: They are annuals, meaning that the plant itself dries up and dies in the dry season.' Within their mere one year of life, annual plants inevitably remain small herbs. Many of them instead put much of their energy into producing big seeds, which remain dormant during the dry season and are then ready to sprout when the rains come. Annual plants therefore waste little energy on making inedible wood or fibrous stems, like the body of trees and bushes. But many of the big seeds, notably those of the annual cereals and pulses, are edible by humans. They constitute 6 of the modern world's 12 major crops.' (Diamond, 1997 p. 136)

[118] Clonal and sexual are the basic forms of biological reproduction, but species offer other alternatives (e.g. biannual plants. See Ch. 6). Many roots reproduce by cloning; a part of the plant (e.g. part of a stem) can be used to obtain a new plant. This applies to cassava and sweet potatoes. Also, many bushes and trees produce aesthetic fruits that contain seeds and when consumed by mammals, will be dispersed by passing in the faeces. The fruits became gain aesthetic attributes to mammals by varying in colour, taste and flavour (e.g., golden berry, oranges, and grapes).

and barley, and mammals, such as cattle, horses and donkeys, suitable for the use as draft animals to support agriculture. In the Mexican territory, large mammals were not domesticated, so indigenous communities did not have the opportunity to use them in this way.

Before the 16th century, the population in Europe were large, comparable to China (Durand, 1977), and these countries traded with Asia (enabling the exchange of cultivated species across the Eurasian land mass). The arrival of the Spaniards in America was the result of Spain's keenness to find a new route to Asia since Spanish traders were struggling to maintain routes through the Middle East. The arrival of the Spanish in America provided access to precious minerals and resources from biodiversity (new species for cultivation) for Spain, whilst for the American empires and their populations, it brought disease and genocide.

Mestizaje[119] referred to the inter-breeding of the Spanish colonisers with the indigenous people and resulted in an eclectic process of learning indigenous and Spanish skills and routines by indigenous people, mestizos (i.e., indigenous descendants), and the American born of Spanish parents.[120] A spectrum of actors including indigenous people, mestizos and Spaniards emerged in the succeeding centuries, throughout the territory. A brief summary of how these actors and organisations used the species shows the long use of the species before the 1950s and the building of contemporary organisations and institutional arrangements (see Section 5.2).

In the 16th century, Spaniards used Cartagena on the Caribbean Ocean (in today's Colombian territory) to settle trade with South America and Europe,[121] and, after reaching the Pacific Ocean via what is now Panama, the port of Callao, a few kilometres from Lima. Lima was the capital of the Viceroyalty of Peru and Callao became an

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[119] Some authors refer to miscegenation, although it is avoided because the term suggests a concrete biological phenomenon, rather than a categorization imposed on certain relationships.

[120] Characterising the actors through history is difficult. Here we refer to indigenous actors as those who maintained the traditional skills and cultivation routines for the species under study, and refer to mestizos as those indigenous peoples who as well as maintaining their traditional skills, learned new skills and routines and focussed mainly on trade, research and teaching. to the particular activity will be highlighted in any reference to mestizos.

[121] The Spaniards replicated the control of territory established by the indigenous communities. The largest indigenous communities in South America were the Chibcha in the Bogota Sabana, and the Inca in the Peruvian territories. Cartagena was connected to the centre of the Chibcha territory by the Magdalena River.

important trading port in colonial times. The surviving indigenous communities of Peru maintained their agricultural practices on the lands under the control of extended family groups or *ayllus,* which ensured sufficient labour for their agricultural practices. Different indigenous communities maintained connections based on, for example, their language or altitudinal vegetation zone commonalities. Some maintained a presence in both the coastal and highlands areas.

The Spaniards established several routes from the Pacific coast to the centres of power established by the Inca Empire. Thus, a route was settled from Callao-Lima to Cuzco, La Paz, Potosí and Chuquisaca (today Sucre) (Klein, 2003 p. 32) stretching over near to 2,000 kilometres. The route was based on the Inca pre-colonial trail which controlled the whole Empire from the centre in Cuzco (James, 1925), but included extensions to ensure links to the port of Callao to export silver to Spain. These adjustments also allowed transport of other metals, for example, mercury which was produced in Huancavelica in today's Peruvian territory, which was used for refining silver.

Potosí population is an example of the actors' spectrum that emerged in colonial times and which contributed to actors' cooperation in the use of the species of biodiversity and in the related learning process. Potosí and Mexico City were the largest cities in the Americas. In Potosí, silver exploitation in the 17th century brought together more than 160,000 inhabitants (Braudel, 1948). After the city was established, in 1545, indigenous people various areas, including the Lake Titicaca basin, worked under the pre-Hispanic organisation of *mita* (a tribute or tax paid with indigenous labour to Spaniard *Encomendador*[122], see Sub-section 5.2.1), and food was transported from adjacent zones including Cochabamba Valley. The cold climate and high altitude allowed the production of an inedible straw that was used to process silver. Spaniards, mestizos and indigenous people cooperated in transporting the silver (and food to feed the Potosí population). Several *tambos* or inns established at distances of 20km to 35km along the trail, and were maintained by the indigenous Andean people living in the vicinity and supplied 'with food,

[122] The Spanish crown gave as incentive to the conquers the life right to establish under a territory, giving them the position of *encomendador*. This position entitled them to exploit the land, including the indigenous attached to it, and to collect taxes. A portion of the taxes was for the Spanish crown. Taking into account that some conquers married Inca relatives, the *encomendadores*, in certain way, had the right to claim the same position as indigenous leaders, that entitled, given their linkage with the Inca, to received 'tributes' (like taxes) from the indigenous population (See section 5.2.1).

animals and even carriers as they were needed by travellers' (Cobb, 1949 p. 25). Pack animals included introduced horses and mules and native llamas. Transport of the main staples, including maize, potatoes and quinua, was facilitated by the trail and reports indicate that, at least in the case of potatoes, some Spaniards became dealers and grew wealthy from specialising in trading this commodity (Salaman *et al.*, 1985 pp. 41-96).

The silver mines attracted the Spaniards to Cerro de Pasco, Junin, highlands east from Lima. Their presence explains the tributes given to *encomendador*[123] and the *Archivo General de Indias de Sevilla* of 1583, reports that 15 to 18 tonnes of maca constituted part of the in-kind tributes given by the district of Chinchaycocha (or Lake Junin[124]), to the *encomendador* Juan Tello de Sotomayor (Obregón Vilches and IFA, 1998 cited in Hermann and Bernet. 2009b p. 25). '[The] Spanish might have used maca to maintain fertility in their domestic animals' (Hermann and Bernet, 2009b p. 25) in the highlands, such as sheep and cows, raised for Spaniards' consumption, or horses used to move minerals from Pasco to Lima (Sánchez León, 2006). The subordination of indigenous people to the Spanish hierarchies allowed the latter to *voice* their preference for what should be cultivated, for example introduced sheep, cows and horses, but also the native maca to ensure these animals' fertility.

The tough working conditions in the mines led to high mortality rates among the indigenous population throughout the 16th century. Recruiting more indigenous people from the highlands reduced the numbers of the workforce devoted to producing food for the population. In the 17th century, new forms of work emerged in cities, such as Potosí, where waged workers became a large percentage of the labour force, mainly Spanish descendants who had learned mining skills, but also slaves brought from Africa, who were imported in their thousands during the 17th century. The slave trade opened new transport routes with Africa through Buenos Aires, in today's Argentina, and via Cartagena–Panama–Lima. In the 18th century, thanks to advances in navigation, routes

[123] In the second half of the 16th century a new centralised provincial bureaucratic organisation was established: The Viceroyalty, the Audience (similar to a state council) and *Corregidores*. The *Corregidor* position replaced the *encomendador* position (see fn. 122), and it became responsible for the enforcement of justice, local government and collection of taxes, The absence of a labour market meant that the success of private initiatives, such as rearing animals or mining, was dependent on the use of the *mita* (see Contreras Carranza, 2002).
[124] Cocha means lake and Chinchay name was replaced by Junin.

via Cape Horn, in the Southern part of Chile, replaced the Panama route, which made possible other sea connections between Europe, America and Oceania, while Lima–Callao continued to be the headquarters of the Viceroyalty and the trading port for the Pacific.

The species flow from Europe to South America for food was facilitated by the food that was needed to feed ship's crews. While plant species such as wheat, barley, and faba beans (*Vicia faba*) were carried for voyages from Europe to America other species were included for the return voyage. The interest in finding species that could be consumed on these long sea voyages, extended later to finding ways that species might to be gathered to produce crops that could be commercialised in Europe. One of the most successful of these was the Andean potato, introduced to Europe in the second half of the 16th century (Salaman *et al.*, 1985), and considered as the solution to the 1586 famine in Spain.[125] Its use diffused throughout the 17th and 18th centuries to the whole of Europe.[126]Andean species were used also for medical purposes, for example, the bark of a cinchona tree (which in 1820 was found to contain the active ingredient quinine) to treat fevers (Medina Rodríguez, 2007 p. 195), a major cause of illness and death in Europe at that time.[127]

The introduction of Andean species to Europe (or *vice versa*) was uncertain. Even after the introduction of potatoes to Spain, which occurred before 1600, this crop was neglected in many regions of Europe for various reasons: The land was used for other crops; the species did not produce tubers due to the different day and night lengths; and fears, myths and misunderstandings about the plant (Salaman *et al.*, 1985 pp. 63,116,425).[128]

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[125] The reference to potatoes as a solution to famine in 1586, is attributed to Diego Dávila Briceño, Corregidor of Huarochiri, regarding the possibilities of potatoes produced in the province of Yauyos of being produced in Spain (see Cobo and Jiménez de la Espada, [1653] 1890 p. 362).

[126] In 1653, Spanish chronicler Cobo reported that potatoes and other Andean species, such as oca, maca, mashua (isaña), olluco (ulluma), had potential to be used in Europe, and belonged exclusively to America. These were all grown in the cold Andean highlands, but only the potato was introduced successfully in Europe.

[127] Although extracts from cinchona bark containing quinine are a well-known treatment for malaria, in the 17th century malaria had not been identified as a disease, on its symptoms, especially fever, had been reported. Once malaria was identified in the 19th century, it was confirmed as a major health problem in most parts of Europe (see Wahigren and Perlmann, 1999 Ch. 1; Medina Rodríguez, 2007).

[128] Salaman *et al.* (1985 p. 101) describes prejudices 'premature, hasty, or ill-founded judgement' against potatoes in Europe in the 16th to 18th centuries. Opinions in Europe were mixed about potatoes but restricted their production for centuries. Potatoes were considered the food of the poor. In 1620, consumption of potatoes was forbidden in Burgundy because 'too frequent use of them cause the leprosie'

Actors had limited skills and agency to introduce species from other continents and the conditions for species to flow and reproduce added to the uncertainty involved in the introduction of such species to Europe. The most likely centre of origin of potatoes and quinua is the highlands of Lake Titicaca between Peru and Bolivia, where their domestication process that began thousands of years before the Inca Empire, allowed their dispersion and diffusion of use from the Northern Andes in Colombia to Chile in Southern Andes during pre-Hispanic times. The availability of potatoes and quinua in more places increased the chances that a Spaniard or mestizo would move these plants to Europe, while maca was confined to the Junin and Pasco regions. The first transport routes between America and Europe connected the Caribbean coast, where neither potato, quinua nor maca were produced, with Spain. Routes connecting the highlands, which involved use of pack animals, with the Pacific coast, became viable only in the second half of the 16th century, enabling the movement of highland species. These conditions help to explain why the introduction of these species in Europe entailed users with precise aims and skills, as well as voice and agency to mobilise resources (i.e., complementary means).[129]

For example, in the 1560s, King Phillip II ordered his officials to collect seeds and plants for his garden and 'organised' the first natural history expedition to America. Other users were also involved and Nicolás Morandes, a physician and entrepreneur, was part of a group of scientists and dealers from Seville that participated in the exchange of species to be introduced in Europe during the 16th century. The group used a network of officials (including soldiers) and dealers in America to access animals, plants and derivatives to be used for research and to identify potential commodities. The collectors

(Salaman *et al.*, 1985 p. 108). This prejudice spread to other regions of France where the potato was seen as responsible of producing 'fever' and famine (Salaman *et al.*, 1985 p. 114). In Prussia, it was believed that potato consumption gave rise to 'scrofula, rickets, […] and doubtless many other evils' (Salaman *et al.*, 1985 p. 115). Eating potatoes in Europe was akin to eating the 'forbidden fruit of Eden, a sinful act which […] was bound to create a feeling of personal guilt, which demanded some kind of expiation' (Salaman *et al.*, 1985 p. 116). Herbalists in Europe made a link between the Solanaceae family, to which potatoes belong, and evil, referring to them as poisonous and classifying them as weeds rather than a valuable crops (Salaman *et al.*, 1985 p. 119).

[129] The cases of wheat, barley and faba beans are similar; there were few opportunities for their production on the Caribbean islands since they originated in regions with 'Mediterranean climatic' type cycle and, in South America, they were productive in the highlands.

used informants (such as indigenous people) who provided information on the use of the species, including its cultivation (Barrera-Osorio, 2006 pp. 120-7).

American indigenous people or mestizos, with skills for using the species as crops (farming and post-harvest), had agency in the introduction of these species to Europe and underlying knowledge in its use and cultivation. European actors interested in the use of these species, such as King Phillip II and Spaniards who had learned about their consumption and benefits, used their voice and agency to support their introduction and to mobilise the necessary resources. The movement of species in the form of food for crews making the voyage from America to Europe, is not enough to explain their introduction and diffusion of use in Europe. Actors were motivated by their individual needs (i.e., food, health) and organisational goals (e.g., enriching the royal garden to demonstrate control over the colonies, research to find potential therapeutic or medicinal plants or commodities to trade). The motivations for moving species is described in terms of the organisational goals and institutional arrangements involved (Sub-section 5.2.1). This movement was often accompanied by codified information, an aspect that is discussed in Sub-section 5.2.2.

5.2 Organisations and institutions in Latin America involved in the introduction of species to the international market

This section presents the organisations, which allowed the actors to coordinate their efforts, and the institutional arrangements influencing the shaping of the two Andean species: Maca and quinua. This section provides the historical background relevant for understanding the context in the second half of the 20th century, when indigenous Andean people and mestizos shaped the two Andean species towards their commercialisation as crops at the international level (see Chs 6 and 7).

The section is organised in two parts. The first sub-section discusses how the indigenous people and communities controlled, replicated and imitated their skills and routines during colonial times to enable them to use the Andean species under study. The second sub-section introduces the education system, which was an important institutional arrangement for the articulation and codification of knowledge and movement of this information. The movement of information and reports complemented the species flow; the codification of knowledge, under certain circumstances, can reduce the costs of sharing the meanings of species in the shaping process. In both sub-sections, attention is paid to the complementary means that constrained or enhanced the appropriation of benefits. The section explains the organisations and institutional changes related to the appropriation of benefits from the use of biodiversity through the cultivation of maca and quinua. The history of these changes is up to the 1900s to emphasise the patterns of social structure in place.

5.2.1 Indigenous communities, colony and species

Indigenous communities have exchanged plants and animals for the last 10,000-13,000 years since the beginning of *cultivation/husbandry* rather than *hunting/gathering* (Cardale Schrimpff, 1987 p. 17; Diamond, 2002). Latin America and, particularly, the Andean Region, is a centre of origin, dispersion and domestication of several plants and animals. Cultivation/husbandry allowed the population to increase based on a better availability of food and this emerged alongside new forms of cooperation ('organisations' in institutional economics terms).

It was pointed out in Chapter 1, Section 1.2 that actors overcame slack (Hirschman, 1970 pp. 5-12) in the use of the species and found patterns of social structure (Wittfogel, 1957 Ch. 2) that better addressed their individual needs. In the case of indigenous communities, cooperation and specialisation (or division of labour) allowed more people to be fed based on the efforts of a few: In appropriating the benefits via hunting/gathering, the whole community moved around the land looking for the very few species available for food. However, some scholars suggest that cultivation/husbandry reduced the effort (i.e., workforce) required to obtain food, to between a tenth and a hundredth of the numbers involved in hunting/gathering (Diamond, 1997 p. 88). Archaeological and linguistic evidence indicates that the appropriation of benefits by cultivation/husbandry involved settled communities growing both local species and introducing foreign seeds and ideas (Diamond and Bellwood, 2003; Heggarty and Beresford-Jones, 2010). This allowed actors to find more productive or more suitable places and practices for cultivation.

Actors' cooperation within different organisations might involve the family or a large state, or states and empires. While some forms of organisation, such as the state (Wittfogel, 1957 Ch. 2), were built to enhance yields, family-based organisations preferred slack in performance which ensured underutilised labour was available for busy periods.[130] Both applied to the shaping of the two Andean species (see Chs 6 and 7).

The Incan Empire, the largest organisation in pre-colonial times, emerged in the 13th century as a result of efforts to maintain control of Cuzco, considered a sacred city by local communities, and implemented several mechanisms of military and political power over other communities in the Andean highlands. They stretched from the Southern part of Colombia in today's Nariño department to the Western area of Bolivia, the area around the Lake Titicaca basin, and the Northern part of Chile. These areas grew species such as potatoes, maize and quinua, but not maca. Sometimes the Inca imposed their customs; Quechua was imposed as the language in most of those areas. In other cases, there were agreements between other communities and the Incan Empire that allowed continuation of the formers' own traditions under the Inca authority. This applied to the Aymara culture, where its language was respected and retained despite expansion of the Incan Empire to the Lake Titicaca basin, home of the Aymara community.

The Incan Empire emerged from ancient communities that had already domesticated animals and plants. Pumpush, an indigenous people who disappeared as a distinct culture before the rise of the Incan Empire, had domesticated maca and other crops more than 3,000 years earlier (Rea, 1994 p. 165; Indecopi, 2003 p. 8). This was long after the domestication of potatoes, which occurred 7,000 to 10,000 years ago, in a southern region and on low level lands. Similarly, indigenous Andean communities

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[130] Wittfogel (1957) claims that a state is a complex political organisation common in ancient hydraulic societies including China, India, Meso-America and South America, that could build and maintain hydraulic systems of thousands of kilometres. One of the goals of states was to regulate the availability of water, which followed annual cycles of extremes, inundations and drought. Regularising its availability allowed the capability to manage cultivation/husbandry to increase (see Wittfogel, 1957 Ch. 2). However, Stanish's (1994) analysis highlights that at the local level, communities put in place different strategies for survival which did not always include creating states. E.g., in the Andean case, Stanish evaluates archaeological evidence that shows that, far from an intensification of cultivation/husbandry, communities, including several indigenous Andean communities, historically, had both hierarchical organisations, which fitted with hydraulic state societies and the drive to achieve intensification of cultivation, and other organisations aimed at long-term survival based on the 'underutilization of labour in normal period[s to maintain] a reservoir of labour (sic) capacity that permits temporary intensification, and thereby minimizes risk, in periods of stress' (Stanish, 1994 p. 314), or, a slack in the use of the species (Hirschman, 1970).

domesticated quinua around 5,000 to 7,000 years ago (Tapia, 2015 p. 3) around Lake Titicaca. Subsequent communities, including those belonging to the Incan Empire (such as the Quechua and Aymara), inherited maca and quinua and the knowledge underlying their definition, cultivation and consumption (see introductory paragraphs in Ch. 4). These indigenous Andean communities, introduced their own staples when they expanded to isolated territories or when disputes over territory favoured them, and they found the right weather conditions for the seed.

The Incan Empire upheld the old community organisation of *ayllus* to control the territory. The *ayllu*, the basic Andean social unit, was based on the nuclear family extended by kinship. The *ayllu* was set up to ensure self-sufficiency. Ayllu members' organised themselves based on ecological complementarity between controlled altitudinal vegetation zones (Murra, 1975 pp. 59-61), while maintaining a central zone *qechwa*, (see Section 5.2.2) usually at an altitude of between 2,300 and the 3,500 metres above sea level (masl), similar to the city of Cuzco. Therefore, some *ayllus* maintained their central zone in the middle of the highlands, where potatoes, maize and quinua were produced, while others still members settled in the *suni*, at higher altitude, as camelid herders and producers of quinua (i.e., a mix of farmers and herdsmen). Yet, other *ayllus* became specialised in the domestication of camelids in the coldest part of the *puna* (Vergara, 2000 p. 37). The *suni* in the Lake Titicaca basin was considered a mixed farming zone, including mainly quinua and herdsmen (see Ch. 7), and the wet *puna* in the Lake Junin basin was considered a zone of herd zone, with production of maca as a marginal complementary agricultural practice (see Ch. 6).

This form of controlling the territory helps to explain the transition from hunting/gathering to cultivation/husbandry in pre-colonial times, which transition helped to ensure availability of food that allowed the *ayllus* to survive for many generations. Archaeological and linguistic evidence [131] (Seminario, 2004; Morales Garzón, 2007;

[131] Different issues have been proposed to explain the move from hunting/gathering to cultivation/husbandry. Seminario (2004) bases his analysis on potatoes and uses them as a reference to explain the origin and cultivation of other Andean roots. Morales Garzón (2007) combines molecular and taxonomic studies with archaeological evidence to explain the large prehistorical diffusion of the use of potatoes. Heggarty and Beresford-Jones (2010) use archaeological and linguistic evidence to explain the development of agriculture in the Andean region. Langebaek (1987) explains the transition from hunter/gatherer to settled farmers and herdsmen as based on control over several altitudinal vegetation zones.

Heggarty and Beresford-Jones, 2010) indicates that cultivation/husbandry was not immediate since, in principle, if a community was settled in a region with an abundance of resources from biodiversity to gather (or hunt), they were not likely to consider undertaking the costly learning process involved in domesticating species. Being gatherers or hunters in a region where resources become scarce, resulted in communities moving to another area with more abundant resources to gather or hunt.

Agricultural production began as the result of institutional arrangements which meant that the communities settled in certain lands, first according to seasons, and then gained control of them and accessed what was available. This, in turn, allowed movements, possible in a single day, between different *altitudinal vegetation zones*. These movements were between small 'towns' controlled by the same community (Langebaek, 1987). This strategy permitted the community members to maintain hunting/gathering skills and routines and to begin the initial processes of domestication that led to sedentary cultivation/husbandry. This practice explains how the same community simultaneously used potatoes, maize, quinua, and even, maca and gathered plants such as golden berry (*Physalis peruviana*).

Despite the expansion of the Inca Empire and its stable crop, many species cultivated in warm regions were not suitable for cultivation in cooler regions and vice versa. Thus, the cultivation of species was not based wholly on the movement of people, but relied also on the introduction of ideas and imitation of what had been seen or learned in some other region, or with other species (Cardale Schrimpff, 1987 p. 107). Despite indigenous peoples' interest in using other species for their welfare, many species remained limited to certain environments. Indigenous people in the highlands domesticated maca[132] among other roots and tubers (potato, olluco, oca, and mashua), quinua among other grains (such as kiwicha or cañiwa), and Andean camelids (llama *Lama glama*, and alpaca *Vicugna pacos*). In most cases these species remained exclusively to the Andean highlands, and were rarely seen at lower levels or on the coasts, where other species were more successfully adapted.

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[132] Even in the case of maca, archaeological and historical records refute the idea that it was cultivated by communities from Ecuador to northern Argentina at one point, and conclude that from its domestication before 1,600 BC, up to colonial times, maca was produced exclusively in *punas*, the highlands of Junin and Pasco in Peru, at altitudes of over 4,000 masl (see Hermann and Bernet, 2009a p. 27).

Indigenous communities traditionally performed communal thanking rites to (e.g., for harvests) or rites related to requests for favours (e.g., avoid evils), which were offered up to their deities. These rites involved sacrifices (mainly camelids) and other offerings (Vergara, 2000 p. 82) such as samples of local crops. Maca, maize and potatoes were offered in rites practised in Junin (Obregón Vilches and IFA, 1998 cited in Hermann and Bernet, 2009a).[133] Also, archaeological studies suggest that *chicha*, a fermented drink made from several species including quinua and maize (Cobo and Jiménez de la Espada, [1653] 1890 p. 347), played a role in the political economy of Tiwanaku, a large political organisation in the Lake Titicaca basin previously inhabited by Aymara, which was based on competitive hospitality. Competing by offering the best *chicha* was the mechanism for gaining sponsorship for feasts and triggered factional competitions (Goldstein, 2003 p. 152), which replaced other forms of dispute.

Therefore, community members belonging to a territory cooperated, over both the payment of tributes and the sharing of labour, with the expectation of reciprocal favours during festivities. They thus became part of a community that supported performance of agricultural practices using labour. At the same time, seasonal repetitive practices standardised the species and its use. Chapter 6 considers the valuable attributes defining maca, and Chapter 7 considers the relevance of these practices for the persistence of quinua in the face of introduced grains.

At the time of the arrival of the Spaniards in the 15th century in today's territories of Mexico and Peru, there were large populations of between 10m to 15m people (Denevan, 1992 p. xxviii-154).[134] The populations of indigenous communities that had settled on the coasts of both the Caribbean and its islands and the Pacific Ocean, mostly collapsed after the arrival of the Spaniards. In Peru's territory, from an estimated 3m to 14m people in 1520, only around 600,000 survived to 1620 mainly in the highlands and the jungle (Cook, 1981). Even though the numbers of Spanish and indigenous people in

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[133] The Obregon report is based on a document in Lima's Archivo Arzobispal, dated 1650.

[134] The whole American population may have equalled the European population at that time. (Durand, 1977 p. 259) evaluates the historical estimates of the world population and presents population ranges in the 16th century of between 30m and 60m in Middle and South America, and 60m to 70m in Europe excluding the Union of Soviet Socialist Republics (USSR)).

America could not be comparable, the former's superior technology gave them greater bargaining power.

The Spanish Kingdom gained sovereign rights over the territory by exerting its bargaining power to adapt the existing organisations and institutions to serve their commercial and political interests. This adaptation worked at different levels depending on the distance from the settlements and trade ports under Spanish influence (Spalding and Rogers, 1984). The Inca Empire had a relatively bureaucratic managerial economy, implemented by members of *ayllus* trained in Cuzco (see Sub-section 5.2.2) and transferred through extended family linkages.[135]

The Inca maintained a monopoly over access to the land and manufacturing production, directly or through the collection of taxes. Also, male heads of households were required to pay both taxes in kind (e.g., crops, textiles, etc.) and in the form of the *mita* (labour) and military obligations (Wittfogel, 1957 pp. 45,79-81). In return, the Incan Empire provided defence, food in times of hardship through the supply of emergency resources, agricultural projects (e.g., aqueducts and terraces) to increase productivity, and occasional feasts (Vergara, 2000 p. 20). The bureaucratic management of the Incan Empire passed from being based on the Inca descendants' kinship of military subordination to Spanish officials.

The Spanish Crown adapted, by law, *mita* and introduced encomienda, a reward given to conquerors in the form of a right to control a territory and demand for payment of tributes, rather than claiming ownership over the land, and rule over the indigenous people belonging to the territory[136] (Molino García, 1976; Hampe-Martínez, 2000). *Mita*

[135] Wittfogel (1957) analyses the Inca Empire and several other states. In the Inca Empire, leaders had links to the government apparatus and regulated the landed possessions of ayllus members. The classes were defined based on their relationships to the Empire. The curacas, or priests in charge of the local management and ceremonies, were integral to the imperial officialdom (Wittfogel, 1957 p. 309). The curacas supervised the farmers. The sons of curacas were captured and taken to Cuzco, where they were taught the Incan way of life. The Inca also maintained polygamous relationships. Incas' relatives (by blood or marriage) enjoyed distinguished social status and, often, considerable material advantage. The male descendants of the Inca sovereigns were organised in *ayllus*, whose numbers increased with the advance of the dynasty. The members of these *ayllus* 'formed a useful court circle of educated men trained in the imperial ideology, and interested in its perpetuation. The emperors chose their top administrators from this group when possible' (Wittfogel, 1957 p. 312).

[136] Several forms of encomienda occurred. They changed based on the precolonial arrangements, which differed from region to region, and the power exerted by the royal bureaucracy to control *encomendadores* (see Molino García, 1976; Hampe-Martínez, 2000).

was used in both Peru and Bolivian territories and last until just before independence. It ensured labour as a means of enhancing the appropriation of benefits from agriculture. Also, given that America did not rely on draught animals, large groups of organised men were essential for tilling the land and building and repairing infrastructures.

In the 17th to 19th centuries, the presence of such institutional arrangements competed with other forms of access to land (i.e., haciendas) and labour (i.e., slavery or waged labour). Landlords and slave owners became the new elite and gained benefits from the production and export of crops such as tobacco, cotton and sugar cane during those centuries. Although *mita* and encomienda disappeared with independence in the first half of the 19th century, their effects persisted; in Peru and Bolivia, the new nation states delayed clarification of land rights and the resulting uncertainty reduced the incentives to create public goods (i.e., new and large roads to connect with the cities and access technologies or schools to educate children) (Dell, 2010). *Hacendados* and landowners were particularly active in stimulating scientific cultivation of land and husbandry of animals because large-scale farming resulted in high crop yields which were labour intensive and technology was required to replace the workforce. Also, trading the production of large scale farming stimulated the construction of infrastructure (Wittfogel, 1957 p. 276).

This section explained how indigenous people cooperated in organisations to satisfy their individual needs and organisational goals of subsistence. The control of several altitudinal vegetation zones by indigenous people allowed them access to different species (including those discussed in succeeding chapters) to augment their diets, while leaving room to imitate routines for new or introduced foreign species (i.e., diversification). These organisations (Inca Empire, communities and *ayllus*) had persistent effects on different forms and levels, even after colonial times. The pre-Hispanic figure of *mita*, that provided tributes in the form of labour to the Inca, was adapted by the Spaniards and maintained up to independence. In the meantime, new elites emerged among the mestizos; they used alternative institutional arrangements, including haciendas (or big farms in the hands of landlords), slavery, and other forms of land rights or access to cheap labour, to appropriate benefits on a large scale, from both the cultivation and the commercialisation crops from native and introduced species.

5.2.2 The education system and the codification of knowledge

Knowledge codification entails, not only model building and language creation, but also the writing of messages (Cowan and Foray, 1997). Chapter 1 Section 1.3 and Chapter 2 Section 2.3 described how knowledge codification affected how actors coordinated with each other to address individual needs and pursue collective goals related to biodiversity-based innovation. The education system in Latin America increased the use of written languages by indigenous peoples and indigenous descendants, who had agency over the Andean species under study. During colonial times, several organisations, including those related to the education system, were part of the institutional arrangements 'for testing and establishing accurate information. […] Empirical information was used for the production of new knowledge' (Barrera-Osorio, 2006 p. 1), which became an input to the innovation process. This sub-section discusses how knowledge was organised and disseminated before and after the introduction of the education system during and after colonial times. It provides details of knowledge codification from colonial times to the 1950s in relation to the two Andean species.

The Spaniards' bargaining power derived from the introduction (for many seen as imposed) of the Spanish language via the education system. Although Latin American inhabitants were considered to be either Spanish or Portuguese speakers (both Latin and written languages), a proportion of the modern population in Latin America speak and write neither of these languages. The transition from the use of the pre-colonial native languages, Quechua and Aymara, to written Spanish affected the shaping of the Andean species, since the costs and benefits of diffusing knowledge changed. Indigenous people and mestizos gradually adapted Spanish written language after colonisation, but its use did not become widespread until the 1950s.

When the Spaniards first invaded, indigenous Andean communities in today's south of Colombia, Ecuador, most of the highlands of Peru and in the middle altitudinal vegetation zones of Bolivia were mostly Quechua speakers, and in the Lake Titicaca basin at higher altitudes they spoke Aymara. Precolonial and even postcolonial indigenous written references to species are limited or inaccessible because not all of these languages were written languages. The few available records require further study and translation.[137]

The Inca Empire was a hierarchical society and classes were established based on relationships with the Inca and on bureaucratic roles. Public servants included curacas (similar to priests), fine craftsmen, members of the army, *pacariscap* villa (who recited historical records[138] in the form of chants) and *quipucamayoc* (*quipu* holders or accountants of people, lands, soldiers and ceremonies). Their training was different from that given to agricultural workers related to cattle raising, fishing, basic crafts, and culinary practices, skills that were taught in the *ayllu*. Public servant training was done in Cuzco for a period of four years, and included Quechua language from Cuzco, deities and cults, *quipu* management and laws (Vergara, 2000 p. 99). Thus, those hierarchies determined the education for each individual, which extended to colonial times.

The Spanish written language ensured communications between Spanish conquerors in Peru and the Kingdom in Europe.[139] Although the Inca Empire was a complex and centralised political institution,[140] lack of a written language when the

[137] Anthropologists and ethnographers employ techniques to learn from communities that have maintained their practices and traditions over time. Some of the results of these archaeological studies are presented in Ch. 6 for maca and Ch. 7 for quinua.

[138] Cowan and Foray (1997) describe the word 'record' as 'ambiguous' to the extent that codification entails those who codify knowledge (how to record it) and others who use the codified knowledge which requires non-codified knowledge about how to read or understand the codified or 'recorded' knowledge (Cowan and Foray, 1997 p. 606). Records were oral or written, but even the written records have some limitations. The advantage of written records versus oral records is that they are less costly to reproduce and more valuable in use. The costs of reproduction include the costs of storing and retrieving data. The value in use can be interpreted in terms of language deterioration (or decay) vs language evolution, which affects interpretation or reliability (Cowan and Foray, 1997 p. 611).

[139] Diamond (1997 p. 236) explains the introduction of written languages as due to societies becoming more complex and the establishment of centralised political organisations. Cowan and Foray (1997 p. 613) recognise that 'efficiency of codification will be greater in very large systems having specific requirements regarding coordination among agents'. Codification occurs, in particular, in (i) systems that need memory to the extent that too little codification increases the risk of 'accidental uninvention', such as how to achieve a task that can involve several generations (e.g., crossing the Atlantic ocean between Spain and America in the 16th century); and (ii) systems that need to describe what actors do in order to control inefficient market transactions, given that the 'legal warranty, insurance, reputation and test are not efficient to reduce the information asymmetry' (Cowan and Foray, 1997 p. 614) (e.g., The King of Spain needed to know what the conquerors were doing in the colonies using the minerals obtained).

[140] Diamond (1997) refers to writing as one of the reasons for Spanish domination of the Incan Empire, but acknowledges the difficulty involved in introducing a language and, particularly, a written language. Given the centralised institutions in the Andean region in 15th century, the Inca Empire is an exception for among other civilisations at that point in time, in having a written language. Although *quipus* (i.e., talking knots in strings made of llama or alpaca hair) were used, perhaps for accounting purposes rather than writing, and were less developed. It was easier to borrow, totally or partially, from another culture, such as the Azteca. However, as is common with other technologies, it seems that distance and geographic conditions limited

Spaniards first arrived, let to indigenous people as options to: (i) maintain the native spoken languages, at least for family relatives or in settings away from Spaniards; (ii) adopting Spanish as the spoken and/or written language and benefiting from access and movement of information; or (iii) codifying their spoken language. A mix of these options occurred. Some indigenous people learned Spanish, but the adoption of spoken and written Spanish was not homogeneous throughout the territory. Quechua (became) 'identified with the physical territory of rural communities, while the colonial language, Spanish, is linked with the cities, mines, and coastal areas' (Romaine, 2000 p. 45). Therefore, use of Spanish became differentiated by territory and social class.

One Quechua speaker who learned Spanish was Felipe Guaman Poma de Ayala. He acted as a translator because most of the indigenous population did not learn the language. Guaman Poma de Ayala[141] learned his Spanish serving as translator for a Spanish chronicler. Guaman's close relationships with the upper levels of the Inca hierarchy allowed him to reference Incan customs such as use of maca as an invigorating agent used by Incan kings to ensure long life (Guamán Poma de Ayala *et al.*, [1615] 1944).[142] In addition to Guaman's reports, other information about the indigenous people and their consumption of plant and animal species in pre-colonial and colonial times were produced by Spanish chroniclers.

Introduction of the Spanish language was related also to the organisational goals of the Spanish Kingdom to enforce its introduction. For example, the foundation of towns marked the end of an era of conquest, but created the risk of military heroes being surrounded by local loyalties, powerful enough to ignore royal instructions. This led to

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this possibility. Wittfogel (1957) refers to desert-like conditions along large segments of the coasts, and the high mountains, as constraints on long-distance communication by navigable rivers or seas. Instead, communications were sent by land over the highlands on the trails maintained by the Inca Empire (see Wittfogel, 1957 p. 248).

[141] Guaman (1615 (1944)) wrote his own chronicle to try to denounce the treatment meted out to the indigenous people and indigenous descendants by the conquerors. Guaman's report, in a mix of Quechua phonemes and Spanish, offers an eclectic perspective; he distances himself from the common indigenous people, identifying himself as an Inca elite descendant. However, he distances himself also from the conquerors, although it is easy to trace his links to the Spanish administration and his deep catholic convictions.

[142] Spaniards used to avoid fair payment to indigenous people for feed, maize, potatoes, chicken, eggs, lettuce, onions, garlic, quinua, *chicha*, and other goods for the trip via the *tambos* along the Inca trail. Guaman denounced this deception of indigenous people in charge of the *tambos*. Guaman's work was an attempt to change this unfair situation by reporting it, in the Spanish language, to the Spanish King.

new management arrangements in which the Spanish King and his court sought out loyal civil servants, who would adhere to the royal instructions (i.e., produce minerals and send them to Spain) and keep Spain informed about what was happening in the colonies (Contreras Carranza, 2002 p. 7). Members of the Catholic church were often civil servants who were visitors,[143] magistrates or advisors (Hampe-Martínez, 2000 p. 187).

One of these was Fray Antonio Vasquez de Espinoza, who travelled to Mexico and then Peru between 1612 and 1622. He died in 1630, but in the last years of his life he submitted at least 11 memoranda to Philip IV's court, commenting on the army's defence of the American colonies and the ethical and material value of silver (Marsilli and Cisternas, 2010 p. 466). Fray Antonio's writings included many recommendations, but his main goal was to provide a description of the provinces (Vázquez de Espinosa *et al.*, [1620] 1948 p. vii). It seems that the silver mines led him to travel to the highlands between Huanuco to Huancayo and Huancavelica, passing by Pasco (see Ch. 6 Sub-section 6.1.1 Map. 1) (Vázquez de Espinosa *et al.*, [1620] 1948 p. vii). He reported details of the tough conditions of the cold *puna*, where crops such as maize and wheat, could not be grown. The only valuable crop was maca, which had an exceptional requirement of a long fallow of 30 years after its cultivation (Obregón Vilches and IFA, 1998 cited in Hermann and Bernet, 2009b p. 26; Vázquez de Espinosa *et al.*, [1620] 1948 p. 456) (see Ch. 6 Section 6.1). These particularities became part of the 'contingent reality, adaptable to human plans and needs', ready for exploitation and collection (Barrera-Osorio, 2006 p. 23).

Another of those servants was the Jesuit Bernabé Cobo. He was born in Spain in 1582 and lived in America for 63 years, mainly in Perú. His encyclopaedic writing *Historia del Nuevo Mundo* (translated into English as the *History of the Inca Empire*), prepared in 1653, was the result of his role as a priest and missionary. Cobo's writing provides detailed descriptions of the different plant species found in America and in Spain, ranging from exclusively American species, exclusively Spanish species and present in both regions (Cobo and Jiménez de la Espada, [1653] 1890 Book 4). Many of the species

[143] Cieza de León was a visitor to the colonial administration (see Cieza de León, [1553] 2012 Ch.LXXXIII). Writing about his travels, Cieza mentions that in Quito, together with maize and potatoes, quinua was produced and consumed widely, and that in the Lake Titicaca basin (or Collas region), the most populated region in Peru, quinua was produced and used as part of the tributes. It can be speculated that, in Lake Junin, maca could have been the 'root cultivated' that he referred (see Hermann and Bernet, 2009a p. 25).

exclusive to America had different biological and agronomic characteristics from those in Europe; reports of where and how these species were produced by indigenous people would be useful for actors interested in their introduction to and use in Europe. Cobo had intended to explore these uses of the species in Europe; his writings remained unpublished until 1890.

In addition to the origins of species, a second criterion for Cobo's ordering was the role in human diets: Cobo ranked first staples, the first being maize, and the second quinua. He highlighted quinua resistance to cold temperature, which matched many of the environments where European barley was produced and suggested it could be consumed as a grain or a green leafy vegetable similar to spinach. In the case of maca, grown in the Junin region, Cobo noted the skills of the indigenous people and the ability of the crop to withstand the harsh environment of *puna*. He noted also that it could be consumed fresh, dried and cooked He described it also as a fertility-enhancer (Cobo and Jiménez de la Espada, [1653] 1890 p. 364). The role of Catholic representatives in supporting the Crown was two-fold: First, it was to maintain the official *status quo* (even after independence in the nascent nation states), and second, it was to be identified with education and literacy.

The establishment in Lima of a Spanish oligarchy in the first half of the 16th century included introduction of European-style education to supply people trained in navigation, ethnography, natural history, cosmography and medicine (Barrera-Osorio, 2006 p. 129). The Universities of Salamanca and Alcala in Spain were used as reference for creating universities in Latin America. Hence, the *Universidad Nacional de San Marcos* was founded in 1551 in Lima under the control of the Catholic church, to provide education in the arts, theology, law and medicine (Hampe-Martínez, 2000 pp. 167-8). Schools in Lima taught reading, grammar and doctrines as preparation for attending University. The *Universidad de San Francisco Xavier* was created in Sucre, modern day Bolivia, in 1624 and, over the centuries, received students from Bolivian, Chilean and Rio de la Plata (todays' Argentinian) territories.

Attempts were made to establish Catholic schools in Lima and Cuzco to teach mestizos children (mainly boys) and indigenous children (primarily caciques children) to read and pray; however, whether these happened before the 17th century seems uncertain (Hampe-Martínez, 2000 p. 145). Members of the Puno and Junin community in Peru received the traditional training in the *ayllus*; eventually caciques' children were sent to Lima and Cuzco for university training. Spain's scientific achievements in the 16th century in 'natural history, cosmography, navigation, medicine and mathematics', relevant for 'mastering the ocean and lands of the Atlantic world', entailed reinvention in light of information coming from America (Barrera-Osorio, 2006 p. 7). The need for accurate information about the American colonies gave rise to empirical scientific practices and their institutionalisation. It contributed also to an early scientific revolution in America since it challenged the knowledge available in the Old World, but provided a broader perspective which underpinned the scientific revolution in the 17th century in Europe (Barrera-Osorio, 2006).

In Europe, the scientific revolution in biology was related to an increasing interest in herbalism (i.e., use of plants for treatments) and botany (i.e., systematising, naming and classifying species) during the 17th and 18th centuries (Mayr, 1982 p. 105). In 1735, Carl Linnaeus published a basic taxonomy for the natural world based on local expeditions and collections maintained in Sweden (Blunt, 2001 p. 98). His studies induced curiosity among others to understand species and their contribution to human welfare and health. Alexander von Humboldt, the Prussian naturalist and explorer of Latin America between 1799 and 1804, followed scientific method to write about the richness of the plants in Latin America (Humboldt and MacGillivray, 1833 p. 289). Similarly, Jose Celestino Mutis, a Spanish priest, botanist and physician, was sponsored by Spain' King Carlos III to lead the Royal Botanical Expedition in 1783; Mutis maintained a regular correspondence with scientists in Spain and other parts of Europe, including Carl Linnaeus (Colmeiro, 1858).

In 1777, the Spanish explorer and botanist, Hipolito Ruiz, reported on maca and quinua as Peruvian crops: Maca root was described as a fertility enhancer for women that was used in Lake Junin, Peru, and quinua grain was used as a food and to produce fermented *chicha* in Chile (Ruiz *et al.*, [1793] 1940 p. 63). After a 10-year trip, Ruiz and his companions brought to Europe samples of the species collected. Another member of this Spanish expedition was the French botanist, Jose Dombey, who returned to France with 'a precious herbarium' to be preserved in the Jardin des Plantes of Paris (ibid [1793] 1940 p. 9). In 1843, the German botanist, Wilhelm Walpers, reported maca as a species in the *Novorum Actorum Academiae Caesareae Leopoldinae-Carolinae Naturae Curiosorum* (Al-Shehbaz, 2010 p. 155). There was interest in using American species; biological material, such as seeds, was available in Europe, which explains the dispersion of many species throughout Europe. Reports of uses of maca root and quinua grain are discussed Chapters 6 and 7. Scientists and farmers outside the Andean territories tried to use plant species (e.g., maize, potatoes) because of their interest in the potential benefits and there are reports of some successful efforts.

After independence, the bargaining power of the *hacendados* and foreign investors, who became the new oligarchy versus the indigenous communities, changed in line with the political changes and were accompanied by changes to the institutional arrangements for the development of academic activities. For example, some education organisations in Lima were privileged and became pioneers in many areas. In the 19th century, under the influence of the scientific revolution in Europe, the *Universidad Nacional de San Marcos* began to offer teaching in natural sciences and maths, and administrative sciences. Also, many indigenous and mestizos' children from the highlands moved to study in Lima, which had the most opportunities. It took longer for universities in the Peruvian highlands to achieve consolidation. *Universidad San Antonio Abad de Cuzco*, was founded in Cuzco in 1692, but was closed after few years. *Universidad de San Pablo* in Puno, was established by public law in the Aymara territory[144] in 1856, but was also closed several years later. Like many other universities in the highlands, it lacked resources because the difficulties of exploiting minerals and then because the Pacific War between Peru and Chile (1879-1884). These universities and *Universidad Nacional del Altiplano* in Puno reopened in 1954 (Ortiz Robles, 2006).

At the beginning of the 20th century, as the education system developed, Spanish was expected to be spoken in the emerging cities. The presence of universities in Lima privileged Spanish as the teaching language. The practices for recording accurate information, for importing foreign reports (i.e., journals and books mainly from Europe), and the use of empirical information for the production of knowledge was frequent in

[144] Independence from Spain resulted in the creation of the nation states of Peru, Bolivia and Chile. This three nation states shared the Aymara Republic indigenous territory extending from the central and south of Peru to the north west of Bolivia. Aymara is the second largest indigenous community in Peru after Quechua, and the biggest indigenous community in Bolivia.

regions where Spanish was the main language spoken. The new political and economic elites, including *hacendados* and mine owners, were settled in these regions. In regions that had a university, the chances of Spanish becoming the official spoken and written language increased. Since 1770, King Carlos III had prohibited indigenous languages in his domains (Godenzii, 2007 p. 54). However, in the Peruvian and Bolivian territories, lack of education establishments in the highlands until the end of the 18^{th} century meant that Quechua and Aymara continued to be spoken. Eventually, the advantages of a common written language and the cost involved in new models and records to accommodate Quechua and Aymara as written languages, led to Spanish continuing to be the official language after independence.

In 1902, the creation of the government National School of Agriculture and Veterinary (ENAV, for its Spanish name *Escuela Nacional de Agricultura y Veterinaria*) in Lima, fulfilled a long-standing interest to include agricultural science into the higher education system. Similar histories had happened in Europe, and in the rest of America, including Mexico, Canada, Chile, Argentina, Colombia, (San Martin Howard, 2011 p. 6) and the USA. In the USA, the Morrill Act, in 1890, supported the establishment of 'land-grant universities', by which one eligible state university received $120km^2$ of federal land to teaching and research in agriculture and the mechanic arts (Kloppenburg, 2004 p. 12). A Belgian mission was involved in creating ENAV and in subsequent decades, scholars come from other countries to visit or work permanently in ENAV, while Peruvians went to study in countries in North America and Europe. In 1941, ENAV became the independent National Agrarian University - La Molina (UNALM, for its Spanish name *Universidad Nacional Agraria La Molina*). It was set up to satisfy the military's demand for veterinarians to tend horses and other animals; it satisfied landowners requirements for technical support for their haciendas. The new Peruvian Ministry of Agriculture (MINAG) set up an extension department. These organisations focused on supporting the haciendas and their crops and had close links to government.

In the 1930s, some of those born in the highlands began to use concepts and techniques learned at school and university to understand their own environment. One of those highlanders was Javier Pulgar Vidal, who was born in Huanuco, and was a geographer who had studied at the *Pontificia Universidad Católica del Perú*, Lima's first private University. In 1940 he submitted a thesis on the eight Natural Regions of Peru. In 1941, he presented his work at the III General Assembly of the Pan-American Institute of Geography and History. He criticised the simple divisions in the Peruvian territory of coast (Pacific Ocean), highlands (Andes) and forest (Amazonas rainforest), the three macro-regions defined in colonial times. Vidal's research acknowledged the Quechua understanding of the eight zones,[145] which considered *qechwa*, *suni* and *puna* as distinct highlands zones. He began a career as a civil servant in 1941 but this ceased with his exile to Colombia in 1948. When he returned to Peru in 1958, he established several universities in the highlands of Peru and in Lima, and published several articles about the richness of the Andes. One of these articles, entitled *Maca, poderoso fecundante natural* (*Maca, a powerful natural way to increase fertility*), was published in 1960 in *La Voz de Huancayo* (Pulgar Vidal, 1960 cited in Hermann and Bernet, 2009a p. 28).

Before 1960, boys received a basic education in the Spanish language, but for girls the situation varied. Some schools, mainly in Lima, allowed girls access to education, following trends in Europe and the USA. At the end of the 19th century, the *Universidad Nacional de San Marcos* was the first university to open its door to young women. Laura Rodriguez Dularto was the first woman to be awarded the degree of physician, but others soon followed in different knowledge fields. For example, Gloria Chacón de Popovici was awarded a bachelor's degree in Biological Sciences in the 1950s and wrote a dissertation entitled *Estudios Fitoquímicos de la 'Maca'* (in English *Phytochemical Study of 'Maca'*).[146]

Bolivia and Peru followed different paths to the introduction of Spanish in the Andean highlands where maca and quinua were grown. Up to 1960, the Spanish language was an exception in the highlands of Peru and Bolivia, where Quechua and Aymara were spoken: Quechua was spoken in the central and northern region of Peru and the middle range mountains of Bolivia, and Aymara was spoken in the southern region of Peru and northern and western regions of Bolivia. The introduction of education systems in these

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[145] The eight zones are (i) *chaala* – coast, (ii) *yunka* – warm valley, (iii) *qechwa* – lands of temperate weather, (iv) *suni* – broad mountains, (v) *hanka* or *janca* – white lands, (vi) *haallqa* or *puna* –altitude sickness land, (vi) *rupa rupa* – hot lands or highlands jungle, (vii) *omagua* – land of sweet water fishes or lowland jungle, and (viii) *hatun-qucha*.

[146] Chacón later became a maca dealer and her commercial web pages report that her research identified an alkaloid extract that stimulated the reproductive organs of male and female rats, scientifically proving popular beliefs about fertility (see Alternative, 2000 - 2014; Realymed, 2011; Pachamaca, 2015).

countries, with university education being the highest level of education, was influenced by developments abroad such as in Europe and the USA. These education systems allowed indigenous people and mestizos to acquire new skills (to read and write Spanish) and gave them the opportunity to voice their views in relation to other organisations and institutional arrangements. This increased their agency in the process of biodiversity-based innovation in Andean species.

This section introduced the organisations and institutional arrangements related to the two case studies. The arrival of the Spaniards in America at the end of the 15th century triggered a rearrangement of the ancient indigenous organisations. The Spaniards adjusted these ancient organisations and institutional arrangements to suit the Spanish Kingdom's goal of extracting metals and opening trade with its new colonies, which evolved together with skills and organisational routines. The goals defined by these organisations entailed the cooperation of indigenous communities, mestizos and Spaniards, who considered the costs and benefits of pursuing organisational goals and addressing their individual needs. The Spanish language was one of the institutional arrangements that indigenous people and mestizos adopted, rather than constructing new models and codifying the ancient Quechua and Aymara languages.

5.3 Forms of governance and appropriation of benefits from goods from biodiversity

Organisations and institutional arrangements set the conditions under which actors appropriate the benefits from biodiversity-based innovation.[147] Goods emerge from the use of biodiversity when actors use their skills and perform organisational routines. Appropriating benefits from biodiversity through hunting allowed the community to obtain sufficient food for their subsistence. The food obtained from hunting and gathering activities was used for self-consumption, while control of the territory was the 'complementary means' to enhance the benefits. Trade and bartering were marginal in

[147] Human beings, either organised in states or as individuals, benefit from biodiversity since it provides food and other renewable resources, helps to regulate the climate, and allows the emergence of cultural and supporting services (Sukhdev *et al.*, 2010 p. 7).

hunting/gathering since this form of appropriating benefits satisfied subsistence requirements without supplying a surplus.[148]

The appropriation of benefits through cultivation/husbandry was accompanied by the setting up of organisations and institutional arrangements deriving from the establishment of the Inca Empire and, later, the influence of Spain and then the new independent nation states. These organisations and institutional arrangements included markets, which allowed actors that produced surplus to trade.

This section explores the organisations and institutional arrangements related to the goods arising from the use of biodiversity and the associated appropriation of the benefits derived from these goods. Market are an institution that allows the appropriation of economic benefits and overlaps with other institutions considered in the previous section. The first sub-section explains the tension between indigenous people and other actors involved in development of the market. The second sub-section explores how another institutional arrangement, related to seed production, changed the options for appropriating benefits and the means that enhanced (or restricted) such appropriation over time.

5.3.1 Benefits from self-consumption to new independent nation states, and the development of markets for monetising benefits

Private property was common even in those states or territories where it was considered not to exist.[149] Property rights range from simple private ownership of items utilised for agriculture (e.g., tools for tilling the land), but not necessarily the land, to more extensive and more complex property rights. In complex levels of ownership, actors own both movables items and fixed assets (i.e., land), which provides higher income from manufacturing or services (Wittfogel, 1957 p. 231). The most complex levels of ownership

[148] In hunting/gathering, one of the problems related to producing a surplus is lack of technologies for storage. The perishability of goods attracted actors to explore storage of food.
[149] Wittfogel (1957) refers that Marx did not consider that private property existed in Oriental societies; he also explained that the presence of classes gives evidence of property rights (p. 4). However, he recognised that different forms of property (and private property) exist that differ from society to society, and that the scale depends on the active (or not) role of states (see Wittfogel, 1957 p. 244).

involve class, with the higher classes holding political power positions (Wittfogel, 1957 pp. 258-9).

There has been a trend across the world towards the creation of states that define formal institutions, governing, among others, the commercialisation of goods emerging from the use of biodiversity, or rules (and, therefore, appropriation), which gives control over rights-based means. As in the case of the Jersey cow, where the state defined levies on imports of cattle to the Island, the capability of the Andean states (i.e., Peru and Bolivia), in the following chapters, we consider the conditions for the commercialisation of maca root and quinua grain.

Simple levels of property rights occur under hunting/gathering forms of appropriation of benefits, to the extent that the game and fruits belong to and are consumed by the hunter-gatherer. More complex levels of property rights evolved with the introduction of cultivation/husbandry, where issues related to the type of organisations and the institutional arrangements affect the appropriation of benefits. Some institutions facilitate the appropriation of benefits, as in the case of monetised exchange in markets, which reduce the costs of the exchange, but allows the accumulation of the benefits (i.e., wealth).[150] Markets are an important institution in the analysis of maca and quinua.

Agriculture based communities, such as those around Lake Junin and the Lake Titicaca basin, made limited use of monetised exchange before the first half of the 20th century. The bureaucratic managerial economy of the Inca Empire left little room for the development of private initiatives and there is no evidence that private actors competed with government over artisanal activities, crafting or long-distance transportation, where the Inca Empire maintained a strong presence until colonial times (Wittfogel, 1957 p. 248). In 1562, Spanish chronicler Iñigo Ortíz de Zúñiga mentioned maca in the context of limited (local) bartering practices in Huanuco province, on the north side of Lake Junin (Ortiz de Zúñiga, 1972 cited by Hermann et al. 2009). During the 16th century, most Andean indigenous people appropriated benefits from goods (i.e., crops grown for food and fodder) through self-consumption, rather than monetised exchange or barter. Goods

[150] Dillard (2016 pp. 1623-5) presents an analysis of money as a central institution of capitalism, although recognising that it exists in other economic systems as a form of wealth and exchange.

from the use of biodiversity allowed indigenous people to satisfy their basic requirements (i.e., food, healing), and to exchange some products using basic barter (see Ch.7 Sub-section 7.2.1 for a description of bartering practices).

At the end of the 16th century, the monetised market extended to the larger towns, such as Potosí, La Paz (both in today's Bolivian territory), and Lima and Cuzco (Peru), and to exchanges related to metals and some commodities such as wheat, barley, maize, quinua, potatoes, and coca.[151] The integration of indigenous communities into the Spanish markets was possible restricting the *encomendador* rights, by liberating indigenous communities from the control of the *encomendadores* and forcing indigenous communities to pay taxes – in cash or in kind - to the Crown. The 'rationalization of the tax(es)' (Klein, 2003 p. 37) was complemented by the creation of towns where it was possible to control the extraction of taxes from indigenous people, which rationalisation served also to defend the territory from foreign indigenous communities (Quechua and Aymara speakers), that were not under the control of the Crown,[152] or Portuguese invaders in search of slaves or trying to control the territory. At the end of the 17th century, Buenos Aires port in the Atlantic was recognised by the Crown, making it possible to send Potosí silver production either through Lima–Callao port or Buenos Aires. Buenos Aires enhanced production and trade between Potosí and Sucre with the Atlantic coast, leaving La Paz to grow independently as a market based on agricultural production (Klein, 2003 p. 69).

The wars of independence at the end of the 18th century and the first half of the 19th century across Latin America affected the appropriation of benefits for different actors. In 1780, the emancipation by Cuzqueñan Tupac Amaru in Peru was one of the triggers that ended with the expulsion of Spaniards from their colonies, and the establishment of the new independent nation states. The independence fostered both mestizaje and 'acculturation' due to the migration of foreign and local military forces (Vázquez, 1970 p. 74). Mestizos and indigenous people promoted and fought for

[151] Together with staples, coca was necessary for resisting the tough conditions for miners working the high-altitude silver mines of Potosí (see Klein, 2003 p. 52).
[152] The rationalisation of the tax(es) had an important impact on the mining activity. It included the monopoly on the production of mercury to control the payment on taxes on mining production, together with the payment of wages to workers, for both private and public initiatives (see Klein, 2003 pp. 37-40).

independence to gain a new political and economic arrangement. The independence of American colonies from the Spanish Kingdom in the first half of the 19th century eliminated Spain's political control, but maintained the trade in minerals and other commodities between America and Europe, although under the control of mestizos. Independence changed the bargaining power of actors to define the institutional arrangements and appropriate the benefits from the commercialisation of goods emerging from biodiversity.

Independence gave a new order to *rights-based, structural and relational means* (see Ch.1 Section 1.4), which enhanced (or constrained) the appropriability of benefits. Independence marked the beginning of attempts to govern and to establish nation states throughout Latin America through written constitutions, manifestos and treaties. After the expulsion of the Royal forces and Spanish oligarchy, mestizos' efforts were directed to introducing law and order, which, in most cases, derived to central forms of government around provinces or cities. Mestizos also gained the right to manage the royalties from mining activities to fund the provision of public goods (i.e., education and road infrastructure).

Peruvian mestizos (the new oligarchy) maintained coastal Lima as the centre of power since Peru has a single coast and was dependent on maritime trade to gain benefits from exporting minerals (Contreras Carranza, 2002), but there remained a large percentage of the indigenous population located in the highlands around Cuzco and other medium sized cities. In Bolivia, the cities of Potosi, Sucre and La Paz were the main centres of trade and power: The economy of the former two was strongly dependent on silver production, which declined at the end of the 19th century.[153] Although political dependence on Spain ended, economic dependence on Europe continued, and dispossession of indigenous lands by mestizos, worsened after independence (Romero *et al.*, 2006 p. 266).[154]

[153] This situation resulted in the Bolivian government being based in La Paz since 1898 and the high courts in Sucre.

[154] Although the new Bolivian government tried to eliminate taxes after independence, it was quickly realised the decline in silver production, which now required imported goods, meant that indigenous communities should continue to be taxed since there was not possibility to tax white investors or *hacendados* mestizos (see Klein, 2003 p. 105).

Mestizos organised the institutional arrangements including laws and mechanisms of enforcement for ensuring rights over land and labour. In most of Latin America, the new oligarchy was *hacendados* (landlords) or mine owners, who adapted Spanish institutional arrangements for securing and retaining slaves and indigenous people as labour.[155] The new oligarchy appropriated benefits from the export of commodities thanks to the control over land and labour. This allowed *hacendados* to appropriate benefits from the commercialisation of commodities such as sugar cane, tobacco, coffee and cotton.

During the second half of the 19th century, communities from the highlands in Peru were attracted by the economic developments on the coast. At the same time, Peru's reputation as a rich and growing economy along with Argentina, Brazil and Uruguay, and the ending of slavery (1854), attracted many around the world to invest in or come to work in the coastal plantations sugar cane, cotton and rice plantations and the guano mines. After independence, there was gradual European immigration to the Peruvian coast from Italy, France, Germany, Portugal, England, Ireland and Spain (Vázquez, 1970 pp. 78-81). In addition, there were Asian migrants, especially Chinese (Melillo, 2012), and Japanese, who were valued by landowners looking for cheap labour.

In the 19th century the Bolivian economy was minerals-based (initially silver, then tin), originating from Potosí and other places.[156] Although during the first half of the 19th century the economy stagnated, several factors allowed an improvement in economic performance in the second half of the century. These included economic consolidation of Santa Cruz, the Eastern region of Bolivia that was well connected to Argentina; and autonomy of the highlands in production of staple food. These improvements were despite loss of access to the Pacific Ocean during the war between Bolivia and Peru against Chile, which occurred at the end of the 19th century, and the dependence on

[155] The haciendas established various mechanisms of coercion over workers (see Knight, 1988).

[156] Potosí, the largest city in the Andean territory in colonial times (and part of the modern Bolivian territory), had the world's largest silver mine in the 16th and 17th centuries. Once the main seam in Potosí was exhausted, in the second half of the 19th century new mines began to be exploited, especially in Huanchaca, Antofagasta and Pulacayo, in the Potosí region. At that point, they were all Bolivian territories, but today Antofagasta belongs to Chile. Klein (2003) explains how external factors, such as the invention of steam, the development of mining in Peru and Chile and the presence of wealthy *hacendados* in Cochabamba, allowed the resurgence of the mining sector (see Klein, 2003 p. 124). In the 20th century, tin from mines in Potosí and Oruro departments, was the main product exported.

foreign ports for exports, and political instability, which, since independence from Spain until the end of the 20th century, alternated between dictatorships and attempts at democracy This kept the indigenous Aymara and Quechua communities in Bolivia mainly illiterate and isolated in rural areas, compared with other Latin American countries. The Aymara and Quechua population travelled between La Paz - Puno (despite the frontier between Bolivia and Peru), and with Cuzco, through a train that connected Puno and Cuzco.

The separation of indigenous communities' lands from haciendas and mines,[157] the indigenous diet that included quinua grain as a staple, the pre-capitalist organisations of the haciendas where migrant indigenous workers had limited rights and limited access to money, and the diversification in terms of both cultivated species and varieties of quinua adapted to places where not many other crops can grow (see Ch.7 Sub-section 7.1.1), were related to the stability and persistence of the Aymara and Quechua communities' agricultural practices for producing quinua rather than replacing it by wheat or barley.

In both in Bolivia[158] and Peru, mining companies were prominent during the first half of the 20th century; their bargaining power allowed them to control government policies in their favour. In the Pasco and Junin regions, a mining company reported on labour and land in these terms:

> The Cerro de Pasco Corporation (with operations in Pasco and Junin region), which emerged as the brainchild of American investors in 1902, was for half a century the dominant force in Peruvian mining. […] By the end of World War II Cerro de Pasco was the biggest employer in Peru after the government itself. Cerro also owned a network of haciendas on which it raised sheep to produce milk, butter, and meat for local consumption as well as wool and meat for export. But much of the land utilised for sheep grazing had been acquired cheaply by Cerro after its mining operations had polluted the soil so badly as to make agriculture impossible, and the company later consolidated its grazing land by expropriating the property of local communities. Cerro was therefore accused of having created a pool of unskilled labor for itself by forcing local people off their land. By the late 1960s the company was facing increasing opposition to its

[157] Several attempts to oust the indigenous communities from their lands occurred, one being the creation of an individualistic Indian 'peasantry' holding *de jure* titles (see Klein, 2003 p. 147). This allowed the haciendas to expand and introduce intensive production of grains and staples to feed the growing cities.

[158] In Bolivia, the most prominent mine owner was Simon I. Patiño, who, in the 1940s was considered one of the five wealthiest people in the world based on his tin enterprises. Many policies and governments were settled to benefit miners and the expansion of haciendas (see Klein, 2003 Chs 6-7).

> hacienda system and its labor practices, while the United States was coming under fire for its foreign policy. (SLULSC, 2011)

The Cerro de Pasco Copper Corporation managed the mining and processing (i.e., smelting) of copper, which previously had been controlled by small family producers. It bought lands from both *hacendados* and communities to change its use from crops to cattle herding. This forced some farmers to become cheap labour in the mines (DeWind, 1987).

In Peru, workers with the freedom to spend their wages and who did not own their own land to produce food, provided opportunities for the development of local markets around mines and haciendas. Basadre (1931), writing about the second half of the 19th century and the beginning of the 20th century, mentions that, in many cases, foreigners acted as food and garment dealers (Basadre, 1931 p. 116), unknown roles at that time. Prosperity derived from the guano boom and public building (i.e., railroads), coincided with the foundation of banks and the issue of bank notes by banks (BCRP, 2010 p. 15). The boom in guano exports to Europe enforced the imposition of centralism to manage the taxes and allow the establishment of a uniform network of local authorities, and the presence in all regions of military bases and religious missions (Contreras Carranza, 2002 p. 17). Something similar was to occur, but on a smaller scale in Bolivia, where the government served mainly haciendas and mining companies, and few investments to promote education were done in response to the indigenous movements in the first half of the 20th century (Klein, 2003 Chs 6-7).

Cultivation/husbandry ensured surpluses that could be traded. In Bolivia and Peru, markets were established in the first half of the 20th century: Some were in large cities. Together with the commercialisation of grains produced on haciendas and commercialised in large cities, migrant indigenous were involved in commercialisation. Some of these migrants succeeded as dealers since they had bilingual skills, they learned how and where (i.e., markets) to commercialise, and they had knowledge of where to gather the harvested crops. Both, local markets and international markets allowed both *hacendados* and indigenous people with skills as dealers to benefit from the commercialisation of food. Haciendas owners received huge economic benefits based on their access to land ensured by the rights granted after independence and their access to cheap labour.

5.3.2 Seed: From local public character to a private regulated service

Actors (and organisations) perform their skills (and routines) under institutional arrangements. Farmers ensure the availability and quality of seeds to be cultivated, maintaining different institutional arrangements. This section discusses how these institutional arrangements changed over time and how new forms of appropriating benefits emerged.

Indigenous people for thousands of years saved seeds and todays seed production, conservation and exchange are part of the use of species from biodiversity. The reproduction and exchange of seeds ensures their availability for succeeding seasons of food production. In the case of indigenous communities, shared knowledge about seed health and availability, and intraspecific diversity (i.e., diversity among the same species) has been the *relational mean* (see Ch.1 Section 1.4) that enhanced the appropriation of benefits from the cultivation of seeds. That knowledge was especially valuable in the case of staple crops such as potatoes and other crops, such as maize and quinua cultivated in the Andean countries by indigenous communities. Indigenous people ensured seed availability through exchange, which was intertwined with access to the land and food production (de Haan, 2009 p. 25). Seed was exchanged among members of the *ayllu*, who shared the same environment. These seeds produced the type of plants preferred for food and saving them did not compromise food availability.

Institutional arrangements and organisations evolved to the extent that seeds passed from being governed as a local public good, where kinship linkages allowed the consumption among members of the *ayllus*, to became governed as a private good (i.e., through PBR, see Ch. 1 Section 1.4), which were excluded from and became subtractable to the appropriate of the benefits of this private good. This form of governance applied mostly to grains and shows the role of governments for defining the conditions for the commercialisation of goods.

In the case of staples, indigenous people who saved the seed from the previous harvest used the same native varieties continuously. De Haan (2009) analysed the case of potatoes in regions under the control of *ayllus* where maca and quinua are produced: During normal years, seed acquisitions among indigenous people involved 'transactions in small quantities, few varieties, few events of exchange, and seed flows over short distances' (de Haan, 2009 p. 133). Each farmer grew a few local varieties, which had adapted to the local conditions. At the regional level, the different microenvironments supported more varieties, some of which were cultivated quite broadly, while others were cultivated by only few farmers and exchanged with low frequency. Although the seeds were governed as private property, like other movable items utilised for agriculture, the set of seeds available in a locality was governed as a local *common-pool resource*, which allowed the appropriation of benefits for those in the locality, while links to the community (or *ayllu*) ensured reciprocity over access to the seed and exclusion of those outside of the community. Exclusion of outsiders is explained by the absence of a market that would have allowed non-community members to access seeds with low transaction costs. Exchange of seeds among *ayllu* members avoided scarcity of regional seed.

In the 20th century, the development of nation states was accompanied by new types of institutional arrangements to regulate availability of seed, seed hygiene and movement of seed. Reports of losses due to pests and diseases increased awareness of sanitary problems, while intensive agriculture and use of a single variety, brought high risks of pest problems (Wilby and Thomas, 2002 p. 353).[159] National and international organisations and institutional arrangements developed for the commercialisation of seed at the national level, and the movement of seeds from one country to another. UPOV was one such arrangement (see Ch. 1 Section 1.4).

Twentieth century-type institutional arrangements (based on nation states) involved at least three kinds of organisations: Universities and researcher centres, and

[159] Francis and Sanders (1978) compared monoculture of maize and beans with associated cropping of the two species. They confirm that monoculture carries higher risks, while associated cropping ensures 'low production costs, greater income stability, and a minimum risk' (see Francis and Sanders, 1978). A more complete analysis of the benefits of agricultural biodiversity (and the associated risks) includes both crop yield and quality, but also 'aesthetic, recreational and the conservation of flora and fauna' (see Gurr *et al.*, 2003). Van de Wouw *et al.* (2009) refer to modern cultivars and modern breeding practices as involved in genetic erosion, at both the level of species (or crop), variety and allele (see van de Wouw *et al.*, 2009).

holders of seed varieties with the skills to compare and breed them on a small scale; seed companies with routines to produce seed on a large scale (including land ownership and commercial arrangements); and farmers with an interest in producing staples and optimise yields. Research on and disclosure of breeding techniques (such as hybridisation in the case of maize) opened new pathways to the shaping of crops. Universities and research centres maintain a large set of varieties (i.e., collections) to be used for the breeding process, which has improved breeding techniques and resulted in new varieties which have been registered by the seed companies for commercialisation.[160]

In the case of Peru and Bolivia, their national governments in cooperation with the Inter-American Institute for Cooperation on Agriculture (IICA), the Canadian International Development Research Centre (IDRC), the United States Agency for International Development (USAID) and the Rockefeller Foundation, trained researchers in maize and wheat breeding techniques in the 1950s and 1960s. That training allowed researchers in Peru and Bolivia to establish collections and breeding of quinua (see Ch. 7) and other Andean plants. This experience and further training, since the 1970s has resulted in large collections of potatoes and tissue cultures for potatoes and other Andean roots, including maca. These collections of maca and quinua seeds were used to shape these crops as described in Chapters 6 and 7.

Breeding techniques focus generally on key technical and economic attributes of distinctiveness, uniformity and stability. Stability meant that expected attributes have been maintained through a minimum of five generations of the plant. Some trials were conducted on universities and research centres' lands, while others were conducted on farmers' lands (Interviews BK, IB). Records were maintained to support decisions to commercialise a bred and register it as a 'new variety'. Some of the breeding process was the responsibility of seed companies, which reduced the breeders' interest in disclosing techniques and research results.

[160] See Ch. 1 Section 1.4 and Annex A.1 for details of how seed companies used their bargaining power to define the institutional arrangements that ensured the benefits from the commercialisation of bred seeds and other agricultural inputs.

Around the 2000s, the Peruvian Government implemented these 20th century-type institutional arrangements[161] in the case of quinua, where the Peruvian National Agricultural Innovation Institute (INIA for its Spanish name Instituto Nacional de Innovacion Agraria) oversaw the provision of bred seeds. Recently, commercial production of quinua seeds established following the scheme common to other grains, such as maize or wheat, which involves the seed company selling certified seed reproduced from bred seeds provided by INIA (Interview BA).

In Bolivia, most farmers used native seeds from their own production, but in 2011 to 2014, the boom in quinua production encouraged the Bolivian government to promote use of quinua bred by the Bolivian Foundation for the Promotion and Research of Andean Products (Fundación PROINPA for its Spanish name Fundación para la Promoción e Investigación de Productos Andinos) and certified by the Bolivian National Agricultural, Livestock and Forestry Institute (INIAF for its Spanish name Instituto Nacional de Innovación Agropecuaria y Forestal), especially in the highlands in the Northern area of Oruro region and La Paz region and the valleys of the Cochabamba region (Bonifacio *et al.*, 2015).

In the case of maca, in Junin and Pasco, two of the regions of its main production in Peru, farmers produce their own seeds or obtain them by traditional exchanges among members of the same community. There is not modernised production of maca seed (see Ch. 6 Section 6.3).

The institutional arrangements for the movement of seeds from one country to another involve coordination between states. The transboundary movement of seeds is of commercial interest to seed companies working under 20th century-type institutional arrangement since it enhances the appropriation of benefits. Access to capital, authorities and knowledge necessary to perform the protocols that ensure the distinctiveness, uniformity and stability of seed required by UPOV, and the seed

[161] The Peruvian plant health organisation was established in the 1930s as the *Junta de Sanidad Vegetal*, which is part of the modern history of entomology in Latin America; in the 1960s the Ministry of Agriculture organised a Deputy Direction of Plant Health, with experimental laboratories funded by IICA; (see Enkerlin, 1967), and in the 1990s this became the Peruvian National Service of Agrarian Health (SENASA, for its Spanish name Servicio Nacional de Sanidad Agraria).

production and commercialisation regulated under international protocols, all enhance the appropriability of benefits.

As discussed in Chapter 1 Section 1.2 and Annex A, international protocols regulate the commercialisation of goods emerging from biodiversity. In this respect, the Organisation for Economic Co-operation and Development (OECD, 2012 p. 3) reports that:

> A number of international organisations, conventions and treaties deal with the regulation of seed trade. […]. Among these organisations are the Organisation for Economic Co-operation and Development (OECD), whose Seed Schemes are globally recognised for the certification of seed moving in international trade. The International Seed Testing Association (ISTA) developed globally recognised standard procedures for seed sampling and testing. UPOV provides breeders of new plant varieties with an intellectual property protection. The International Seed Federation (ISF) provides seed companies with trade and arbitration rules. Besides (sic), there are the international conventions and treaties hosted by the […] United Nations[162] that provide the international regulatory framework for related aspects of seed trade, including plant health and phytosanitary measures, access and benefit-sharingfor plant germplasm and use of pesticides.

As discussed in Chapter 1 Section 1.2, the United Nations CBD reaffirms countries sovereign rights to regulate access to its genetic resources as opposed to their being treated as global 'common-pool resources'. Every country can establish protocols for access to biodiversity and should receive a share of the benefits arising from the use of biodiversity. Andean countries, including Bolivia and Peru, have introduced an *ex ante* contract and a regulated procedure to access biodiversity (see Ch. 1 Section 1.4 and Annex A.5). Therefore, any access that does not fulfil these conditions is illegal.

[162] The United Nations also has mechanisms for cooperation with other international bodies such as the World Trade Organization (WTO). 'The movement of seed in international trade is based on the WTO's principles laid down by the *Agreement on the Application of Sanitary and Phytosanitary Measures* or SPS Agreement, agreed in January 1995 (OECD, 2012 p. 3). '*The International Plant Protection Convention* (IPPC) is currently recognised by the WTO-SPS Agreement as the only international standard setting body for plant health. […] The Convention is governed by the Commission on Phytosanitary Measures, which adopts international standards for phytosanitary measures. Currently 177 governments adhere to the IPPC' (OECD, 2012 p. 8). 'The WTO's *Agreement on Trade-Related Aspects of Intellectual Property Rights* (TRIPs) obliges its signatories to implement a system for the protection of plant varieties through patents, an effective *sui generis* system or a combination of both' (OECD, 2012 p. 9). The FAO of the United Nations negotiated *The International Treaty on Plant Genetic Resources for Food and Agriculture*. This is an international legally binding instrument governing access and benefits-sharing related to plant genetic resources for food and agriculture (PGRFA), with the goal of 'facilitating the exchange of plant genetic material for research and breeding and of balancing the interests of all involved stakeholders, including commercial breeders and farmers. It came into force in June 2004 and currently counts 127 Contracting Parties.' (OECD, 2012 p. 10).

Under the Andean regulation Decision 391 (CA, 1996), for any movement of seed from the Andean country that is its centre of origin requires adherence to an *ex ante* contract and regulation. Movement of seeds across borders that does not follow Decision 391 in the case of maca and yacon is considered by many to be examples of biopiracy (Hermann, 2013). Although it could be the case of quinua as well, there are not references to quinua biopiracy. This is explained because the unique and isolated origin of maca (see Ch. 6 Section 6.2.1), which does not happen in the case of quinua (see Ch. 7). It is possible to confirm the unique Peruvian origin of maca, which enhance the sovereignty feelings for maca and justify the biopiracy discourse against any actor that could use maca reproductive material without fulfilling the Decision 391. Instead, phylogenetic and evolutionary reports on quinua cannot deny the shared origin of quinua in both Bolivian and Peruvian territories. Also, several historical records refer quinua use in all Andean countries during Colonial times and archaeological studies confirm the presence of quinua outside the today Peruvian and Bolivian territories. Given that, quinua seeds could be moved at any point in history from several countries, making difficult to trace the origin of quinua, and therefore a unique sovereign discourse for quinua.

Farmers operate under local, regional and international institutional arrangements for in seed production. At the international level these arrangements reflect experience with grains. However, in the case of staples, such as potatoes and less commercialised grains (e.g., quinua, kiwicha and cañihua) and other roots and tubers such as maca, the seed is governed as a local *common-pool resource*.

5.4 Summary

The two Andean species under study belong to the small group of edible plants. Indigenous Andean people domesticated maca and quinua thousands of years ago; today, these plants achieved a level of standardisation. Quinua and to some extent maca are considered staple foods known to indigenous communities for generations.

In colonial times, several organisations and institutional arrangements were involved in the movement and diffusion in the use of these species, first to Europe and then to other continents. However, neither achieved levels of diffusion in use similar to potatoes and maize. They did not become innovations in the international market before the 1950s, but remained niche products used mainly in Latin America.

Institutional arrangements, such as links to Spain and the Catholic church, were important for the establishment of education organisations, and imposition of Spanish as the official language allowing codification of previously uncodified or unarticulated indigenous knowledge of the species. The education system combined the organisational and institutional arrangements related to education in Spain and the Incan Empire. Education hierarchies and teaching areas were established and in the 20th century, expansion of the education system meant that a large percentage of the population were taught the Spanish language and reading and writing skills (a larger percentage of the population along the coasts of Peru and the low lands of Bolivia). Indigenous people used the skills acquired to enter universities and research centres. These organisations contributed to codification of the meanings of these two species, their use within different routines to increase understanding and information of them, and allowed routines to be applied that imitated the experiments conducted on other species such as maize and potatoes; to achieve greater standardisation.

Since the 1700, the emergence of cities and improved communication has been accompanied by the development of markets. Structural patterns emerged, such as surpluses production from rural areas, which was moved to urban areas. Thus, the benefits based on self-consumption changed to becoming economic benefits enhanced by rights-based, structural and relational means (e.g., capital, access to authorities, land and labour).

Finally, indigenous people ensured their subsistence by the availability of healthy and diverse seeds. Seed passed from being governed as a *common-pool resource* to being governed as both a community-regulated *common-pool resource* and a state-regulated private good (i.e., 20th century type institutions such as PBR). Traditionally, indigenous people saved a portion of their harvested seed for the next season's planting and for local exchange (i.e., across short distances). This structure continued alongside a system based on authorisation and certification by a government authority. The state-regulated private goods system works at the international, national and local levels. International regulations related to protecting varieties (i.e., PBR), regulating trans-boundary movements/trade (i.e., TRIPS), and access to and sharing of benefits (i.e., CBD and Nagoya Protocol), currently govern the movement of seed from its centre of origin to other countries. However, the importance of these regulations in the shaping of biodiversity-based innovation varies from case to case.

This chapter extended the research design introduced in the previous chapters, in three ways. First, it explained different forms of biological reproduction -, sexual and clonal - of plant species, and highlighted that other forms of biological reproduction are possible. Second, it introduced patterns of social structure that explain how communities improved their welfare, by reducing the percentage of the population engaged in food production. Third, it introduced the history of use of the two Andean species under study (i.e., from precolonial times); it discussed (i) the different pathways that indigenous people could have followed (e.g., neglecting the species given the abundance of other species), and (ii) the unintentional circumstances and unintended consequences along the shaping process (e.g., the *sui generis* settlement of the highlands and the establishment of markets). Finally, it provided the background to the current state-based institutional arrangements for the provision and commercialisation of seed, which is efficient for some species (such as grains), but not others.

Chapters 6 and 7 discuss the shaping process of the two Andean species that are the focus of the empirical research: Maca and quinua. They follow the template used in the heuristic example and the research approach (see Ch. 3 and this chapter). The case studies provide insights that should be interesting for policy-makers in the area of biodiversity-based innovation.

6 Maca (*Lepidium meyenii*) case study

The present day commercialisation of maca flour is a biodiversity-based-innovation. Maca is an Andean plant with nutritious properties which also has effects on the human reproductive system (Hudson, 2008; Gonzales *et al.*, 2014). Indigenous Andean farmers have used it for centuries in the regions that are known now as Junín and Pasco, remote highland regions of Peru. Over the last three decades, maca has escaped risk of extinction and maca consumers around the world have encouraged its production in the highlands of Peru, Bolivia and China.

Maca has been used for thousands of years (see Ch. 5 Section 5.2.1) at the local level when it was identified as a species for human consumption by indigenous people who learned the (control and replication) skills for reproducing and cultivating the species. It was not until the 1990s that the use of maca diffused beyond Junín and Pasco regions. At that time, defining, basic and ancillary knowledge about the species was diffused and, following a further shaping process, maca flour began to be commercialised around the world.

This chapter examines how actors' use of maca shaped it as an artefact and influenced the technologies of production and use (Bijker 1997 p. 3). Rather than being a linear pathway coordinated by a single individual, the shaping process was based on the choices of farmers, dealers, researchers and consumers at the micro level. These actors performed their skills at the macro-level of organisational routines. Actors' use of maca has an institutional context, which can be considered a meso level phenomenon. Institutions reduce uncertainty by providing a structure to everyday life (North, 1990), allowing actors to make choices about the use of maca and to consume the goods that emerge from such use. Governance over the emerging goods is related to these institutional arrangements and the technological attributes of the species, and defines the benefits to individuals or groups or both. Although institutions appear static, they are social constructions derived from the interactions among people.

The maca case is presented to understand how the appropriation of benefits took place along its shaping as an innovation. The interest is in promoting policies in order to pursue the aims of the CBD and of the Nagoya Protocol of the greater benefits for biodiverse countries, and equitable sharing of the benefits arising from the use of biodiversity.

This chapter is the second of three case study chapters that analyse how the biodiversity-based innovation process occurs. It is organised in three sections. Section 6.1 presents the innovation process which brought maca into commercial use. Section 6.2 presents the institutional arrangements that affected this innovation process. Section 6.3 analyses the forms of governance over the goods that emerged from the maca shaping process and how the actors appropriated benefits. The chapter concludes with a summary in Section 6.4.

6.1 The maca innovation process of maca

This section explains the social practice of controlling several altitudinal vegetation zones which defined maca as a crop for human consumption and explains the actors' involvement in the innovation process. Although its domestication process was lengthy, the focus in this thesis on the last 50 years, which makes it possible to trace the social practices that drove the commercialisation of maca products at the international level.

Before presenting the social practices and actors involved in the innovation process, it is useful to recall the conditions that allowed maca to flow to different regions and to reproduce as a species (see Ch.5 Section 5.1). When indigenous Andean farmers attempted to move maca from the wet *puna* in Junin and Pasco regions to other zones (i.e., *suni* or *qechwa*) they found it difficult to articulate their knowledge about it. Reference to other species was not effective since maca is quite different from many other plants. This explains the absence of maca in other parts of the continent before colonial times[163] although movement of plants (e.g., maize from Meso-America) and

[163] Hermann and Bernet (2009b) provide references to maca in archaeological studies. They found the oldest findings are referenced in Pearsall (1989), who documented the Panalauca cave in the Junin region. This site was inhabited between 7700 BC and 1200 AD and shows the transition towards domestication of maca based on the size of the roots found. Its domestication period coincides with the domestication of camelids. There is no evidence of the presence of maca in other archaeological sites despite Pearsall's

trade using domesticated camelid [164] caravans were common throughout the highlands.[165] The Spaniards likely encountered similar problems in trying to move this species to Europe,[166] despite evidence of many attempts to move and produce Andean crops in Europe and other European colonies around the world (Roxburgh and Carey, 1832; Nees von Esenbeck, 1834; Diamond, 1997 p. 318; Ochoa and Frey, 1999; Ochoa and Frey, [1990] 2001). Maca is a biennial plant which differs from most other plants traditionally cultivated for food, which are annual or perennial. Also, it reacts to the low temperatures in the wet *puna* by the growth of a reservoir root, the edible part of the plant, storing nutrients during the rainy season that would allow its survival through cold weather. The low temperatures in the wet *puna* would kill most other plants.[167]

In its growth habit, size and proportions, maca is similar to other species of Brassicacea family, some of which are annual roots, such as radishes. However, in the Andean wet *puna*, maca has two separate but complementary life cycles: The first year, during nine months after the seed falls into the soil, an enlargement of the stem above

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extensively studied of the highlands and coasts of Peru, Bolivia and Chile. Hermann and Bennet are sceptical about toponyms of plants and places or containing ‘maca’ based on historical and archaeological evidence is sufficient evidence to describe diffusion of maca use outside the confirmed region of origin (see Hermann and Bernet, 2009b p. 24). The difficulty involved in moving maca was corroborated by interviewee YNA, who reported failed attempts to introduce it in the 1960s at an altitude of 2,800 masl in Nariño, Colombia, where the plants did not tuberise.

[164] After glaciation, the wet *puna* in Junin became a natural habitat (i.e., corral) for camelids. ‘Within the *Puna* of Junin there is an abundance and variety of natural pasturage for the Camelidae’ (Pires-Ferreira *et al.*, 1976 p. 483). The humidity ensures green pastures year round compared to other areas where the dry seasons reduce the camelid population; ‘Here ecological factors and territorial behavior patterns combined to create a stable concentration of Camelidae within a definite geographic area, forming a kind of natural corral which was exploited by early hunters and within which the process of domestication was probably carried out’ (Pires-Ferreira *et al.*, 1976 p. 483).

[165] In the Junin region, Wari expansion, which took place between the 6th and 10th centuries, included use of camelid caravans for trading (see Heggarty, 2008). During the same period and in the 10th to the 16th centuries during the Inca empire, exploitation of silver from Cerro de Pasco occurred, on the north side of the Lake Junin basin, ‘likely driven by demand from Inca nobility for precious metals as a tribute tax’ (Cooke *et al.*, 2009 p. 1021).

[166] The plant was practically unknown in Europe until the 20th century. It was generally believed that many roots from the New World were difficult to manage. Also, the roots grown in Europe were eaten raw while those from America required fire for cooking or else they were inedible due to their unattractive flavours (e.g., aroids), or because they were poisonous if eaten raw (e.g., cassava) (see Cook and Barrett, 1910).

[167] Many species with subterranean edible parts (i.e., subterranean stems, roots and bulbs) are consumed in the Andes since the *puna* lacks large plants (i.e., trees). The phenotypic indication that the subterranean part is ripe for human consumption is loss of green colour in the aerial part of the plant which is related to the adverse conditions that the plant faces and allows the plant to reduce its energy consumption and conserve energy in the subterranean parts of the plant. This applies to potatoes and other Andean tubers, but not maca, whose leaves remain green even when the root has reached its maximum size (see Tello *et al.*, 1992). These attributes make the learning process costlier compared to other species.

the root, grows to take advantage of the humidity from the rainy season. The root then remains dormant during the dry season. Human practices (discussed in Sub-section 6.1.1) involving husbandry of Andean camelids, provided a way to help the root (i.e., vegetative seed) to resist loss of humidity during the day and to withstand the frosts during the nights of the dry season. In the second year, the dormant root begins a new cycle after the rain comes, and produces a large rosette of thousands of tiny flowers. Maca is mainly self-pollinated autogamous species and each flower produces two seeds (Interviews AE, BE, CA, QA and Hermann and Bernet (2009a)). The indigenous Andean farmers remove the rosette and harvest the seeds for replanting the next season. Thus, maca has a two-year life cycle during which roots and seeds are produced. Other plants produce attractive fruits covering seeds which are eaten by animals and in this way the seed is dispersed (e.g., apples, oranges and grapes), or produce seeds that start to grow once they fall into the soil (e.g., wheat, rice, barley and quinua).

The reasons by why indigenous Andean people chose maca thousands of years ago from among the hundreds of species of Brassicacea family and the nearly 50 species from genus *Lepidium* native of South America (Al-Shehbaz, 2010)[168] are unclear. Maca was one of the many options available to the indigenous Andean people for cultivation. Its cultivation was more difficult and costly in relation to other cultivated crops and the lack (or high costs) of articulation of knowledge concerning its cultivation limited its transfer to other areas.

Despite the cultivation of other crops, including well-known staples such as potatoes, maize and quinua, as well as species introduced in colonial times (i.e., winter barley and oats), from zones surrounding the *puna*, indigenous Andean people persisted with maca cultivation and consumption. In pre-Hispanic times, maca may have been less

[168] Some of these 50 species were involved in the mutation, genetic drift, natural selection and gene flow of maca (see Ponce *et al.*, 2005); maca is the only species that was cultivated. Further investigation is needed to understand how the nutritious and health related phenotypes of maca were identified: Some authors suggest the taste was one of the factors considered by indigenous farmers, as in the case of mashua (*Tropaeolum tuberosum*) (see Johns, 1980; 1981). Another phenotype considered probably was root colour. Maca roots are differently coloured and their size also varies. The indigenous people believe that different sized and different coloured roots have different attributes (see Hermann and Bernet, 2009a), which are related to the value given to their consumption (i.e., fresh or dried, boiling time). Researchers have begun to explore differences based on colours (Gonzales *et al.*, 2005; Gonzales *et al.*, 2006; Alzamora-Gonzáles *et al.*, 2007; Gasco *et al.*, 2007; Monteghirfo and Yarleque-Chocas, 2007; Rubio *et al.*, 2007; Gan *et al.*, 2013) and postharvest practices (see Alvarez-Salazar, 2008; Yábar *et al.*, 2011).

relevant since the camelids and other small animals were more important in the wet *puna* region. However, historical evidence indicates that maca consumption helped indigenous people to resist the tough conditions of the wet *puna* and, also, that it was considered a fertility enhancer.

Why did a plant that was native to isolated places and severe weather conditions attract the attention of indigenous communities, when they had a diversity of other plants available at other altitudes? Sub-sections 6.1.1 and 6.1.2 discuss the social practices and the actors involved in the innovation process.

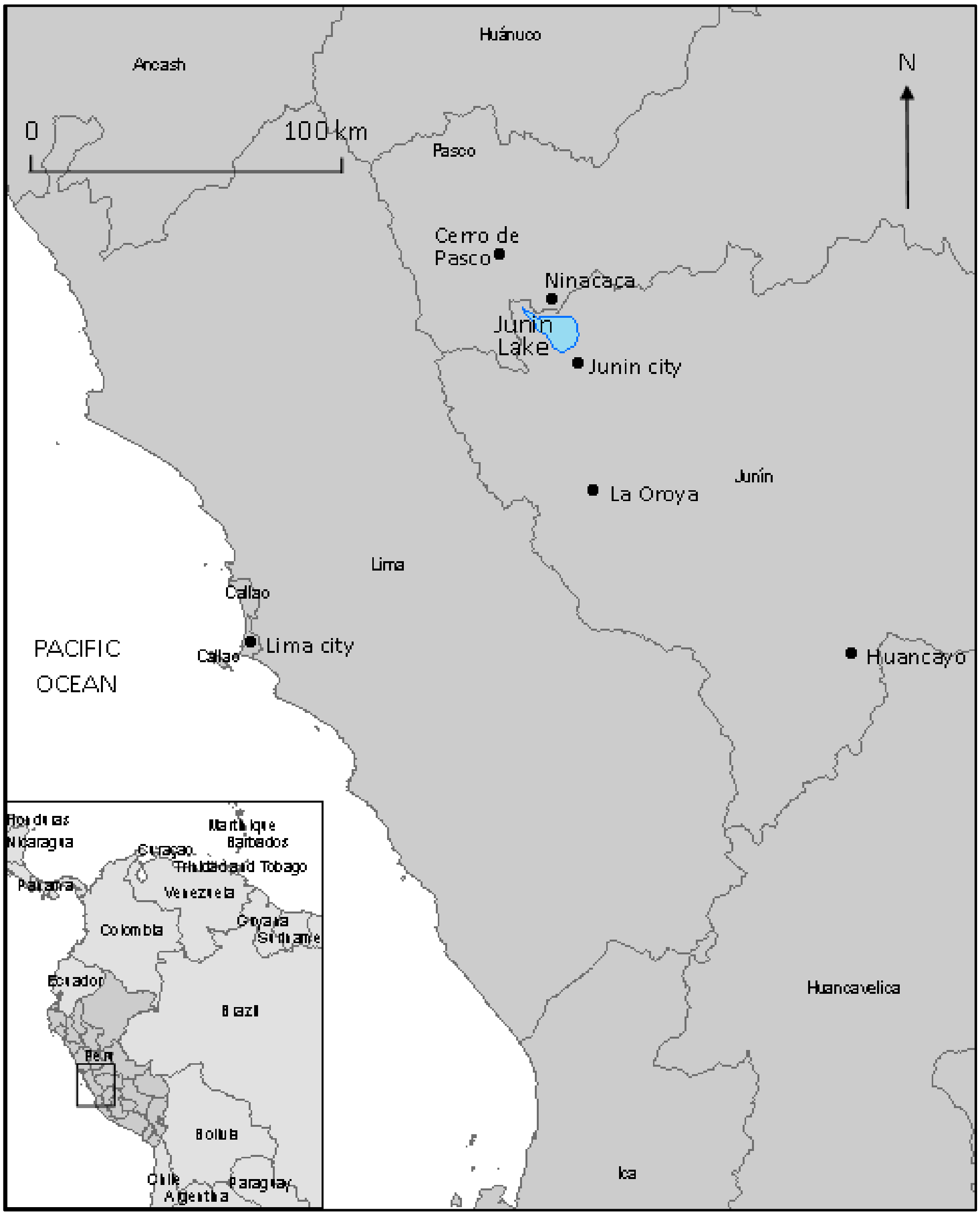
6.1.1 How are biodiversity-based innovation and social practices collectively shaped?

The Andean wet *puna*, where maca was mostly produced in the 20th century, is part of the Peruvian territory. This section discusses the social practice of controlling several altitudinal vegetation zones (Murra, 1975 Ch. 3), which allowed indigenous farmers in the wet *puna* of Junin and Pasco regions (see Map 2) to shape maca as a fertility enhancer.

Indigenous Andean farmers from this region had different skills and routines compared to communities from the coast and the forest (see Ch. 5 Section 5.2.2), and they were Quechua speakers (see Ch. 5 Sub-section 5.2.2). As in other parts of South America, the indigenous Andean farmers in the highlands satisfied their food needs with staples, complemented by other plants and animals. In addition to potatoes, maize and quinua, the main staples in the last three thousand years, communities grew maca, oca (*Oxalis tuberosa*), olluco (*Ullucus tuberosus*) and mashua (*Tropaeolum tuberosum*)[169] (Tapia, 2000; Tapia Núñez *et al.*, 2007).

[169] The Spaniards introduced plants such as wheat, barley and faba beans , and animals such us sheep, that adapted well to the highlands conditions.

MAP 2. JUNIN AND PASCO REGIONS LOCATION IN PERU



Quechua speaking indigenous Andean farmers had the social practice of controlling different altitudinal vegetation zones, here they cultivated crops suitable to the weather conditions (Langebaek, 1987). The highlands includes four such zones (Pulgar Vidal, [1941] 2014): *Qechwa* (i.e., lands of temperate weather) where potatoes, maize, quinua, wheat, barley andsomefruits are grown; *suni* (i.e., broad mountains), where potatoes, wheat, barley and sheep are cultivated; *janca* or hanka (i.e., white lands) where nothing grows; and *puna* (i.e., altitude sickness land), where maca, grasses, camelids, sheep and bitter potatoes are cultivated (Tapia and Mateo, 1989; Tapia, 2000; Morales Garzón, 2007).

Thus, the same Quechua speaking indigenous community controls several altitudinal vegetation zones, giving them a set of places to satisfy their food requirements year round. *Puna* in the Junin and Pasco regions in central Peru have high levels of rainfall - more than 1,000 millimetres (mm) per year -,[170] compared to the *suni* and *puna* zones in the Lake Titicaca basin on the border with Bolivia (around 700 mm per year) and the dry *puna* in northern Argentina and Chile, which can receive around 400 mm per year, but this could also be as little as 100 mm per year (WWF, 2001; Santa Cecilia Mateos and Mata Olmo, 2012). Despite the tough conditions of the *puna*, which restrict cultivation of major staples (potatoes and maize), the humidity makes the *puna* in the Junin and Pasco regions more suited to human settlement, herding and some agricultural activities compared to the dry *puna*.

Indigenous Andean farmers have produced maca and bitter potatoes for thousands of years. These crops and a few grasses, are able to withstand the strong winds, high solar radiation and low temperatures of the wet *puna*. Daytime temperatures are around 18°C; night time temperatures can be around 8°C (Dostert *et al.*, 2013 p. 389) or as low as -10°C (Tello *et al.*, 1992; PeruBiodiverso and Molina, 2007). Andean camelids (llama *Lama glama* and alpaca *Vicugna pacos*) are highly valued by indigenous Andean communities for use as pack animals and for meat and wool. They naturally consume both maca and the available grasses. The presence of Andean camelids explains why the indigenous farmers settled in the *qechwa* zone[171] and made regular trips to the wet *puna* to herd camelids.[172] The activity of camelid herding in the wet *puna* was complemented by cultivation of maca and bitter potatoes[173] for human consumption. From precolonial times until recently, the wet *puna* was considered as a home to herdsmen with maca

[170] Several classifications of *puna* have been proposed; one is based on rainfall, some on the presence of flora and fauna and some on latitude (see Cajal *et al.*, 1998).
[171] The transition from hunting/gathering to agriculture took place some 5,000 to 13,000 years ago, when intensive hunting wiped out the major mammals from the warmer territories, such as *qechwa* (see Morales Garzón, 2007).
[172] The presence of camelid hunters in the wet *puna* of Junin can be traced back to some 5,500 years ago. Then, the wet *puna* inhabitants shifted from hunting to pastoralism and domestication of camelids (see Gorbahn, 2013 p. 61).
[173] Bitter potatoes are more frost resistant than potatoes from *qechwa* or *suni* zones. Bitter potatoes called *luki* and *ruki* are sterile and require human intervention to reproduce; they are human invention artefacts (see Murra, 1975 p. 47).

production a complementary practice (Murra, 1975 p. 118; Aliaga-Cárdenas *et al.*, 2007 p. 31).

The indigenous Andean farmers began to use camelids manure to protect the maca roots during the dry season and ensure the viability of vegetative seeds. Traditional production of maca was 100 square metres of crop (Aliaga-Cárdenas *et al.*, 2007 p. 17), across small square plots around 15 metres by 15 metres called *sharpo* which were surrounded by a *pirca*, a low rustic stone wall (Interview QA). These facilities were attached to temporary shelters which housed the herdsmen during their visits to the wet *puna* from lower altitudes or small towns. These small towns were located along the routes between the silver mines in Cerro de Pasco and the centres of power.[174] The *sharpo* were used also to collect and to protect the camelids at certain times. During the maca production season, the walled *sharpos* protected the plant from being eaten by the camelids, who consider it a food.

Indigenous Andean farmers coordinated their efforts around the *ayllus* (see Ch.5 Sub-section 5.1.2). *Ayllus*, specialised in herding activities, had temporary or permanent settlements in the wet *puna*. The temporary settlements were convenient for visiting the camelids herds during calving and for shearing (Murra, 1975), and when the weather was less harsh. Most of the permanent *ayllus* were in the *qechwa* zone. The ecologic complementarity of the *qechwa* and *puna* zones in term of access to species and food derived from the social practice of controlling several altitudinal vegetation zones. Human settlements in the *puna* entailed the imitation of skills and routines acquired with potatoes and bitter potatoes. Air drying them and storing them for use before next year's harvest were technique that extended to all Andean region in pre-Hispanic times (Morales Garzón, 2007 p. 4) and were imitated in the case of maca (Cobo and Jiménez de la Espada, [1653] 1890 p. 364).

The control over several altitudinal vegetation zones allowed cultivation of staples (i.e., potatoes and maize) in the *qechwa* and *suni* zones, while meat supply was ensured by the camelid herds in the wet *puna*. The fact that the camelids could survive and reproduce in the wet *puna* attracted attention to their habit or consuming maca and

[174] The centre of power of the Quechua people was Cuzco under the Incan Empire, and Lima during and after the colony.

instilled in the indigenous farmers the idea that it improved their stamina and fertility. It is suggested that communities decided to herd camelids for their meat. Humans evolved from lowlanders and a set of physiological and cultural adaptations, such as cultivation and consumption of certain plants, allowed their adaptation to life at high altitudes (Aldenderfer, 2006). However, the herder's valuation of maca among the grasses and other plants that were found in the wet *puna* and consumed by the camelids, is unclear.[175]

The positive effect of maca on the reproduction of animals affected by the altitude in the wet *puna* might explain human consumption of maca and its domestication. However, there is no evidence of negative effects of altitude on animals before the arrival of domesticated mammals brought by Spaniards in colonial time. Nevertheless, reports from the 17th century mention the positive effects of maca as an human invigorator and fertility enhancer among men (Guamán Poma de Ayala *et al.*, [1615] 1944; Cobo and Jiménez de la Espada, [1653] 1890; Ruiz *et al.*, [1793] 1940). In the 20th century, the positive effect of maca on fertility has been reported for mammals (i.e., domestic animals including horses) (Bonnier, 1986 p.101, based on Rostworowski (1975) La visita a Chinchacocha de 1549; Obregón Vilches and IFA, 1998; Sánchez León, 2006). The effects of altitude on reproduction are difficult to confirm (Clegg, 1978). Acute exposure to altitude[176] and possible evolutionary adaptations and physiological processes have been studied (Gonzales, 2007a; Reyes *et al.*, 2012).

In summary, indigenous Andean communities, before the 1950s, maintained the social practice of controlling several altitudinal vegetation zones, which allowed them to

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[175] Bitter potatoes and maca can withstand the wet *puna* weather and both are cultivated. The weather conditions required for humans 'living at high elevation is very demanding in caloric terms' (Aldenderfer, 2006). So, humans looked for plants that would satisfy their caloric demands; maca does not have the typical botanical performance of other plants in the region (see fn. 167). Further research on the domestication of maca might add to our understanding of the phenotypic attributes that humans valued in maca and its wild relatives.

[176] Gonzales (2007a) mentions 'that fertility is reduced during acute exposure at high altitude but is normal in populations born and living at high altitude'. This was based on observations of perinatal and neonatal mortality in populations in the lowlands and in the highlands of the South and Central Andes of Peru. 'The rates of perinatal and neonatal mortality are lower in populations that have resided at high altitude for longer; populations inhabiting the southern Andes have a longer antiquity at high altitude and lower rates of foetal and neonatal deaths than those in the central Andes with a shorter residence at high altitude. Clearly, antiquity and genetics are important components in determining survival and quality of life at high altitude' (Gonzales, 2007a).

use maca to complement their diets of staple foods and camelid meat. The shaping process of maca was multilinear. For example, several different plants were available and some were regularly defined, consumed and produced. The skills and routines of indigenous Andean farmers provided multiple options for cultivation and consumption for these plants.

6.1.2 What were the roles of voice and 'choice' in shaping and stabilising maca?

Quechua speaking indigenous farmers from the wet *puna* and other social groups, such as bilingual Quechua and Spanish speaking dealers and researchers, shaped maca as an innovation for the international market. This sub-section discusses the roles of these actors in the process.

During the first half of the 20th century, Quechua speaking indigenous farmers from the wet *puna* of Peru, accumulated and retained skills and routines to produce maca. The improvements made to the roads, the growth of cities and the establishment of a centralised state education system in the second half of the 19th century, had resulted in new organisations in the highlands (i.e., universities, schools, regular markets) and actors (i.e., teachers and dealers) with skills and routines common to the Spanish speaking coastal area (see Ch. 5 Section 5.2). The indigenous people and indigenous communities maintained the skills and routines common to the highlands while also accessing skills and routines from the new organisations and actors.

In the first decade of the 20th century the establishment of a train line between the highlands, in Junin and Pasco regions from around 4,200 masl was constructed to allow exports of metals to the coast. The improvements made to the roads infrastructure allowed more intense movements of people and agricultural products between the coast and the highlands. This consolidated the coast's position and Lima as the capital city. The port of Lima (i.e., Callao) was used to export products from the highlands, which produced metals, agricultural products and labour for mining and construction of railroads and roads and housing for the growing cities. This provided opportunities for the indigenous people to access the higher education system in Lima, particularly, universities.

Bilingual Quechua speakers with skills and routines from the highlands and literate in Spanish were rare in the 19th century, but became more widespread in the 20th century due to the expanding education and communication systems. In the 1950s, the Universities of Huancayo, Cuzco, Puno, Ayacucho Cajamarca and Huánuco (Tapia, 2000) were established in the highlands. Bilingual indigenous people were involved as staff and students at these universities in areas such as agriculture and sciences. They participated in the development of international collaborative programmes such as that established by the IICA, on Andean Crops, which was led by Jorge León. While bilingual indigenous people had access to Andean species and the associated knowledge, León provided the skills and routines learned during his employment at IICA, in Turrialba, Costa Rica, which he brought with him when he moved to Lima, Peru, in 1962.

León was a botanist educated in the USA at the University of Washington, which was allied to the Missouri Botanical Garden. He was also active in the IICA, which was set up in 1942 to ensure a geopolitical alternative 'for fostering the development of tropical crops and stock raising' and to achieve the Pan-American Union's –now the Organization of American States (OAS)– goal of promoting agricultural development (IICA, 2012). The aim of the IICA was to ensure geopolitical and economical control by the American government based on the work of scientists such as León. León's objective was to establish and maintain plant collections and, eventually, to produce some of these plants commercially.

In Perú, León published word on the rich biodiversity in the Andes and the meaning of 'neglected' Andean food plants, including maca.[177] This meaning was based on the understanding that, unlike potato, which already had an important role as a staple around the world, the production of a large set of Andean plants was marginal and they were unknown outside the local regions of production, despite their nutritional and medicinal value. These plants deserved to be used since they could help to address social needs

[177] This was not the meaning given by indigenous people. For indigenous people maca was available all year-round. Once harvested, it could be consumed fresh or could be dried during the dry season in June to September when strong winds and huge temperature changes were used as dehydration techniques (Vietmeyer *et al.*, 1989). Indigenous Andean communities used technologies to ensure the availability of food along the year. So, indigenous farmers stored the dried maca and other Andean roots and tubers for consumption during the year. They stored potatoes (obtained chuño) and, occasionally, with oca (Oxalis tuberosa). The technique for maca consisted of spreading the plant on the ground and letting it to freeze and dehydrate.

(León, 1964b). Since large scale commercial production was not established, from an agricultural development perspective, the opportunities for using such resources were being neglected. While living in Peru, León published two works on maca. First, *Plantas alimenticias andinas* (or *Andean food plants* in English) (León, 1964b), which had a chapter dedicated to maca and became a reference for further botanical studies. Second, an article written in English entitled 'The maca (Lepidium meyenii), a little known food plant of Peru' (León, 1964a).

León came to Peru to try to replicate what he had been doing in Costa Rica. However, replication was challenging in this much larger context, which was multilingual (in the highlands Quechua and Aymara were the dominant languages, but many more were used in the forest) and had a huge variation of environmental conditions. Alongside his pioneering role in the collection of plants biological material, León is recognised for training and inspiring young agronomists during the 1960s (Tapia, 2000; García G, 2014). Some of these young agronomists were bilingual and, therefore, had better skills and routines to access materials and their users, some were trained in the collection of such materials and the codification of the related knowledge and became involved in the routines of international cooperation organisations.

León and his co-workers took part in the routines of organisations in which they got involved. These organisations had two types of goals:

- Promoting agriculture through commercial farmers organisations, Ministries of Agriculture, Universities and IICA. Fear of food shortages and need to increase food crop yields were evident in Latin American countries in the 1960s and 1970s. At that time, the FAO began to report on the percentages of the populations in rural areas with unsatisfied food requirements. However, none of these organisations were agreed about how to address this problem. Promoters of main crops (i.e., maize and wheat), who were lobbied by industry for production of cheap raw materials, focussed resources and efforts on increasing the yields of these crops and reducing their prices to increase the chances of poor people accessing food. Promoters of main crops considered 'neglected' species as unnecessary and saw supporting those species as a form of perpetuating poverty since their commercialisation as crops would never allow farmers to obtain sufficient income for self-subsistence (Interviews

AJ and AK). Nevertheless, in some cases, researchers and breeders of these main crops (especially phyto-pathologists) supported collection of neglected crops because they were aware of the potential of some to provide genes which would explain the tolerance and resistance to certain diseases. On the other hand, those who supported neglected species considered that maca and many other Andean Crops were important because of their unique conditions. This group was more keen to preserve biodiversity even within the same species.

- Biodiversity preservation involving organisations concerned over the loss of biodiversity. Carson's ([1962] 1967) seminal book *Silent Spring*, articulated concerns over environmental issues and the threat of agrochemical pollution. A few years later, the environmentalist communities received unprecedented support. President John F. Kennedy, who 'set up a special panel of his Science Advisory Committee to study the problem of pesticides. […] (Carson) book helped to make ecology, which was an unfamiliar word in those days, one of the great popular causes of our time'. This appeared as a foreword in later editions of Carson's book. The organisations raised their concerns about species that were at risk of extinction and systematic records began to be published about the state of these species.

A tension between focussing on few species and broadening the set of species to work with, was common among the actors involved (i.e., farmers, breeders, university and research centres' researchers). In the 1960s and 1970s actors switched between two different perspectives, to increase food crop yields and working with neglected species and species at risk of extinction. In Peru, the Agrarian Reform (1969-1976) during the military dictatorship of General Juan Velasco Alvarado (Montoya and Gorman, 1978) was significant. The new tenants of hacienda land faced a choice between producing main crops, for which routines (i.e., including facilities and technologies) were available and which they were encouraged to believe were the most 'feasible or at least worth to attempt' (Nelson and Winter, 1982 p. 258), or to produce neglected species and species at risk of extinction.

In the Peruvian highlands, for instance, former small holders land indigenous Andean farmers of major staples (potato, maize and wheat) expanded their production in the lands of haciendas previously owned by mining companies or landlords. These indigenous farmers exercised control over their biological and agricultural skills and routines related to the well-known commercial species. Attempts to change to other species were costly. Also, the rewards for replication of farmers' skills and routines, such as increasing yields or hectares, were already established for the commercial species. With larger markets, which assured better cash income, the new-hacienda-tenant indigenous farmers pursued the goal of commercial production of major staples and were rewarded for the numbere of tonnes per hectare that they produced.

Those indigenous Andean farmers that valued the skills and routines relating to neglected species, such as maca, had a different understanding. Two social groups, indigenous Andean farmers and botanists, provided these other meanings, differentiated in terms of *what* each actor from each group thought about maca and *how* they could act on it (i.e., their capability for 'acting' or not on shaping the species) (see Ch.4 Sub-section 4.1.2). Thus, the actors in each group had individual ideas about the problematic use of species. Until the 1980s, botanists had been voicing their interest maca: León (1964a) referred to it as a 'little known food plant', King (1987) as a 'promising food' and a researcher team from the USA National Research Council (NRC) included maca in the set of what it called 'Lost crops [...] with promise for worldwide cultivation' (Vietmeyer *et al.*, 1989).

However, it seems that the indigenous Andean farmers abandoned their efforts since the International Board for Plant Genetic Resources (IBPGR), a creation of the FAO, reported in 1980 that there were no more than 15 ha of land under maca cultivation, which suggested it was likely to become extinct (Hermann and Bernet, 2009b p. 28).[178] Although it is unclear whether the practice of cultivation had ceased, this would not have

[178] It is not clear how and why this report came to this conclusion. There were no official statistics on maca roots commercialisation, which is consistent with the fact that most production was for self-consumption. Thus, production was not visible to the agricultural agency (i.e., Peruvian Ministry of Agriculture), and it is not possible to confirm whether the number given was true, or was higher or lower. Interviewee FA considered the FAO statement to be an exaggeration: 'The conditions for declaring it (maca) in extinction were that areas of production were limited and its reproduction systems was inefficient. For example, panda bear has a very low level of reproduction (1%) while cuy (*Cavia porcellus*) is very efficient (100%). Though production areas were reduced, maca is prolific and with a single plant, without creating endogamy, you could repopulate all the Peruvian highlands in four years. Maca has a very high level of germination' (author's translation from Spanish).

resulted in the species extinction since maca can reproduce naturally.[179] The Peruvian government proposed a solution to the *probable* maca extinction problem by redefining increased maca production as a solution to feeding poor communities in the Andean regions of Peru. In the second half of the 1980s, the Peruvian government promoted 'maca production in different parts of the country through its agricultural research and extension program (INIA)' (Hermann and Bernet, 2009b p. 30) and other instruments established by Peruvian Law 24520 of 1986 (Perú, 1986). The Peruvian Government's interest coincided with an international trend towards considering 'minor (or underutilised or neglected) crops', as an option for 'marginal growing conditions such as those of the Andean and Himalayan highlands, arid areas, or salt-affected soils' (Hermann and Heller, 1997 p. 4). In those areas, the commercial production (i.e., yield) of major staples (i.e., maize, wheat, barley or even potatoes) was less successful than expected.

In the 1990s, the indigenous Andean farmers were focussed on increasing production of maca. These farmers learned the different meanings given to maca in deciding whether to cultivate it or not, and in what quantities. The indigenous Andean farmers from the wet *puna* had the agency to produce maca. The meanings given by other users involved imitating their treatment of other species, such as potato, produced more widely than maca. Indigenous Andean farmers acted as potential inventors/innovators in redesigning maca as a commercial crop (i.e., producing in larger quantities).

The indigenous Andean farmers had agency for producing maca, but they were aware of the physical constraints on production. They imitated larger production of maca using their knowledge about potatoes. Their understanding of physical constraints to its cultivation allowed the farmers to achieve a level of stability in the meaning given to maca. The constrains included the amount of root the plant could produce, the availability and reproducibility of seeds, the availability of suitable land and allow for fallow after harvest, and the local capabilities to manage and dry larger quantities of maca to avoid being

[179] Although further study is required, interviewees FA and QA agree that maca can reproduce naturally, without human intervention. The human practice of saving the vegetative root to resist the loss of humidity during the dry season *increases* survival and reproduction rates and the size of the root harvested for consumption, compared to the natural occurring situation.

damaged. They implemented new routines for transporting, processing and delivering *dried maca* for commercialisation. All of this required the involvement of other actors.

The shaping process was based on the skills and organisational routines of indigenous Andean farmers. The skills and routines of the actors and their multiple meanings resulted in a range of variation that allowed selection. A certain level of stabilisation was achieved in the meaning given to maca, but there continued to be difficulties related to the standardisation of production that would be solved by indigenous Andean people (see below).

6.2 From bartering to trade and from Quechua to the Spanish language: Institutional change and organisations involved in the innovation process:

Indigenous Andean farmers and researchers cooperated while simultaneously addressing their own needs and organisational goals. The stabilisation of meaning given to maca during the 1990s, as a commercial crop with exceptional nutritional value, entailed standardisation of the crop to ensure the expected benefits for each actor. The organisations and institutional arrangements that allowed cooperation between Indigenous Andean people and researchers, were subject to several adjustments during the 20th century. These organisations and institutional arrangements evolved through a learning process, in which the costs and pay-offs of the actors' decision had to be considered. The organisational goals and institutional arrangement provided a context for the actors' decisions about the goods that emerged from the shaping of maca.

This section discusses the institutions and organisations affecting the shaping process towards international commercialisation of maca flour in the last half of the 20th century. It includes a focus on the languages spoken in Peru, Quechua, the native language of the indigenous people in the Junin and Pasco regions, and Spanish, the language introduced by the Spaniards and, since the 18th century, the official language of Peru.

After Peru consolidated the nation state after independence in the 19th century, it alternated between democracy and militarism. The role of the state has changed from being liberal to one of aggressive intervention in all spheres including taxation, production subsidies, centralised education systems and building infrastructure.

The herding of camelids and sheep and the cultivation and trade of some crops, ensured the food supply for the inhabitants on the wet *puna* and embedded the skills for working in these tough conditions. The supply of carbohydrates and proteins supported settlement and consolidation of small towns such as Ninacaca, Carhuamanyo and Junin around Lake Junin.

6.2.1 How do institutions and organisations affect the shaping and standardisation of the biodiversity-based innovation?

Maca commercialisation has increased significantly since the 1960s. In 1964 maca was produced mainly for self-consumption and only two regions in the *puna* were reported as growing maca: 'The mountains surrounding Lake Junin, where macas were sold in the market towns of Carhuamanyo and Ninacaca, particularly to be sent to the Lima market; the other region is the mountainous area of Jarpa, west of Huancayo, which produces small quantities sold mainly in the Chupaca market' (León, 1964a p. 122). In 1994, a large portion of production was still for self-consumption (Aliaga-Cárdenas *et al.*, 2007).[180] In the 10 years 1995 to 2005, maca production expanded to all the Peruvian highlands, from the North in Cajamarca and La Libertad regions to Puno. After that it was restricted to the regions of Junin, Pasco and Huancavelica. The area of land in Peru suitable to produce maca is around 239,000 hectares (Aliaga-Cárdenas *et al.*, 2007). In 2012, Peru produced 22,000 metric tonnes of maca from 1,484 hectares, distributed across 652 agricultural units (INEI, 2012; 2015), 870 tonnes of which were exported as flour (Peru, 2016). In 2016, more than 50 countries import maca produced in the highlands of Peru,[181] and it is now being cultivated in Bolivia (Aliaga-Cárdenas *et al.*, 2007) and China (Lim, 2015).[182] This sub-section explores how institutions, such as the market,

[180] In 1994, 69% of maca was for self-consumption, in 2002 to 2014, the proportion of maca for self-consumption is likely to be lower than 69%, while exports of maca increased from 160 tonnes to 1,880 tonnes.
[181] In 2015 Peru reported exports of maca to 55 countries (see Peru, 2016).
[182] Chinese maca cultivation is concentrated mainly in northern-west area of Yunnan Province, in the Lijiang, and Diqing prefectures. In 2012, it is estimated that more than 800 hectares in Lijiang prefecture, and 200 hectares in Diqing prefecture were down to maca (see Hu *et al.*, 2013).

and organisations allowed the shaping and standardisation of maca production for commercialisation at the international level.

The commercialisation of products in the highlands began in the first half of the 20th century with the introduction by *local dealers* and acceptance of money by the indigenous Andean farmers, which, in some regions, was facilitated by the payment of wages for mining activity. However, small towns in the highlands communities retain barter allowing local dealers to exchange local products (i.e., Andean grains, roots and tubers) for meat, clothes and other commodities. The local dealers monetised the local production of Andean products obtained through barter in bigger markets such as Huancayo, or Chupaca, where they bought products that could be exchanged in smaller towns. An *intermediary* gathered these Andean roots and tubers and transported them to cities, mainly Lima, to be commercialised by them directly or by indigenous dealers (Interview IB) (see Ch.7 Sub-section 7.2.1 for a more detailed description of the bartering practices). Transporting the goods, previously done using backpack animals, was facilitated by the roads and railroads built during the first decades of the 20th century (Interview AJ)

Many intermediaries were indigenous Andean people with local production skills and routines and trust links within their own communities. They learned new skills and routines for the commercialisation of the Andean roots and tubers. They learned skills and routines including using money, which was practised by Lima dealers in regular markets in the city centre and in some districts around the city, and new forms of transport for taking their production to Lima.

In the 1960s, indigenous dealers offered to the flourishing bourgeoisie, staples, such as potatoes, and other Andean roots and tubers, wheat and barley brought from the highlands. They had access also to a mix of crops and animals from around the world that had been introduced to the rich Peruvian environment (i.e., cows, sheep chicken, citrus and vegetables from Europe and Asia). Andean roots and tubers were demanded mostly by 'cholos' or 'serranos', as the indigenous people and mestizos from the highlands who immigrated to Lima, were called.

Maca was a marginal product among the set of Andean roots and tubers commercialised in the markets of Lima. The growing demand for potatoes, wheat and barley was rewarding for those who replicated their routines to produce these staples in the highlands. This successful replication attracted others, but reduced the time and highlands area that indigenous Andean farmers devoted to growing other crops (i.e., maca and other Andean roots and tuber) (see Sub-section 6.1.2 on the reduction in growing areas by IBPGR).[183] However, it allowed the commercialisation, on a small scale, of those other Andean roots and tubers. After potatoes, olluco was the most common tuber found in the markets in Lima and was used in a dish called 'olluquito con charqui'[184] (Interviews AE, PA RA), while oca, mashua or maca were found in markets frequented by 'serranos'.

The areas of maca cultivation in Peru have increased since the 1990s. In Peru, maca increased from 556 ha in 1994 to around 1,000 in 2003 (Aliaga-Cárdenas *et al.*, 2007), and 1,484 in 2012: The departments with the most hectares under maca cultivation are Junin, with 904 hectares, Huancavelica with 341 hectares and Pasco with 130 hectares (INEI, 2012). Authors (Gonzales, 2013) and experts (Interviews AE, CA, FA) were in agreement that the increasing international demand for maca's positive effects on the human reproductive system coincided with its being advertised as a natural Andean

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[183] Sub-section 6.1.2 examines how IBPGR played a role in the shaping of maca. Sub-section 6.2.1 indicates how IBPGR begins its presence in Peru, thanks that its staff learned skills and routines in other organisations. Concern over loss of biodiversity had already attracted interest and resulted in the creation of organisations in Europe and North America. The IBPGR, which in the 1970s and 1980s focused on coordinating an international plant genetic resources programme worldwide, began emergency collecting missions and built and expanded national, regional and international gene banks (BI, 2014). Peruvian researcher, Miguel Holle, was involved in these activities. Holle was born in Germany in 1937 but grew up in Peru and obtained his bachelors, masters and doctoral degrees from the USA. He had experience in international funding programmes and worked with the Canadian and the Swiss governments when he went back to Peru in 1988. He gained experience in international cooperation between 1976 and 1982 when he worked in the Tropical Agronomic Centre on Research and Training (CATIE for its name in Spanish *Centro Agronómico Tropical de Investigación y Enseñanza*) in Turrialba-Costa Rica, under an agreement between the IICA and USAID. Between 1982 and 1988, he was the IBPGR's Regional Representative in Latin America, and worked out of the International Center for Tropical Agriculture (CIAT for its name in Spanish *Centro Internacional de Agricultura Tropical*), in Cali, Colombia. In 1988, he returned to Peru. Holle's knowledge and experience in IBPGR motivated him to look for support from the international cooperation agencies he had been involved. Holle's interest was fired by the movement of Andean crops in 1968 with the First Convention of Chenopodiaceae Quinua – Cañihua, held in Puno, Peru, which in 1977 became the International Congress on Andean Crops held in Huamanga, Peru. During the next 30 years, similar events were held in Colombia, which to some extent coordinated with similar initiatives in Peru, Ecuador and Bolivia (Interview YAG). Those brought together a group of senior researchers working with indigenous communities on agricultural issues in the highlands. Some of them had experience in Andean grains, others had contacts within universities in the highlands and held positions in international cooperation agencies and government agencies. It increased the chances for cooperative on maca.

[184] The traditional dishes from the Peruvian highlands included olluco and charqui (dried camelid meat) as the main ingredients with added potatoes, beans and peas.

Viagra (DiscoveryHealth.com, 2005; PeruVillage.com, 2005; PeruDelights, 2013; Roberts, 2014; Collyns, 2015b).

Also, some indigenous people (e.g., in Huancayo) were processing maca on a small scale to obtain flour. University researchers improved the industrial processes of transporting, transforming and commercialising maca (Interview FA). Others, motivated by the decline in maca production collected and studied it during the 1990s and concluded that the origin of maca was Peru.

In 2002, Begoña Venero, a civil servant working on intellectual property rights received information from several non-governmental organisations (NGOs) and civil society representatives, concerned about the granting of intellectual property on plants in the USA. It had been observed that patents had been awarded by the United States Patent and Trademark Office (USPTO) for inventions related to Peruvian plants, including maca. Venero convened an informal group, which became known as 'The Maca Group'.[185] Venero and her colleagues analysed the legal status of the patents granted on maca and the gathering of information related to the species under the direction of the CBD related to the botanical dispersion of the plant, its production, etc. The group concluded that the legal status of the granted patents was questionable in relation to the claims about

[185] Venero worked alongside Manuel Ruiz. They recognised the risks posed by patenting of derivatives from maca. Rather than defending the intellectual property rights system, Venero was critical of it. The international NGO Action Group on Erosion, Technology, and Concentration (ETC Group) made Peruvians aware of the patents granted to Pure World Botanicals Inc. in the USA, which covered use of maca to prevent cancer and the sexual dysfunction (see Indecopi, 2003 pp. 11-3) For the ETC Group, an NGO with experience of participating in the CBD negotiations, Pure World Botanicals Inc. were biopirates. At that time, the Peruvian legislation did not refer to 'Biopiracy' and no one took responsibility for the Pure World Botanical Inc. case, which was not applying for patents in Peru. However, the Maca Group studied two patents granted by the USPTO and one international application submitted to the same office by Pure World Botanical Inc. (see Indecopi, 2003 pp. 23-4). The Maca Group challenged the novelty claimed since the patents referred to uses already known by the indigenous communities as reported by Spanish chroniclers and others. They also challenged the access to maca, citing the Common Regime on Access to Genetic Resources, Decision 391 approved in 1996 by the Andean Community (see Ch. 1 Section 1.1). This 'non-formal' exercise was the background to the law of the 'National Commission for the Protection of Access to Peruvian Biological Diversity and Collective Knowledge of Indigenous Peoples', known also as the 'National Commission against Biopiracy' or CNB for its Spanish name Comisión Nacional contra la Biopiratería. The Commission was just a single individual, who invited peole to discuss new patent submissions for a set of prioritised species. This could result in requests for aplicants to provide further information on access to the genetic resources and require informed consent according to Decision 391. If it became clear that the regulation had not been adhered to, the commission would inform the applicant that the patent violated a sovereign right. In many cases applicants withdrew their applications. If they did not, the Indecopi would begin an action against the applications. Since 2002, some 10 filings have been traced by the Commission.

novelty, industrial use and inventiveness required for a patent to be granted (Interview CA) (Indecopi, 2003 p. 23-4). Thus, it appeared that foreign commercialisation of maca products did not fulfil the conditions of the CBD that access had been granted by the Peruvian CNA under MAT and could be deemed an example of biopiracy.

On the other hand, the meanings given to maca by indigenous Andean communities as a fertility enhancer or an Andean Viagra, were difficult to evaluate by potential maca consumers. This situation was considered problematic for companies investing in facilities enabling transport, transformation and commercialisation of maca. Some companies received complaints about these claims (Interview FA).

The increase in the demand for maca revealed the lack of indigenous Andean people with skills and routines to produce the expected volume of maca and showed that institutions were failing to reduce the uncertainty and, thus, to stabilise the expectations of consumers. The rush to produce maca caused indigenous people to disregard issues such as hygiene or humidity levels, well known in their traditional routines, but ignored in attempts to increase production and achieve the expected benefits from commercialisation. The Andean Viagra did not have the immediate effects of Pfizer's blue pill (Sparrow, 2002). Also, the costs of decodifying (and understanding) the meanings given by different users were high (see section 6.2.2 on language).

In this situation where several different actor had different meanings for maca, attempts were made to achieve standardisation when the Peruvian government promulgated Supreme Decree N° 039-2003-AG (Perú, 2003) in 2003, which 'prohibited exports of botanical or vegetative maca seeds, or sub products in their natural state or with primary transformation, to promote their export at higher added value' (author's translation from Spanish). This regulation provided mechanisms for enforcing sovereignty over Peru's genetic resources, which limited open access by other countries to reproductive material, and recognised maca as part of the 'Peru's Genetic Heritage' (author's translation from Spanish) (Perú, 2003 "Considerando"). The norm sought to prohibit maca production in other places in the world and *defined* (David and Greenstein, 1990 p. 4) maca as a processed product (e.g., flour or any other higher added value product) rather than a root (i.e., vegetative seed) or a seed (i.e., botanical seed).

The commercialisation of maca as a flour made its identification difficult, since it could be confused with other flours and might not be pure since there was no way to make maca flour easily recognisable (interview NA) (Gonzales, 2010a p. 41). An agreement in 2008 between the Peruvian Government and indigenous Andean farmers, researchers and processors, introduced a further stage for standardising maca through the Technical Quality Norms for toasted maca flour (Indecopi and CNT 066, 2008b)[186] and gelatinised maca flour (Indecopi and CNT 066, 2008a). The choice of a voluntary *minimum quality* (David and Greenstein, 1990 p. 4) standard for maca flour for human consumption was the solution the Peruvian government proposed to address counterfeit production and consumer expectations regarding the effectiveness of Andean Viagra. The flour can be produced by milling the dehydrated maca roots or with the addition of an extrusion processing, which gelatinises the starch. The gelatinised product can be milled and is soluble in water (Hermann and Bernet, 2009a p. 38).

The gelatinisation technique, proposed by an indigenous researcher (Interview FA and NA), is interesting since maca contains nutritional compounds that could be lost if maca is consumed as a tuber or flour (i.e., no gelatinised). The maca fibres are complex; molecules of starch encapsulate nutritional compounds and can pass through the digestive system without being digested. Gelatinisation allows the nutritional compounds to become available during digestion. So far, no single compound is considered relevant for the nutritional value of maca (i.e., marker) (Interview NA). For example, some suggest

[186] Preparation of the technical norm was contested. In principle, maca was considered a clonal plant like the potato, and was self-pollinated. In this case, seed produced from the same plant could be expected to be homogeneous and that, after repeating reproduction practices, it would produce more homogeneous plants (Interview BF). In 2004, when exporters were facing problems related to the quality of the product, the industry decided that the simplest solution was homogeneous root colour, which would be expected to show up in the flour. In principle, maca is autogamous, which means that pollination is by pollen from the same flowering plant. However, at the beginning of 2000s, one researcher began working in the CIP laboratory on whether maca was truly autogamous. Using a fluorescence microscope, he studied how pollen grain entered the pistil and travelled down the pollen tube to reach the ovule. He noticed that the mechanism of reproduction differed according to the position of the flower on plant, in the centre in the rosette or on one of the extreme branches of the rosette. Flowers in the middle of the plant rosette were 100% cleistogames and pollination occurred before the flower opened. Flowers at the extremes on the rosette branches could be cleistogames or could be chasmogames where pollination takes place after flower opens, exposing its stamens and style to pollen from other plants. This explained why maca plant seeds did not produce roots of the same colour (Interview CA). For those unfamiliar with the species this was seen as a problem (i.e., a disease, or loss of enhancing or invigorating power). For biologists, the high level of segregation (i.e., low standardisation) is indicative of the early process of domestication: When a supposedly cultivated plant is reproduced, a percentage of wild plants is produced.

that maca is an antioxidant (Pu, 2009; Oré *et al.*, 2011; Berłowski *et al.*, 2013; Doroteo *et al.*, 2013) which could explain its positive effects on spermatogenesis. However, compared to other Peruvian plants, maca has low level of carotenoids, polyphenols and antioxidant (Ranilla *et al.*, 2010; Campos *et al.*, 2013) (i.e., antioxidant activity). Camu camu (*Myriciria dubia*) has higher levels of polyphenols and antioxidants, and has similar effects on spermatogenesis, suggest that the effects from maca are not related to its antioxidant content.[187]

Maca's commercialisation as a flour or a gelatinised product offered versatility as a raw material for use in several products such as water, juices, spirits, sweets, caramel, pills, capsules, chocolate, jam, bread, biscuits, flakes, cereals, sausages, pasta, honey, compotes, starch, shampoo, oils, creams, soaps, perfumes, cosmetics, among others. There are not conclusive figures about whether flour or gelatinised flour is more important; both are found in the international market.

During the last 50 years, indigenous Andean farmers learned new skills and routines for the commercialisation of maca production. The attempt to imitate commercial production of potatoes in the commercial production of maca, was problematic since the actors involved in the shaping process did not satisfy consumers' expectations or product meanings. The solution was standardisation of maca as a flour and a gelatinised flour. The Peruvian Government played a leading role by protecting the sovereignty of the maca.

6.2.2 What is the role of knowledge codification in the shaping of the technology?

This sub-section considers language as an institution that played a role in the codification of knowledge used in the shaping of maca. Maca passed from involving relations between relatives and friends from the Junin and Pasco regions, to a range of commercial relationships between the Junin and Pasco regions and the rest of Peru and the world.

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[187] Gonzales *et al.* (2014) critically reviews the reported biological properties of maca. In the case of sexual function, spermatogenesis effects, stamina enhancer, antiaging, among others, he states that results are not conclusive (see Gonzales *et al.*, 2014). He suggests that an unknown single compound or a set of compounds is responsible for its nutritional value.

Quechua was the main language spoken in Junin and Pasco regions and there are areas today where most of the women speak only Quechua. The education system implemented by the Peruvian Central Government at the end of the 19th century in most regions of the country, prioritised teaching of boys, and teaching in the Spanish language, so it took more than a century for large parts of the population in the highlands to transform from being monolingual Quechua speakers to becoming bilingual. Spanish was the official language since the 18th century, imposed by the Spanish King for the Vice-royalty of Peru. However, English became a *lingua franca*[188] in the 1980s. English is the main language used for international trade, marketing, and articles and general publications codifying maca knowledge.

There are three tiers involved in languages related to the shaping of maca. The first involved use of maca by Quechua speaker, the second involves commercialisation of maca production to Spanish speakers; and the third includes English speakers. Hence, codification differed in all three tiers.

First tier: Quechua speakers use

The use of maca in terms of its definition, production and consumption, was the result of the collective memory of the skills and routines practiced by the Quechua speaking indigenous Andean farmers for hundreds of years. The expectations about use of maca at this tier were stabilised by the practice being repeated by generation of these communities. Farmers grew maca, and mothers fed maca to their children for breakfast since they considered it ensured proper development of the brain. It was recommended to young married couples to ensure fertility (Interviews AE, AJ). Some people who were born in Pasco and moved to Lima or to other countries (e.g., the USA was a favourite destination in the 1970s and 1980s),[189] maintained links with their relatives and friends

[188] The concept of a *lingua franca* refers to a language that serves as a communication bridge among these working in a bilingual environment. However, Gordin (2015) refers to *lingua franca* as a pidgin language used by dealers, in opposition to commentators who describe Latin as the *lingua franca* for both dealers and scientists. Gordin (2015b) describes Latin as the language used by 'those living in a world surrounded by various learned languages —French, Dutch, German, Italian, and so on—' before it was replaced by English. This thesis considers the *lingua franca* as a language used by both scientists and dealers.

[189] Until the 1970s, Peru had very low emigration and a neutral balance of migration because migrants from Asia (China and Japan) come to Peru. In the 1970s and 1980s, migration to the USA, Chile, Canada and Venezuela grew, and the number of migrants become larger than the number of immigrants (see INEI, 2009).

and obtained maca from them for self-consumption (Interview FA, RA). They believed in maca whose benefits had been passed from parents to children and grandchildren, and trust derived from direct and close learning experience from producers (i.e., parents) and consumers (i.e., family members).

Maca is consumed in Junin as fresh and dried product. Fresh consumption occurs at harvest time (June to September) (Aliaga-Cárdenas *et al.*, 2007), and it is eaten dried during the remainder of the year. Fresh maca can be cooked like fresh potato. The drying processing is the same as the drying process for bitter potatoes to make them edible and ensure availability throughout the year. The product becomes very hard from exposure to sun and air and for consumption needs to be rehydrated or ground.

Maca commercialisation in Lima for local consumption involved fresh tubers that eventually were dried. It is easier to export dried maca for sanitary reasons and because transport is cheaper. Migrant indigenous people consumed dried maca. In 1997, 89% of exports of maca were of dried maca (Aliaga-Cárdenas *et al.*, 2007 p. 31); and there is no reason to believe that the rest of the maca export was fresh but processed in other ways.

Quechua was not a written language until the first half of the 20th century, so the knowledge about maca use from indigenous people was not generally codified or articulated. Based on Cowan *et al.* (2000 p. 233-6), there are two possible scenarios: (i) although a 'codebook'[190] existed, it was not available to users and outsiders did not know of its existence. Users internalised the knowledge and communicated without referring to it (i.e., without articulating it); (ii) users had a collective memory of uncodified, but stable skills and routines for using maca and the conventions related to its use (e.g., degree of dryness to allow maca to be stored) (Interview QA). When new comers decided to use maca, they had to cover the costs of: (a) decodifying the knowledge (i.e., learning from a codebook), by learning Quechua or some of the jargon and standardised concepts used in the performance of skills and routines (i.e., learning together with users), or (b) accessing maca and applying their skills and routines.

[190] A codebook is any form of recorded knowledge in a socio-temporal context (see Cowan *et al.*, 2000 p. 230). In this case, since Quechua was not a written language, the codebook consisted of chants, *quipus*, or other forms of recording knowledge.

The Jesuit priest Bernabé Cobo (see Ch.5 Sub-section 5.2.2), as a missionary had unusual opportunities for obtaining reliable information. He highlighted the capabilities of indigenous people and plants for resisting the tough conditions of the cold *puna*: Cobo described how maca was the only plant with human nutritional properties growing in the present day Lake Junin and its surroundings. He also described how it was consumed fresh or dried, cooked or toasted. He also referred to its fertility-enhancing properties (Cobo and Jiménez de la Espada, [1653] 1890 p. 364). This information could only have been obtained through knowledge of the Quechua language. Despite Cobo's efforts, the Quechua indigenous collective memory of uncodified but stable skills and routines and conventions for cultivating and consuming maca remained hidden from or undocumented by Cobo. The knowledge relevant to maca cultivation remained local. Thus, the relevant knowledge for bringing maca into commercial use was only partially codified in Cobo's writing.

Second tier: Spanish speakers use

In the second half of the 20th century, reports in Spanish about commercialisation of maca in Lima (Pulgar Vidal, 1960; León, 1964b). There is anecdotal evidence of non-indigenous Spanish speaking women seeking maca in Lima's stores, to give to their husbands. However, there was a taboo on discussing sexual matters. For monolingual Spanish speakers, consumption of maca was new and their individual expectations about its effects were unclear. How should it be eaten, drunk and spread? Should it be taken as a single dose (like a headache pill) or considered as a treatment (like a course of antibiotics)? Was its fertility enhancing effect long or short term? Publications (Pulgar Vidal, 1960) and theses (Chacón, 1961) were available in Peru since 1960s and provided information on the virtues of maca. In the 1990s, there was a boom in publications providing answers to consumers' questions.

The government's interest in expanding the production of maca in the 1990s gave the indigenous people with the skills and routines for using maca who had moved to Lima for higher education, a reason to prepare manuals and write reports on the routines for producing maca. They exploited their writing (in Spanish) skills and the universities and research centres conducted lab and field experiments (Tapia and Mateo, 1989; Rea, 1994; Espinoza and Poma, 1995; Vidal, 1995; Quirós and Aliaga-Cárdenas, 1997; Aliaga-

Cárdenas, 1999). Knowledge on the use of maca was most often codified in Spanish. This codification was made possible by indigenous (bilingual) people's knowledge of the skills and routines employed by indigenous Andean farmers and communities to produce and consume maca. Organisations such as the Andean Crops Programme of IICA, the *Universidad Agraria La Molina* and the International Potato Centre (CIP for its Spanish name Centro Internacional de la Papa), established routines for collecting maca and other Andean roots and tubers, and codifying and articulating the stable skills and routines of indigenous Andean people related to the use of those species.

The codification of this knowledge allowed some of these indigenous people to become inventors/innovators in their attempts to redesign maca. These indigenous people had learned their skills and routines as students and researchers in universities and research centres, in relation to other crops such as maize and potatoes. Indigenous people received inputs of meaning from other users, such as the neglected condition of maca, and the low effectiveness of maca versus Viagra. Hence, indigenous people attempted to redesign maca using the articulated and codified knowledge from other species (i.e., maize and potatoes) and applying it to maca. One example here is the Aliaga family, who lived in Junin region. One of the Aliaga brothers imitated the extrusion (i.e., gelatinisation) technique for maca. Extrusion was a common well documented and regularly used technique to produce starch from maize and other grains. J.G. Aliaga's undergraduate dissertation for the degree of engineer at UNALM was on maca and imitation of the techniques applied to maize (Aliaga-Cárdenas, 1990). His brother wrote a thesis on floral biology (Aliaga-Cárdenas, 1995) and implemented a pilot plant for milling maca. His visits to the Junin region and his understanding of the organisational routines of maca farmers, allowed him to start a manufacturing plant to process maca (Interview FA).

Codification of consumers' meaning about the reduction in production and low effectiveness of maca as a vasodilator, and codification of the extrusion technique allowed J.G. Aliaga and R. Aliaga to redesign maca as a flour. They proposed a technique for extruding maca and began to produce commercially gelatinised maca flour in 2000.

Third tier: Exchange with English speakers

Reports written in English about maca were scarce before the 1950s and some translations into English from Spanish chroniclers were produced in the first half of the 20th century. Today, maca production is highly concentrated in Spanish speaking countries (mainly Peru and Bolivia), but an important percentage of work on maca is written in English. Gustavo Gonzales, the most prominent Peruvian researcher in medical applications of maca publishes 63% of his papers and books (257 in more than 3 decades, and 40 of them focused directly on maca) in the English language.[191]

Botanists and explorers from European non-English speaking countries were able to access Andean roots and tubers because of the colonisation of the Andean territories. European botanists and explorers articulated and codified knowledge in several languages (i.e., English, French, Italian, German, and Swedish) during the 18th to the 20th centuries and, particularly in the case of maca, in Latin, Russian, French, English and German (Walpers, 1834; Weddell, 1857; Thellung, 1906; Cook and Barrett, 1910; Bukasov, 1930; Sauer, 1950; Ruiz *et al.*, [1793] 1940). English overtook German, Latin and other languages after WWI and became consolidated in the 1970s, moving scientific communication from polyglot to English monoglot (Gordin, 2015a).

There were more reports than explorations (attempts to access species were expensive) due to the establishment of collections in botanical gardens and herbaria in Europe (and the USAsince the 19th century). However, some species were damaged, lost, mislabelled, etc. which meant they could not be used for research. The collections in Europe were studied by researchers, who accessed data about the collection of species (i.e., where it occurred was of interest to botanists, and how it was used was of interests to ethnographists) and the samples available for characterising them. The resulting reports were reviewed and rewritten and documented different approaches and techniques. The development of research techniques and the specialisation around new research questions in the 19th and 20th century, allowed researchers to validate (or refute)

[191] There are hundreds of journal articles and patents written in English. The Web of Science records 192 mentions of maca (*Lepidium meyenii*), 152 since 2005, and 145 in English. Google Scholar 2,600 records are reported (2,530 publications excluding patents), 2,050 since 2007 (1,980 excluding patents). In academic repositories there are 31 publications in Spanish (Scielo) and 76 in Chinese (CNKI) 76. Accessed September 3rd, 2016.

new techniques and to question earlier techniques. Maca was used not as a food, or fertility enhancer, but as a research input. The cost of accessing knowledge about how to use maca as a food or fertility enhancer was higher than the cost of collecting and transporting the samples. Researchers began using maca as an input for botanical characterisation and applied techniques such as microbiology in the second half of the 20th century. As already mentioned, knowledge about dosage, forms of consumption, parts of the plant to be used, effects, and so on, was uncodified and unarticulated, so researchers in Europe and the USA with access to maca had few clues to its use. They applied their skills and routines as researchers to redesigning maca.

In the 1950s, ethnobotany as a research discipline changed the way that scholars conducted research. A focus on 'listing names and uses of plants and animals in native non-Western non "traditional" populations', progressed to the study of 'human conceptualisation and classification of the natural world' (Ellen, 2006 S2). The ethnobotanist, Timothy Johns, wrote a thesis for the University of British Columbia, Canada,[192] on understanding how indigenous communities could support their decision to use maca as a fertility enhancer based on the skills and routines established hundreds earlier and without modern phytochemical knowledge (Johns, 1980).

The English language was used to reference the neglected condition of various Andean species, including maca, their benefits and the path towards their further utilisation. The book *Lost crops of the Incas: Little-known plants of the Andes with promise for worldwide cultivation*, written by the group of researchers including Jorge León, supported by the NRC, and led by Noel Vietmeyer (Vietmeyer *et al.*, 1989), can be seen as an invitation to use and study Andean species and reap their reported benefits.

For English speakers, knowledge about maca was based on the available codified knowledge and accessing maca for use was expensive; so, they limited its use to what was allowed by the materials collected.

[192] Timothy Johns was an English speaking Canadian, who, in 1980, wrote a master dissertation *Etnobotany and phytochemistry of Tropaeolum Tuberosum and Lepidium meyenii from Andean South America*, for the University of British Columbia, Canada (Johns, 1980), from which he developed an article (Johns, 1981) and a book chapter (Johns, 1986).

Written languages allow articulation and codification of certain types and levels of knowledge. Given the contextual character of knowledge, actors familiar with certain language can articulate and codify the knowledge associated with that context, which simplifies the actors' meanings to information. Monolingual indigenous Quechua speakers articulated some knowledge about maca, but did not have the skills and institutional arrangements to codify it in Quechua. Indigenous Bilingual Quechua and Spanish speakers were able to both articulate and codify the knowledge, and offer their meanings as research inputs or to provide a commercialisable product at the local level. Indigenous bilingual Spanish and English researchers and dealers provided their own meanings based on their skills and organisational routines.

6.3 Forms of governance of goods and appropriation of the benefits from the goods from biodiversity

Indigenous Andean people and researchers are multidimensional, which allows them to participate in different organisations and operate under various institutional arrangements. The previous section discussed how some indigenous Andean people maintained their skills and routines related to maca production in the wet *puna*, and learned new skills and routines as researchers or dealers. As the actors addressed their needs and pursued their organisational goals during the shaping of the maca, they also generated *goods*. Thus, some of these skills and routines can be considered innovation activities, which helped these goods reach the international market.

Since the 1960s, indigenous Andean people have advanced from being mainly rural and monolingual to becoming urban and bilingual.[193] The growth of big cities, such as Lima, increased demand for food. This growth was associated with technological and institutional changes, which provided solutions to food needs: Some indigenous dealers managed to transport surpluses to markets on the coast from highlands production of

[193] In the intercensal period 1961 – 1972, the percentage of the urban populations grew from 47.4% to 59.4% of the national population (see INEI, 2009 p. 15). Quechua was the most widespread indigenous language in the Andean region. At the beginning of the 20th century, two thirds of Cuzco's population were Quechua speakers, the remainder being bilingual. Up to 1920, speaking Quechua was the norm, but in the 1940s it was looked down upon because Spanish was needed to operate in cities, obtain state employment and to become a member of one of the professions such as teaching, medicine and law (see Itier and Goulder, 2002; Adelaar and Muysken, 2004).

potatoes and other roots and tubers, such as maca. Others studied and reported on agriculture and other food-related sciences in their routines in universities and research centres.

The section discusses the governance of goods and the appropriation of benefits for those actors involved in the shaping of maca. Sub-section 6.3.1 introduces the goods that emerged when actors (indigenous Andean people, dealers and researchers) used their skills to satisfy their needs and applied their routines to achieve their organisational goals. This sub-section considers the institutional arrangements and organisations involved in the innovation process and, in particular, how they intertwined with the forms of governance over goods. Sub-section 6.3.2 discusses how actors and organisations appropriated benefits from these goods. The actors' roles in the shaping process and their relative bargaining power over complementary means, defined the appropriation of these benefits.

6.3.1 How were public and private goods emerging from the maca shaping process, governed?

Benefits arose from the goods emerging from the shaping process. How those goods were governed is analysed in terms of the institutional arrangements that affected ownership and control over and access to these goods (i.e., excludability) and the technological attributes that affected their consumption (i.e., subtractability). The analysis focuses on the goods that emerged from use of the species and its underlying knowledge. We discuss the forms of governance over four goods: (i) maca for consumption; (ii) the set of maca seed in the wet *puna*; (iii) the codified and articulated (or not) knowledge of maca; and (iv) the maca botanical collections established in various parts of the world.

Good (i): The *maca roots* were governed as a private good, produced in the ayllu land and mainly self-consumed by indigenous families (see Sub-section 6.2.1). At some point in precolonial and colonial times, maca surplus was brought to the local market and bartered for other products. Later, during the 20th century, roads and railroads became available and the maca surplus was transported to Lima for commercialisation in local markets. Once the maca had been consumed by the farmer (or buyer) it was no longer available to them or anyone else. The governance over private goods allows their owner to exclude others from using them.

Good (ii): The *set of seeds in the wet puna*. The root, as well as being used for self-consumption as food, can be used by the farmer as a kind of vegetative 'seed' to obtain botanical seeds. In principle, the use of maca as a seed rather than as a food, does not change the form of governance over it (i.e., it is privately governed). However, the seeding process which reduces its subtractability (i.e., a single vegetative seed can be used to obtain thousands of botanical seeds), and the institutional arrangement of kinship linkages within indigenous Andean communities and ayllus members, entailed certain social practices that changed the private governance over this set of seeds to one of collective interest.

The first step involved in obtaining seed was selecting appropriately sized and coloured roots, which were then stored under special conditions (i.e., kept vertical in a hole in the *sharpo* attached to the house in the wet *puna*, covered by camelid' dung, straw, soil, and water) to ensure their viability after the dry season. The root when cultivated produced a rosette and from these flowers the seeds were threshed and saved. A few rosettes produce enough seeds to sow the small plots used for growing maca. Traditionally, seeds were saved only every two or three years since the process of harvesting and storing them was time consuming, so farmers produced enough seeds one year and distributed their planting for the following years by themselves or by other farmers with whom they exchange seeds (Interview QA). The collective interest in producing and maintaining good quality seeds suited to the prevailing weather conditions.

In 2006, once the boom in maca began, it was reported that half of the maca producers in Pasco used 'exclusively their own seed, while the rest relied on external seed sources in addition to their own production, a practice believed by farmers to maintain the vigour of the plants and their resistance to pests and diseases' (Hermann and Bernet, 2009a p. 15). Exchanges of maca seeds involved mainly close relationships among *ayllus* or community members, where trust was based on the direct learning experiences of actors living in the wet *puna*.[194] Since seed ownership is rivalrous, governance over the *set of seeds in the wet puna (good (ii))* was in the form of governance over a local common-pool resource, by the indigenous wet *puna* farmers, who exchanged materials with each other.

Attempts to produce maca from botanical seeds obtained from other zones than the wet *puna* (i.e., *qechwa*) were largely unsuccessful, despite the plants producing large rosettes (Interview BE). There is no evidence on the relationship between conditions outside the wet *puna* and production of viable seeds. However, Oruro and Potosí regions in Bolivia, where the *puna* is dry, and Lijiang and Diqing prefectures in Yunnan Province in China, are growing maca (Lim, 2015). In the case of China, Hu *et al.* (2013) report variable viability (between 30 to 90%) of the seed produced there despite altitude, rainfall and temperature being similar to the Peruvian wet *puna* (Xiwen and Walker, 1986).

Interviewee BE mentioned that farmers believe that seed produced in regions different than the wet *puna* has low capability to withstand the weather in the *puna*.[195] This assertion is supported by the high demand for Peruvian maca seed by Chinese dealers in 2014 and 2015 (Collyns, 2015a), since it would be expected Chinese producers would save their own seeds for the following season. There are also reports that the rapid growth of maca production in China may have outstripped the capacity to produce seed locally, or that Chinese producers are attempting to acquire a group of different maca varieties to support their own breeding programmes (Hu *et al.*, 2013) and reduce the risks

[194] The maca seed usually contains a percentage of the husk; it is difficult to separate seed and husk because of the small size of the seed. Seed purity in a quantity of seed is less than 100% (Interview QA). So, indigenous people follow certain routines for cleaning (i.e., purifying) and defining the percentage of seed.

[195] Seeds have restrictions to be moved from the *puna* or to the *puna* and lands have restrictions to be used recurrently. In the case of seeds, as with potatoes, altitude affects the species mutation, genetic drift and natural gene flow. Lower altitudes require the more frequent introduction of different seed compared to higher altitudes (3,500 masl) where the presence of diseases and other species, the area of the land devoted to maca seed production, and the biotic interactions with insects and diseases, affect the variability and demographic stochasticity or random mutations that can occur. For example, lower altitudes with higher temperatures, are conducive to reproduction of viruses and other pathogens and pests that affect seed quality. The land used to grow maca needs to remain fallow for several years following one year's production of the plants. Some indigenous communities believe a long fallow period is required because maca impoverishes the soil with its high nutrients requirements. QA, an indigenous descendant, argued that the long fallow period is due to the allelopathic condition of the maca, which produces some substances that impede the growth of other plants and the high altitude (i.e., low levels of oxygen) which slows the mineralisation of nutrients in the soil.

and costs associated with monoculture of a single variety.[196] The high demand for maca seeds from Chinese dealers may affect the governance of the set of seeds in the wet *puna* to the extent that the social practices of producing, saving and exchanging with other farmers will break down.[197]

Good (iii): Codified and articulated (or not) knowledge of maca. The boom in maca production was accompanied by publications highlighting the relationship between maca and human reproduction and other advantages related to the immune system, concentration, memory, etc. Information became available on how to produce, process and consume maca. An examination of the three tiers of codification of knowledge (see sub-section 6.2.2) shows how *the codified articulated (or not) knowledge of maca (good iii)* is governed. The launch of Viagra in the 1990s led to maca being described as Andean Viagra (or Viagra Andino or Viagra Inca). This thesis argues that this meaning of maca emerged because it was simple and inexpensive to compare it with Viagra. It increased the number of actors who used the knowledge, which is not exhausted by consumption, and it was difficult to exclude others from using this knowledge. Hence, the widely advertised concept of 'Viagra' makes difficult to subtract users from using it, and it is governed as a *public good*. However, some of the publications describing and promoting the above mentioned properties are governed as private goods, since there are copyrights mechanisms in place.

Researchers, users of maca for research, offer different findings to the claims of maca as a 'Viagra' (Ventas and BBC, 2015). Their reports use jargons and research concepts which outsiders would need to understand in order to access the knowledge, which would increase the cost of learning about maca. Thus, the public character of knowledge is contextual rather than absolute, and the skills of the user affect this public character. Researchers (*insiders* familiar with the jargon and standard concepts and

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[196] After scientific studies showed that higher costs and greater risks of pests and diseases are associated with monoculture (see Ch. 5 Sub-section 5.3.2 and fn. 159), attempts were made to reduce these costs and risks.

[197] Reports of Chinese people buying seed emerged in 2014, a few months after the fieldwork conducted for this thesis. It is unclear how governance was affected, but if every farmer decides to produce and to plant only his/her own seeds and trust linkages are broken, governance could become privatisation. Only loss of vigour and resistance to pests and diseases arising from use of the farmers' own seeds was able to convince the farmer that the costs of exchanging seed were justified. Dietz *et al.* (2003) indicate that international trade and technological changes affect the governance of self-governing common goods.

research routines) have low costs for accessing new information about the properties of maca. This information is governed as a *local public good* by these researchers who contribute to its production. They have access to it and share it freely (i.e., accessing on-line journals and databases, exchanging e-mails with one another). Analogously, indigenous Andean people who grow and use maca as food or as a medicinal plant have maintained uncodified, but stable skills and routines for producing and consuming maca. That knowledge, despite being unarticulated and uncodified, is governed also as a *local public good* by the members of the indigenous Andean community.

For those outside the groups of researchers or of indigenous Andean people, the costs of accessing that knowledge (local public good) is high because it entails unfamiliar skills and routines. As noted previously, Quechua speaking indigenous people had knowledge that was not codified for use by other speakers of other languages (i.e., mainly Spanish and English). Knowledge of the Quechua language was costly to access for other language speakers. The codification of Quechua speakers' indigenous knowledge (primarily into Spanish and English) was enabled by indigenous people's access to organisations such as schools, universities, and research institutes as students, teachers or researchers. The routines in these organisations allowed indigenous researchers to codify their maca related knowledge, making its access less costly for Spanish and then English and other language speakers. Hence, this knowledge become less subtractable and its governance involved not only the group of members of the community but also a broader range of users with the skills to decode the knowledge (it is difficult to exclude users from access to public goods if they have accumulated the required skills).[198] Thus, codification can reduce the cost of communicating meaning for potential inventors/innovators in maca.

Codification of the knowledge related to maca increased the opportunities for accessing maca. In the 20th century, markets grew and were used, initially to exchange major staples (i.e., potatoes, maize, barley, and wheat), but later for exchanges of less

[198] Although codification seems a positive form of involving more users of the knowledge, it can act also as a mechanism to restrict those who cannot decode the knowledge. Restrictions are related to lack of skills or routines to decode the knowledge (e.g., indigenous knowledge codified in a modern language unknown to indigenous people), lack of complementary means to access the knowledge (e.g., knowledge recorded in media that requires purchase of a technology).

commonly commercialised products such as maca. The costs of establishing commercialisation routines for maca were high. Similar to the case of knowledge codification, where efforts were made to knowledge related to the major staples, the reductions in the costs of maca knowledge codification reduced the consumers' costs to access this knowledge, which increased the expected benefits for potential inventors/innovators who commercialises maca products, allowing the involvement of yet other actors.

Decreased costs of access to codified knowledge and the increased expected benefits affected the governance of the knowledge as a local public good and encouraged new actors to contribute to knowledge codification and diffusion. This resulted in forms of governances where the cost of restricting access to knowledge increased (broader public goods).

Good (iv): Maca botanical collections. Organisations, such as universities and research centres, become involved in facilitating access to collected materials (i.e., seeds), as referred to in Section 5.3.2. Researchers and indigenous people were involved in the governance of those collections whose holders jealously maintained their *club goods* status.

In the 1990s, three independent collections of maca for research were established: One by an indigenous independent researcher from a university in the wet *puna* who was an expert in potato breeding (Interview QA); one by INIA on behalf of an agronomist from Huancayo (Interview BE); and one by the CIP headed by a researcher and supported by the Swiss Agency for Development and Cooperation (SDC) (Interview AE). Those in charge of these collections and their maintenance applied the skills related to other crops (i.e., potatoes and maize) to maca.

In 1997, a national course on maca production took place in Cerro de Pasco and was attended by farmers from other regions of Peru. The course was organised by the NGO Eco and the University Daniel Alcides Carrión, with participation from Miguel Holle, from the CIP, Gloria Chacón and other maca experts. A manual on maca production was published in 1999. Also in 1999, as a result of the course and the manual, some Bolivian farmers travelled to the Pasco and Junin regions to collect maca seeds since they believed that the conditions in Bolivian were similar to those in Pasco and Junin (Interview QA).

Some of the researchers that had participated in the course - either individually or representing their universities - maintained the seed collections and became points of contact for potential inventors/innovators wanting maca seeds to standardise and redesign maca (i.e., to produce maca in other regions).

The governance of these maca collections is based on the technical and institutional arrangements related to their access and maintenance. Some collections offer higher levels of exclusion and subtractability. Comparison with former types of governances provides clues to the extent of exclusion and subtractability. For example, in 1980, before the CBD was implemented, Timothy Johns (see Sub-section 6.2.2), received dried maca roots from a US researcher who had collected them in Peru many years earlier. Based on collaboration with a researcher in CIP, he got access also to two varieties of mashua tubers, seeds, flowers and leaves , which allowed him to conduct more detailed experiments and observations. Why was there limited access to maca, but not to mashua? First, the technical conditions, such as harvesting season, altitude, seed size form of reproduction, differed between mashua and maca.

A gene banks expert recognised that the research centres of the Consortium of International Agricultural Research Centers (CGIAR) (i.e., CIP and the International Maize and Wheat Improvement Center, CIMMYT for its Spanish name Centro Internacional de Mejoramiento de Maíz y Trigo) differed in their capabilities to distribute either collected materials or improved seed. For 40 years, CIMMYT has had a budget and training unit (i.e., skilled users and established routines) to bring researchers to its headquarters in Mexico from around the world, to train them in the evaluation of research materials and provide them with bred seeds to experiment with in their own countries. However, other centres did not (Interview AH). The absence of routines to allow outsiders to access the materials increased access costs and made it easier to exclude potential users from accessing collected or bred seeds.[199] Governance that ensures sufficient materials to allow their distribution among a set of identified users without restriction, regards the material as a club good. However, if there is insufficient material to distribute and if there

[199] The CIP maca collection has little chance to be distributed because CIP has neither budget nor routines (training) for activities such as those that CIMMYT has performed for decades, there are institutional arrangement that restrict access to maca associated with TFAO, CBD and Decision 391 and maca cannot be cultivated in as many places as it is possible to do with maize or wheat.

are no routines in place to cover the cost of their distribution, the collections become privatised.

In summary, forms of governance over goods emerged from the shaping process, based on the contributions and access of actors and the technological attributes of those goods. The form of governance for each of the goods takes place when indigenous Andean people and researchers perform their skills and routines for addressing their needs and pursue their organisational goals. The form of governance over the goods entails benefits that can be reaped by individuals, groups or both.

6.3.2 How do actors and organisations give meanings (values in use) to the emerging goods and appropriate the benefits from biodiversity-based innovation?

Indigenous Andean people and researchers (and the organisations to which they belonged) gave meaning to and appropriated the benefits from biodiversity-based innovation through the performance of their skills and organisational routines. The benefits are explained in terms of the values in use that actors (or organisations) gave to the goods that emerged from use of maca. Benefits include the expected output from *routinised* maca production and extend to other goods, as explained in the previous section. The present section is organised according to the actors and organisations that benefited. It describes the values in use that actors gave to maca and provides evidence on how the appropriation of benefits was enhanced or constrained by structural and relational means. Four actors and organisations are presented: (i) the indigenous Andean farmer - actor; (ii) the maca dealers-- actor (iii) the maca researchers – actor; and (iv) the Maca Group - organisation.

Actor (i). The *indigenous Andean people* gave maca value in use as a nutritious food crop grown in the wet *puna*. The wet *puna* is a very harsh environment compared to zones near the coast and on the banks of rivers. The low levels of oxygen reduce the availability of plants and animals. *Puna* means 'altitude sickness' in Quechua and referred to the effects suffered by visitors from lower latitudes. Consumption of maca, a scarce plant even in the wet *puna*, was appreciated as a fertility enhancer something that helped humans survive in the tough conditions in this zone. Maca was not appreciated by population living at lower latitudes. Gonzales (2010b) reports that compared to non-consumers, consumers of maca in the Peruvian central Andes resulted in a 'higher score in health status, lower rate of fractures, lower scores of sign and symptoms of chronic mountain sickness'.

Despite its positive effects on human health, maca production was a secondary activity for indigenous farmers after camelid and sheep herding, the main activities in the wet *puna* until the 1980s alongside cultivation of other staples. Since the 1980s, indigenous Andean people have appropriated economic benefits from the commercialisation of maca production. While, traditionally, maca production was limited to small *sharpo* plots (see Section 6.1.1) and, therefore, the economic benefits were limited by the amounts produced, in the last few decades plots of several hectares have become common.[200]

It was agreed by members of the *ayllu* (Interview FA) that the maca growing areas should be extended. The cultivation of large plots required investment in barbed wire fences and renting tractors to prepare the land, and recruitment of labour to deal with the harvest and postharvest. Maca production expended and increased the possibility to reap economic benefits.

While the health benefits of maca consumption are difficult to isolate and measure, in some cases, it is possible to measure economic the benefits 'reasonably well' (Nelson and Winter, 1982 p. 110). This applies to the indigenous Andean farmers who used maca to produce seed and those indigenous people who commercialised maca production. In the case of indigenous Andean farmers, the economic benefits included the income from selling the crops, the incomes distributed among members of renting and preparing the land, of producing or buying seed, paying labour to maintain the crop, and managing harvest and post-harvest activities before the dried maca was sold to a maca dealer.

[200] The Peruvian National Agricultural Census 2012 reported that from a total of 652 agricultural units cultivated in maca, 207 were between 1 and 2.9 hectares in area, 100 were between 3 and 4.9 hectares, and 80 were between 5 and 9.9 hectares (see INEI, 2012 table 40).

However, it is difficult to measure the knowledge that Indigenous Andean farmers possess about the conditions in the wet *puna*, although this should be rewarded.

Farmers in Bolivia been growing maca since around 2002 (Interview WBA) and in China it has been grown since 2003 (Cheng *et al.*, 2004; Yu *et al.*, 2004a; Yu *et al.*, 2004b), with increases in the area of land to maca in 2007 (Zheng *et al.*, 2009). Also in 2007, Chinese researchers from the Chinese Academy of Sciences, reported use of maca roots to obtain *calli*, cells induced to grow to evaluate their antioxidative activity (Wang *et al.*, 2007). Access to both land outside the original Quechua speaking territories, and techniques, such as tissue culture, affected the appropriation of benefits from the commercialisation of maca. In the first case, farmers and processors were able to produce maca in places other than the original Junin and Pasco regions, including China; and in the second case, it could be produced in a controlled environment (i.e., laboratory-type facilities and greenhouses). The Chinese web page maca-china.net reports that the Chinese group of producers involved in the Li Ma Industry Group accounts for 60% of world maca production (China, 2014), and the increasing number of Chinese publications, including patents (i.e., period 2013-2014) (方新, 2015) and articles, are evidence of the huge interest in maca in China. How the benefits have been affected by China' increasing interest is perceived differently by the indigenous Andean people and the Peruvian government (see organisation (iv)).

Actor (ii) the *maca dealers*, many of them indigenous Andean people, whose multidimensional character allowed engagement in the processing and commercialisation of maca. The value in use for them was maca flour and gelatinised flour, whose commercialisation provides a source of income, despite the costs of transporting the material to Lima and paying for cleaning, milling and packing of the maca for sale. Transport to Lima has become cheaper thanks to the road between Cerro de Pasco and Lima. The processing costs are scale related and are determined by the buyer. In some cases, buyers require a high degree of purity, which implies longer washing, cleaning and checking processes. Some requests gelatinisation by extrusion rather than only milling of the dried root. Finally, packing also can be in sacks for later re-packaging, or in capsules. Access to the machines and the knowledge to fulfil these requirements are complementary means that enhance the appropriation of benefits for maca dealers.

The appropriation of benefits from the commercialisation of maca flour is enhanced by rights-based means, such as geographic indication (i.e., Denominación de origin), which in the case of Peru is the 'Maca Junín – Pasco' (Indecopi, 2011). Bilingual (Quechua and Spanish speaking) indigenous people act as translators, a concept to which sociologist (Callon, 1986) refer to explain the advantage of bilinguals or those holding different knowledge: Bilingual indigenous people perform the skills and routines proper of organisations such as universities, research centres, companies and markets (i.e., the Lima city market), while maintaining links with their communities. The benefits derived from the role as translators include participation in the shaping of the technology and contributing to the meaning of the maca of what they consider as relevant (e.g., yield in maca production and export quality). Also, as Callon (1986) refers, bilingual indigenous people can mobilise resources for redesigning the species in order to solve the problems associated with their meanings. Bilingual indigenous people are able to access research resources and government subsidies to fund the shaping of maca. Some have made innovations in its processing for flour. This allowed them to appropriate further benefits from maca processing and commercialisation: Mostly dried maca was exported before 1997 (Aliaga-Cárdenas *et al.*, 2007). However, after the Supreme Decree N° 039-2003-AG (see Section 6.2.1) prohibited its commercialisation as only seed or root, processed forms were exported. In 2015, Peruvian maca exports totalled US$34 million (Peru, 2016).[201]

Actor (iii) the *maca researchers*. An example of benefits is related to the long-term relationships in organisations (see Ch. 4 Section 4.3.2). For maca researchers, the value in use of the maca root is as a research input. Gustavo Gonzales, a physician from *Universidad Peruana Cayetano Heredia* and, since 1978, an expert in high reproductive health at high altitudes, has conducted research on maca since the end of the 1990s. His first research on maca focused on the effect of aqueous extract of maca on spermatogenesis in rats and consumption of gelatinised maca by adult men. The results were diffused in a conference held in Lima in 2000 and in two papers published in English

[201] Other forms of maca than flour have been commercialised since 2014. In 2014, maca under the tariff heading '0714901000 Maca - Maca (*Lepidium meyenii*), frescos, refrigerados, congelados o secos, incluso troceados o en pellets' (i.e., Maca - Maca (*Lepidium meyenii*), fresh, chilled, frozen or dried, whole or sliced pellets) accounted for US$5 million of exports, and in 2015 this rose to US$7 million. This is in addition to US$24.5 million of maca flour exported in 2014 and US$27 million of flour exported in 2015. Although in news reports the Peruvian Ministry of Agriculture described these exports as fresh maca (see MINAG, 2016), the fieldwork (Interview OA) confirmed that it referred to pellets rather than fresh product.

in the Asian Journal of Andrology (Gonzales *et al.*, 2001a; Gonzales *et al.*, 2001b). Since then, Gonzales has authored almost 40 publications. More recently, his work has focused on the different colours of maca, concluding that maca technological attributes and uses can be differentiated for each of the three basic colours of maca (red, black and yellow).

Gonzales's motivations for studying maca are related to his fascination with health at high altitudes, which involves only a small percentage of the world's population. His research has been supported by the possible thanks to the support of the *Universidad Peruana Cayetano Heredia* where he spent the whole of his professional life, and funding from international organisations such as the World Health Organization (WHO). His role as a general practitioner (medical doctor) and the funding he received have allowed him to gather information on the highlands communities and details about their consumption of maca. He has given meaning to maca, and the findings from his work suggest further standardisation of maca by colour.[202] Unlike the indigenous Andean farmers and dealers mentioned previously, he had no agency for redesigning maca, but the meaning he provided has been used as an input for its redesign by those who with agency. Gonzales is a Spanish speaker, but most of his work has been published in English, not a requirement when he was first publishing, but certainly one in today's research community. Publication in English is considered a requirement to diffuse research outputs (i.e., by organisations of the NSI, such as science and technology agencies, universities and research centres). Access to complementary means, such as health authorities and knowledge, allowed Gonzales access to funding agencies for resources for his projects and publication activity.

Organisation (iv) the *Maca Group* (see Sub-section 6.2.1), which passed to be a law-created organisation called 'National Commission for the Protection of Access to Peruvian Biological Diversity and Collective Knowledge of Indigenous Peoples', or 'National Commission against biopiracy', (CNB for its Spanish name Comisión Nacional contra la Biopiratería). The CNB was responsible for adherence to the Andean regulation and the CBD in the Peruvian territory, including Decision 391 (see Ch. 1 Section 1.1) and the Supreme Decree N° 039-2003-AG (Perú, 2003) (see Ch. 5 Sub-section 5.2.1). Chinese

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[202] Several of Gonzales's publications differentiate maca by colour. (see Rubio *et al.*, 2011; Rubio, 2011; Gonzales, 2013; Gonzales *et al.*, 2013a; Gonzales *et al.*, 2013b; Gonzales *et al.*, 2014; Lembè *et al.*, 2014).

production of maca and demand for seed involved biopiracy and smuggling of both botanical seeds and fresh products (Collyns, 2015a; b). Export of maca seeds must be approved by the Peruvian government (i.e., by CNA based on MAT), and Chinese access to seeds and materials is illegal. As Ribot *et al.* refer, an illegal access is also rights-based, but 'defined against those based on the sanctions of custom, convention, or law' (Ribot and Peluso, 2003 p. 164).[203] Government representatives belonging to the CNB are responsible for ensuring that the law is adhere by those accessing maca and their benefits come in the form of reducing prosecutions for no-adherence.

Despite there are not official and comparative records of Chinese maca production, the interest on Chinese for patenting maca uses, the advertising on media about the Chinese commercial experience and the intensive research agenda, indicate that Chinese producers and consumers are interested in maca products commercialisation. Also, it is clear that the Peruvian government has limited ability to restrict the smuggling of maca seeds since it is very difficult to control the movement of smuggled objects of small size and it is difficult to trace seeds that might be intercepted. Thus, it is generally thought futile to try to prevent diffusion of maca seeds or any botanical resource from their centre of origin.

As already described (see Sub-section 6.3.1), governance over the set of seeds as a local common-pool resource is affected by international trade and technological change (i.e., reductions in the cost of transport and high cost for restricting the access to them). From the perspective of the indigenous Andean farmer, smuggling maca production (both raw roots and seeds) entailed an increase in the prices paid to them. Supply via maca dealers and kinship linkages among indigenous Andean community members were

[203] Ribot and Peluso (2003) refer that the difference between rights-based 'property' approaches and illegal forms of access based on violence or theft is explained by concepts of morality and legitimacy (Ribot and Peluso, 2003). For example, it is common that temporary workers from Philippines, China, or even Peru, travelling to work in Ontario, Canada, introduce seeds for being cultivated, despite it is illegal their introduction for sanitary reasons, but legitimate for those workers for ensuring their nutrition (see Cole, 2016). The introduction of maca seeds to Huize, Yunnan province, China, is reported to be done in August 1993 by an American professor, CEO of an herbal company, who visited a Chinese professor and trained farmers from the region in maca cultivation techniques (see 王顺凤 *et al.*, 2014). Both, Peru and China signed the CBD in 1992 and ratified it in 1993, while the USA, signed it in 1993, but it has not ratified the CBD. The prosecution of the illegal access to maca seeds introduced to China under the CBD would involve actors in all the three countries and would require to assets the legitimate use done for each of those involved.

affected. From a critical perspective, at the aggregate level, the movement of maca seeds to other places (e.g., China) helped to identify environments where the plant could be grown, helped to diffuse use of the species and allowed more actors to benefit from its nutritional attributes, and contributed towards the conservation of maca diversity, by confronting the plant with new environments and new users who defined selection. Those factors counterbalanced the single variety monoculture, which derived from standardisation.

6.4 Summary

The maca innovation process since the 1960s began when actors other than the traditional indigenous Andean users, used maca. Researchers voiced their concerns about the neglected condition of maca and other Peruvian species with potential to benefit consumers around the world.

The reported maca area reduction was overcome and Peruvian exports of maca increased to over US$34 million dollars and more than 55 countries in 2015. Reports of production in Bolivia and China, numerous patents related to maca, and articles on maca are testament to its increase.

Despite users' confidence in maca as a fertility enhancer and the reputation gained by its standardisation as a ground flour and a gelatinised flour, the meanings given by actors are problematic in several senses. The expectations of new users are not stabilised enough since some of the marketing meanings are related to issues such as sexual health (i.e., vasodilatator) and enhancement of stamina, although the evidence is ambiguous. Francisco Gonzales and his team are studying the differences among the three basic colours (red, black and yellow) of maca, which will contribute to its standardisation.

The market for export is an institution that has allowed expectations about maca to stabilise to the extent that indigenous Andean people and dealers follow routines that allow them to produce and transform maca-based products for export and commercialisation. Although this routine has been effective, new arrangements are foreseen due to the interest of Chinese actors in maca production.

Codification of knowledge has helped to increase maca stabilisation and reputation as a commercial food and as a fertility enhancer. Traditionally, universities in Lima have codified information in areas other than agriculture and the first Peruvian written report on maca was in chemistry. The creation of UNALM and organisations that cooperated on agricultural topics (i.e., IICA and European countries cooperation agencies) increased the opportunities to study agricultural issues. Up to 1960, reports on Andean roots including maca, were scarce. In the last 40 years written material has contributed to stabilising users' expectation about the properties of maca. More clinical evidence would help to understand the conditions under which maca is effective as a therapy.

Goods emerged from the shaping process of maca, including (i) the maca to be consumed; (ii) the set of maca seeds managed by the indigenous communities; (iii) the codified articulated (or not) knowledge of maca; and (iv) the maca collections managed by researchers and research centres, show that its governance is contextual rather than absolute. So, together with the technological attributes that define the conditions for gain benefits, the skills and routines of actors allowed them to participate in its governance and to appropriate such benefits. For example, although maca collections were aimed at reducing risk of loss of the biodiversity and, in some cases, to enable access to materials, the institutional arrangements were not appropriated. Some CGIAR centres provide examples of what can be considered more public governance (the case of CIMMYT through its experience with maize and wheat' diffusion of use). It is easier to access reproductive material in the market than from collections. Maca seeds can be bought since the costs of accessing them are low compare to 50 years ago. Although the Supreme Decree N° 039-2003-AG prohibits the export of botanical and vegetative seeds, and sub products, in their natural state or after primary transformation, smuggling of maca and maca seeds has occurred in the last few years (Collyns, 2015a; b). The different users of maca (local producers in Junin and Pasco and the industry) have different understandings about how the sale of seeds benefits them.

Indigenous Andean farmers, researchers and dealers have appropriated benefits from the goods emerging from using maca. Rights-based means, such as ownership of the land by indigenous Andean farmers, have enhanced the appropriability of such benefits. The usable land for producing maca can be extended (so far it includes areas in

Peru, Bolivia and China), to include areas in the Himalayas. New techniques such as tissue culture, and controlled environments (i.e., laboratory-type facilities and greenhouses) can mimic or replace the conditions in the wet *puna*, which could affect the future appropriation of benefits by indigenous Andean people.

7 Quinua (*Chenopodium quinoa*) case study

Quinua is an Andean plant with potential as a staple food crop around the world. FAO declared 2013 to be the International Year of Quinoa (IYQ) , mentioning:

> The grain was carefully guarded by (indigenous Andean) peoples and today it is an invaluable legacy for humanity, due to its unique characteristics: quinua is the only food that has all the essential aminoacids, trace elements and vitamins while being gluten free. It can grow under the harshest conditions, withstanding temperatures from -8 ° to 38 ° C, anywhere from sea level up to 4,000 metres and it is tolerant of drought and poor soils. (FAO, 2013)

Despite its adaptability, only a few regions in three Andean countries (mainly La Paz, Oruro and Potosí in Bolivia, Puno and Cuzco in Peru and some provinces of Ecuador) reported exports of quinua (INEI, 2012; 2015; FAO, 2017), while 'more than 70 countries are performing agronomical tests for its commercial production' (FAO, 2012). Peru recorded exports of quinua to 66 countries around the world in 2014 (Peru, 2016), while in Bolivia quinua was the 12th most exported product by value, in 2013, with growth of 94% compared to 2012 (IBCE, 2015b).

Indigenous Andean people domesticated wild quinua some 5,000 to 7,000 years ago. At that time, domesticated quinua was broadly dispersed from its centre of origin in the Lake Titicaca basin in the southern Andes of Peru and north-west of Bolivia, to several regions along the South America Andean regions: Central Colombia, [204] Ecuador, Argentina and Chile (Jellen *et al.*, 2015; Tapia, 2015). The broad dispersion of quinua led to hundreds of different 'varieties' of the crop adapted to different regions along the Andean territory. It was not until the 1980s that commercial and sustained production of quinua was reported in dozens of countries around the world (FAO and CIRAD, 2015 Sect. 6; IQC *et al.*, 2016).

This chapter examines how quinua was shaped as an innovation for the international market while actors continued to use it in their social practices. The users

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[204] Some Chenopodiaceae pollen was found from 2300 years ago in central Colombia (see Cardale Schrimpff, 1987) and quinua production was reported there in colonial time.

considered are the indigenous Andean farmers, researchers, mechanical engineers with experience in wheat and barley and dealers, at their respective micro levels, and performing their individual skills and the organisational routines. The shaping process occurred within an institutional context at the meso level. Institutions reduced the costs of cooperation by moderating actor uncertainty about use of quinua. Certain goods emerged from use of the species from which benefits could be appropriated, either individually or by groups. The form of governance over the public or private goods that emerged from the use of quinua is related to the institutional arrangements and technological attributes of the goods.

This case is similar to the maca case to the extent that the species under analysis is an Andean crop whose area of production was reduced during the 20th century to levels that were of concern to indigenous Andean people because of the importance of the crop for their social practices. Given that the Aymara communities in the Lake Titicaca basin (see Ch. 5 Section 5.2) appropriated benefits from quinua-derived goods, the reduction in the area of production would lower the chances of appropriating benefits from such goods while an increase in the production area would enhance the appropriation of benefits. Understanding how the innovation process happens, of an area of production being increased and allowing surplus quinua grain to be exported, provides inputs and evidence for policy. Policies need to be in line with the CBD and the Nagoya Protocol aim at achieving greater benefits for biodiverse countries and more equitable sharing of the benefits from using biodiversity. The relevance of the case-study is that quinua has particular technological attributes, and plays a different role in diet and agricultural related practices to maca, so it contributes to reinforce arguments and prevent false conclusions in cases of comparison (see Ch. 3 Section 3.2).

This chapter is the third of three case study chapters that analyse the biodiversity-based innovation process. Section 7.1 follows the concepts in the SCOT approach to present the quinua shaping process, using quinua domestication as the background and emphasising the last 50 years when quinua grain was commercialised at the international level. Section 7.2 explains how the institutional arrangements and organisations increased the chances of variation and selection (i.e., rate and direction) and, especially, the role of codification in the Spanish and English languages. Finally, Section 7.3

introduces forms of governance over the public and private goods emerging from the shaping process and how the benefits accrue to individuals and organisations. Section 7.4 summarizes the chapter.

7.1 The innovation process of quinua

This section explains the social practice of diversification by which quinua was defined as a crop for human consumption and explains how actors get involved in the innovation process. The analysis focusses on the last five decades when quinua grain commercialisation passed from the local to the international level.

The context of the innovation process is the flow and form of its reproduction (see Ch. 5 Sub-section 5.1.1). The domestication of quinua can be traced back thousands of years to the Lake Titicaca basin where the indigenous Andean people valued and identified an early, naturally occurring hybrid form of wild quinua, a tetraploid wild ancestor derived from two diploid species, as a human food. Indigenous Andean communities were able to domesticate the species and obtain seed from two direct ancestors of quinua, *Chenopodium berlandieri* and *Chenopodium hircinum*. Those two species crossed readily with other wild relatives (Bazile and Baudron, 2015 p. 45). Herders using quinua as feed for livestock and farmer with skills in cultivating other grain, such as maize, learned the basic aspects of human consumption of quinua (i.e., the leaves and grains) and its reproduction and cultivation. Quinua is an annual grain and the learning from other annual grains that followed the predictable 'Mediterranean climatic' type cycle, helped to control and replicate the cultivation routines Thus, once the indigenous Andean people had learned the skills and routines for using the species (basic information), and how to reproduce it (ancillary information), with the help of camelids and other animals, they moved the seed throughout Andean Latin America. The ability of quinua to cross with compatible wild relatives was an advantage and allowed its successful introduction in other places.

The broad dispersion of quinua led to hundreds of different varieties of the crop, adapted to several regions along the Andes. The indigenous Andean communities in these regions accumulated knowledge about the definition, reproduction, cultivation and consumption of the different quinua varieties. In places with large variability in growing conditions or applications, the same *ayllu* managed dozens of varieties (see Ch. 5 Sub-section 5.2.1). The varieties were cultivated for their attributes related to high productivity, resistance to pests and diseases, their cooking properties, their levels of saponins, their flavour and colours, their resistance to abiotic stress (e.g., freezing, poor or high toxic soils), harvesting season and the sub-products that could be obtained.

The broad range of uses of phenotypic quinua attributes make it difficult to surmise which made wild quinua attractive to indigenous communities thousands of years ago and triggered quinua domestication. The first indigenous Andean communities around the Lake Titicaca basin hunted wild camelids and other small game, fished the lake and gathered whatever the surroundings had to offer such as birds, eggs, seeds (including those from Chenopodiaceae species) and tubers (including those from the Solanaceaes species) (Bruno, 2008 p. 17). While these skills initially were enough for their subsistence at that time (Archaic period 8000 – 3000 B.C.), several factors (e.g., population growth which affected the stability of settlements, reduced salinity in the water available in the lake and weather conditions that favoured cultivation) (Bruno, 2008 pp. 14-20) led to the adoption of cultivation/husbandry practices at the end of that period when quinua first began to be domesticated.

Domesticated quinua, one of the Chenopodiaceae available in the region, became part of the diet of the indigenous communities of Tiwanaku[205] and Inca states, especially in cold and arid regions (Planella *et al.*, 2015 p. 44) such as the *suni* (i.e., plateau) and the dry *puna*. In the lower territories (*qechwa*), such as the Cuzco and Arequipa valleys in Peru, and the Cochabamba and Sucre valleys in Bolivia, potatoes and maize were the main staples. The migration of indigenous people (see Ch. 5 Section 5.2.1) with skills in the human consumption of seeds and the introduction of domesticated plants, such as maize, whose seeds were a source of nutrients, might led to quinua being identified as a potential food source. However, the naturally-occurring presence of saponins (which are

[205] Tiwanaku state, which emerged at the end of the Formative period (2000 BC-500 AD), is considered the precursor to the Aymara culture. Remains of Tiwanaku state can still be found in Tiwanuku town in Bolivia. During the Tiwanaku state period, quinua was consolidated as a staple for the inhabitants of the *suni* (plateau) and the *puna* around the Lake Titicaca basin. Quinua plus camelids meat and other products obtained from the Lake Titicaca basin comprised the daily diets of these people.

bitter and unpalatable) in quinua seed required further development to reduce their content.

Despite the broad use and huge variability of quinua in several Latin American territories, its use was not internationally diffused until recently. The variability of quinua can be compared to that of potatoes and maize, both of which were used widely in the same Andean regions. Maize was introduced in Europe as early as 1593 (Rebourg *et al.*, 2003) and potatoes were introduced in the 16th century. Both crops were broadly diffused during the 19th century. In 2014, maize and potatoes were the first and fourth most dispersed and used staples in the world (FAO, 2017);[206] quinua grain began to be commercialised away from its local niches of production only since the 1980s. Although quinua was introduced to Europe during the 17th century and there are reports of its re-introduction to England in 1822, when the Botanical Gardens in Kew received a sample of seed, use of quinua was not broadly diffused to become a major staple (see Ch.5 Sub-sections 5.1.2 and 5.2.1). Similarly, Tapia (2015) reports quinua use being common in all the Andean countries until a few hundred years ago when it was ousted by imported wheat.

Many South American species (including quinua) were introduced to other parts of the world in colonial times. However, there are no reports of commercial and sustained quinua production in regions outside Latin America before the 1970s. Instead, the introduction of species from Europe and other economic and technological factors contributed to the disappearance of some quinua production areas and reductions in others. In recent years, quinua use has been diffused around the world. This diffusion of use involves commercialisation of some Bolivian and Peruvian production and the systematic movement of seed and experts. Several seed collections were exported with the intention to conduct field trials in collaborative projects and, together with the cultivation advice provided by Bolivian and Peruvian experts during the projects, there was movement of researchers to other countries that offered higher salaries. Interviewee

[206] In 2014, maize, rice, wheat, potatoes and cassava were the most important world staples (respectively) with 1,021 million metric tonnes, 741 million metric tonnes, 729 million metric tonnes, 385 million metric tonnes and 270 million metric tonnes (see FAO, 2017).

IB recalled that, in the 1980s, the University of Colorado, hired Emigdio Ballon, a prominent Bolivian quinua breeding researcher.

Today's indigenous Andean communities use the quinua plant in different ways and not only as staple food. Its flowers are used for decoration; its leaves are consumed as a vegetable, similar to spinach or kale, and as dressing to fix broken bones; the dry straw is used to obtain ashes and mixed for chewing coca leaves (*Erythroxylum coca*); and the saponins are recovered for use as a soap and as a poisoned bait for fishing (Winkel *et al.*, 2015 p. 371).[207] So, indigenous people put quinua to many different uses. Its saponin content was an important issue in quinua domestication and its standardisation as food.

What follows in this section focusses on the social practice of diversification that allowed quinua to be maintained by indigenous communities until the middle of the 20th century, to survive the challenge posed by other staples, and to commercialise quinua grain in the international market since the 1980s.

7.1.1 How are biodiversity-based innovation and social practices shaped collectively?

The Andean regions where quinua is mostly produced, are part of the Peruvian and Bolivian territories. Most of those regions, Puno in Peru and La Paz, Oruro and Potosí in Bolivia, are part of what is considered the Aymara Republic around the *suni* of Lake Titicaca Basin (see Map 3)[208] and shared with the Quechua speaking communities living in the Andean valleys. All four regions speak the same two indigenous languages (Aymara and Quechua) and social practices related to use of quinua shaped it as a technology, allowing sub-products (e.g. quinua grain) to be saleable in the international market.

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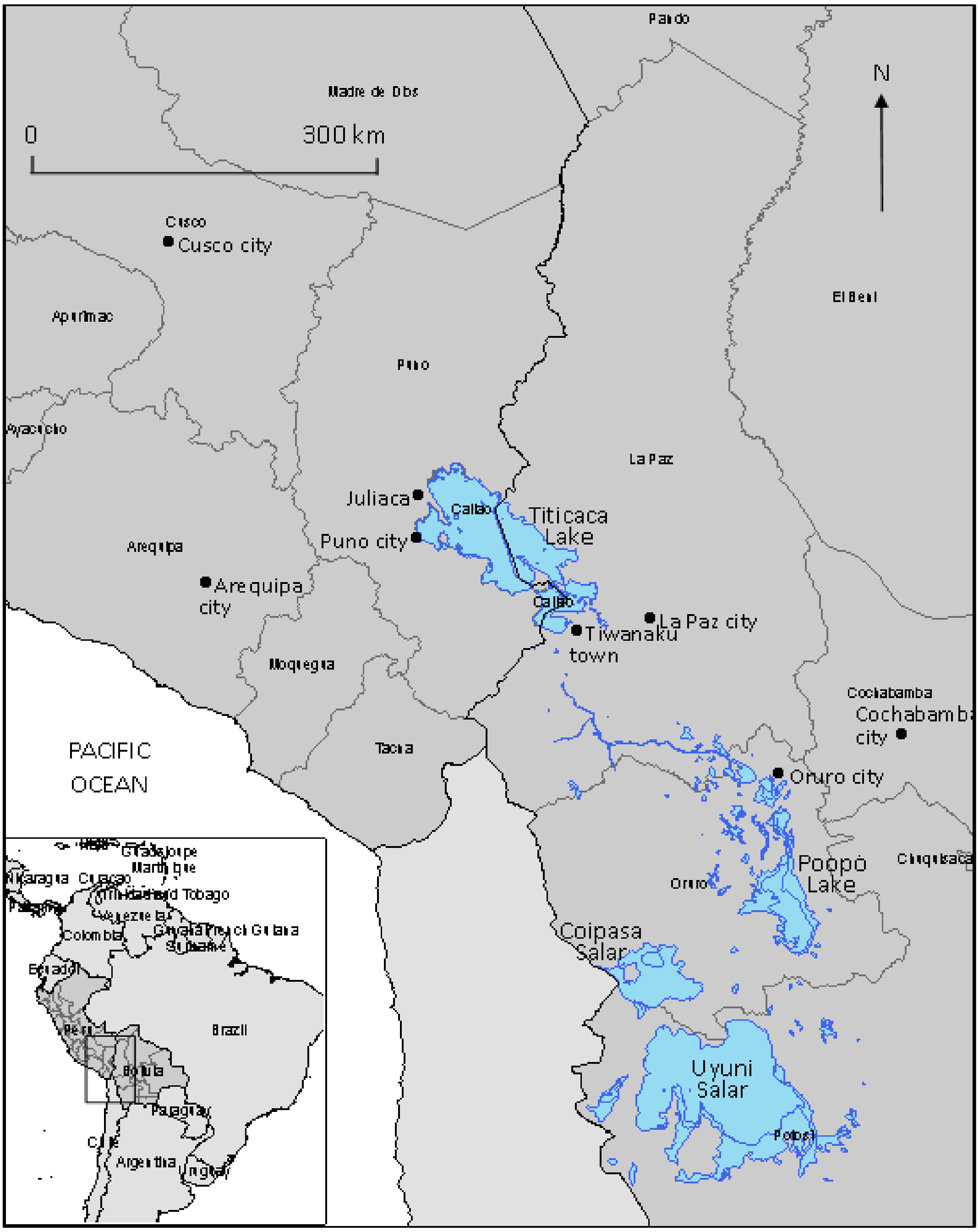
[207] Fish poisoning plants that contain saponin were used by prehistoric communities and would reduce the effort involved in catching fish in the Lake Titicaca basin (Francis *et al.*, 2001; Cannon *et al.*, 2004). The technique of washing the quinua grains to obtain a soapy liquid that leaked into the ponds facilitated fishing and produced a more palatable grain. While this use of quinua is complementary to satisfying food demand, other of the uses are not: Indigenous Andean communities burned the quinua straw to prepare *Llucta,* a bread that is cooked in the hot ash which activates the alkaloids in the traditional chewing of coca (*Erythroxylum coca*) (Winkel *et al.*, 2015 p. 371; Cobo and Jiménez de la Espada, [1653] 1890 p. 351). The small bread is chewed together with the coca leaves. It was used also to make a fermented beverage, drunk at various festivities.

[208] Aymara Republic includes territory belonging to Peru, Bolivia, Chile (Tarapacá region) and Argentina. The *suni* (plateau) extends from Peruvian territory in the north, along the west side of Bolivia, including the Poopó lake, Uyuni Salar and Coipasa Salar

Diversification of crop production is a social practice that shaped quinua as a subsistence crop for daily consumption and also, as a crop used for special occasions. Diversification concerned farm level practices, involving the farmer choosing what to cultivate, and efforts at the level of the *ayllu* and the territories.

MAP 3. LAKE TITICACA BASIN IN PERUVIAN AND BOLIVIAN TERRITORY



Among several social practices related to the emergence of agriculture,[209] diversification is relevant in the case of quinua in the Lake Titicaca basin. Diversification at the level of farmer involved producing several staple species, including quinua, together with crops to feed his camelids. Several quinua varieties also adjusted to the existing microenvironments. According to Netting (1993 pp. 28-9), these species and varieties were interplanted, rotated with grasses and scheduled according to the environmental and seasonal conditions. So the *ayllu* produced a large set of crops and varieties, which were accompanied by the skills and routines to define, reproduce, cultivate and consume quinua. At the regional level, diversification allowed production of several species for subsistence, including those that could withstand the conditions in the high, dry and cold mountains (i.e., *suni* and dry *puna*). In the case of the quinua species, the indigenous practice of diversification shaped hundreds of varieties adapted to conditions in the Andean territory.

The decision to cultivate quinua in a diversified manner entailed a rearrangement of people's skills and routines as hunters and gatherers. This likely met with some resistance since it affected the individual effort and pay-off. In principle, indigenous people maintained the skills to address their immediate needs (Johnson and Earle, 2000). Thus, once the first agricultural practices were implemented, crop selection allowed the farmers to apply their skills to crops and in a range of environmental conditions.

Various factors combined to persuade indigenous people to produce more than was required for daily consumption. These included environmental stresses, depletion of resources and frictions among groups, which entailed adjustments to the political arrangements (Sahlins, 1974 pp. 98-99; Chayanov *et al.*, 1987; Johnson and Earle, 2000 pp. 22-23). Producing surpluses was the solution to all these issues. Production of surpluses usually has social justification. Archaeological evidence suggests that, in the Lake Titicaca basin, surpluses were produced for consumption at harvests time and on special social occasions such as rituals, funerals and communal feasts. Accumulation of

[209] Boserup (1965) considers the problem of economic growth and sees food production and agricultural practices as a response to population growth, which led to intensification of food production. Her approach was criticised, but opened new research directions. One of these was pursued by Netting (1993), who proposed case studies to understand the practices of smallholder farmers. He considered the environmental conditions as influencing the set of practices that shaped the agriculture. He identifies five practices, including diversification, as relevant for explaining intensification of food crops production.

surplus food also allowed efforts to be diverted to construction work, and supported the political power of some groups. Political power allowed storage of food in dedicated spaces, for later redistribution to the community (Bruno, 2008 p. 494; Planella *et al.*, 2015 p. 44). The consumption of Q'usa, a fermented beverage obtained from the quinua grains, which was drunk during the festivities accompanying the harvest in May to July, was enabled by diversification of quinua.

Diversification at the level of individual farmers mitigated the pressure on him or her to produce more than the minimum required for daily life using new crops. The camelid herders' change to cultivation of new crops may have been unintentional since species can be introduced both naturally (e.g., by the wind) or as an unintended consequence of some other practice such as through soil or water disturbance or through an intentionally maintained or introduced species. For example, camelids ate seeds, which passes through them and were deposited in their dung in another location (Bruno, 2008 p. 24). However, stabilisation of the new crop entailed adjustments to individual skills and routines. To foster plant growth, farmers began to move and manipulate the soil, to regulate the water by increasing its supply (irrigation), improve drainage, and protect the plant from growth-inhibiting competition or predation by weeds, diseases, insects and other pests. Hence, stabilisation of the new crops involved additional costs linked to the skills applied to maintain and use these new plants.

Archaeological evidence suggests that the first quinua grain was a mix of small dark and white grains. Initially, both quinuas were used under the same conditions (Bruno, 2008 p. 22), but the dark quinua eventually was considered a weed. Plants considered likely to produce dark coloured grains were removed from the field. Also, quinua showed strong resistance to the tough environmental conditions of the highlands and after planting, required further care. It appears that the earliest farmers cultivated quinua on a small scale, in gardens or small plots (Bruno, 2008 p. 22). Also, in order to avoid the costs associated with moving soil or irrigating the plant, the indigenous Andean farmers adjusted their herding practices and planted quinua in places where grasses grew, which indicate the presence of moisture in the soil. They rotated the grazing of their animals in order to take advantage of the previous season's dung to nourish the plant. Thus, the efforts involved in diversifying from solely camelid herding to the introduction and stabilisation of quinua were likely very low.

At the regional level, indigenous people in the Lake Titicaca basin diversified their herding camelid practices for cultivating quinua. They also cultivated other species such as mashua (isañu in the Aymara territory, *Tropaeolum tuberosum*), oca (*Oxalis tuberosus*), ullucu or papa lisa (olluco in the Aymara territory, *Ullucus tuberosa*) and potatoes; and other grains such as cañihua (*Chenopodium pallidicaule)*.

At the level of species, thousands of quinua varieties became available with different seed sizes and colours (i.e., red, yellow, white), and different stalks and panicles. Each of those ecotypes adapted to the microenvironments along the *suni* of the Lake Titicaca basin in the Peruvian and Bolivian territory, and the dry *puna* and the salares in today's Argentinian, Bolivian and Chilean territories, the Bolivian yunga and Chiloe island in Chile at sea level and 42° South, and in the inter-Andean valleys of Colombia, Ecuador and Peru at 1° to 5° North (in Ecuador and Colombia).

The indigenous Andean herders also diversified the types of camelids they herded in the highlands. Three types were herded , the big llama (*Lama glama*) kept as a pack animal, a medium sized camelid bred for meat and alpaca (*Vicugna pacos*), kept for its fine wool (Bruno, 2008 p. 460). This wool was the raw material for fine-textured woollen blankets and for sacks for handling and processing the small quinua grain, which could be as small as 0.5 mm in diameter. Alpaca fibres were closely linked to quinua since other means of carrying and storing were unsatisfactory. All the three kinds of camelids were a source of dung, which fertilised the growing quinua, and the llamas could be used to transport dung to other areas. Once agricultural practices became stabilised at the end of the formative period (around 500 BC), and larger animals were available,[210] indigenous farmers maintained a rotation system for their land, based on their knowledge about the 'natural variation of water retention in soils', and planted their crops according to the different soil types (Bruno, 2008 p. 471).

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[210] Paleontological evidence suggests that in the Formative period, llamas increased in size by as much as 40% compared to earliers remains from the Archaic period. They also lived for longer, which allowed animals initially reared for meat and slaughtered early to became used for transporting cargo (see Bruno, 2008 p. 480-2).

Until the arrival of Spaniards, herding of camelids, gathering of plants and animals, fishing from the Lake Titicaca basin, and farming of quinua, potatoes and maize were the most important sources of food (Tapia, 2015). The crop rotation system involved the development of dozens of quinua varieties with variability of the colour of the grain, flowering time, grain size, plant size, duration of the crop cycle and saponin content. The saponin occurs on the surface of the quinua grain and must be removed prior to consumption. Its antinutritional properties and undesirable organoleptic qualities were relevant to the uses of each variety. Table 4 presents some attributes of the most frequently produced and consumed quinua types in Puno, a locality in the Lake Titicaca basin, grouped by colour, frost tolerance and principal and secondary uses. This information is complemented by information on vegetative cycles and saponin levels.

TABLE 4. TYPE OF QUINUA DERIVED FROM THEIR DIVERSIFICATION IN PUNO

Type of quinua (1)	Colour plant/grain	Frost tolerance (2)	Main / Secondary use (1)	Vegetative cycle	Saponin level
1. Jank'o o Yurac	White/White	Medium	Soups / Mashed quinua or pesque		Low
2. Chulpi o hialinas	White/transparent	Good	Consommé / Mashed quinua	Semi early (156 days)	Low
3.Witullas, Wariponcho	Red/Red, purple	High	kispiño / Flour, torrejas		High (3)
4. Koito Jaku Juiras	White or grey/grey, brown	Good	Torrejas / Flour		
5. Pasankallas	White or lead/lead, brown	High	Pop corn Maná / Flour	Long (170 days)	Low
6. Cuchi willa	Red/black	High	*Chicha* o ksuca / Kispiño	Long (172 days)	

Source: (1) (Canahua *et al.*, 2001), (2) (Quiroga *et al.*, 2015)

In colonial times, indigenous Andean communities diversified their crop production by introducing species from Europe that were suited to the environmental conditions (i.e., humidity, less frost). Grains, such as barley (*Hordeum vulgare*), oats (*Avena sativa*), and wheat (*Triticum sativum*), and legumes, such as faba bean (*Vicia faba*) and peas (*Pisum sativum*), were introduced and became part of the crop rotations and fallow routines. In addition, pigs, cows, sheep and goats were introduced (Bruno, 2008 pp. 160-1) (see Ch.5 Sub-sections 5.1.2 and 5.2.1).

Similarly, Andean crops were moved from America. The first attempt at movement of quinua to other parts of the world may have occurred as early as the 17th century when potatoes were introduced to Europe via Spain, and institutional arrangements allowed regular connection between the Bolivian and Peruvian highlands (see Ch. 5 Sub-section 5.1.2) and the Peruvian coast and, thence, to Europe. Lawson and Lawson (1836) report the introduction of quinua to England in 1822 with a sample of seed sent to the Botanical Gardens in Kew. The seeds were planted in a trial in subsequent years. Quinua was considered a grain comparable with rice, barley or wheat, and a vegetable that could replace spinach (Lawson and Lawson, 1836; Paillieux and Bois, 1884 pp. 839-841). In 1854, Simmonds (1854 p. 310) refers the red quinua, which could be used as a medicine, and the white quinua, which was a nutritious food, superior to rye, barley, rice, maize, plantain or potatoes, with scarcely any gluten content and suitable for making porridges and cakes. There are no reports of quinua's disappearance after its first introduction to Europe.

In America, maize, barley and wheat registered outstanding increases in production and yield compared to quinua and other grains; quinua production was reduced but it did not disappear from the Lake Titicaca basin. While maize did not adapt well to the *suni* and *puna* zones in the Lake Titicaca basin, barley and wheat were viable. So, indigenous Andean communities had to decide between producing quinua and other grains, such as barley, and why decide quinua if barley produced a larger yields?[211] One of the reasons why they persisted with quinua is its outstanding nutritional attributes. It has a high protein content (13%-17%) compared to other grains (Vega-Gálvez *et al.*, 2010). Also, 'the aminoacids are well balanced and comparable to those of soy protein, casein, and wheat. Lipids in quinua (sic) seed is about 6.9%, which is higher compared to other cereals. […] Most minerals in quinua seed (sic) have higher content compared to that in wheat, which is deficient in iron, copper, manganese, and zinc' (Wu, 2015). Despite the long history of quinua production in the Lake Titicaca basin, the outstanding nutritional attributes of quinua grain and its role as an important staple for several centuries, commentators refer to a substantial decrease in its production in the first half of the 20th century. While some

[211] In Bolivia, average yields from barley in 1961-2014 were 27% higher than from quinua. In Peru, although both crops produce high yields, barley was 29% higher than quinua (FAO, 2017).

relate the reduction to the massive imports of wheat (Tapia, 2015 p. 3), other are more interested in why it persisted. Vidal (1954) suggest that the diversification of crops highlighted quinua's advantage in the *suni* and dry *puna*: Some varieties are highly frost resistant and are a very low input and low labour crop. Wheat production in the Bolivian *puna* is dependent on nitrogen and phosphorus input, while quinua is suited to the alkaline soils. It is considered a 'nomad crop' since it can be planted and left until harvest (Pulgar Vidal, 1954 pp. 174-192).

In regions at lower altitudes, diversifications with other crops has reduced the quinua production area. This occurred in the inter-Andean valleys of Ecuador, Peru and Bolivia in the mid 20th century, while quinua as a crop disappeared in Cundinamarca, Colombia, between the 17th and 19th centuries and in Nariño in the 20th century when it was overtaken by maize and potatoes. Quinua was reduced to being planted around other crops as a defence against birds, fungi and insects based on its saponin content (Interview YJA (Woldemichael and Wink, 2001; Valoy *et al.*, 2015; Harder *et al.*, 2016)).

Since the 1960s, in the Puno region, Peru, quinua production has been complemented mainly by barley, which is the second most produced grain after maize at the national level. In Bolivia, quinua is grown only in the *suni* and dry *puna*, where wheat and barley were produced also in some zones. Maize is the most frequent grain in Bolivia. In both Bolivia and Peru, in the period 1961-65 to 2010-2014, maize production and maize yield have increased four-fold and two-fold respectively. In the case of quinua, Peru achieved a yield increase of 47% over the same period, while this was only 9% in Bolivia. In both countries, quinua production has increased since 1996 (FAO, 2017). Although the presence of saponin increases the costs of processing to render it edible, technological changes in wheat processing have contributed (see Sub-section 7.2.1).

In summary, Aymara and Quechua indigenous Andean farmers maintained a large variability of quinua to satisfy their family requirements (i.e., subsistence crop). Diversification of quinua and other crops and animals was a social practice that ensured surplus food production. The introduction of some plants and animals during colonial time and establishment of the early nation states reduced or wiped out the quinua production areas. Nevertheless, in the mid 20th century, quinua grain was an important staple for indigenous communities in the Lake Titicaca basin in the Peruvian and Bolivian territories. All attempts at commercial and sustained production of quinua on other continents before the 20th century failed.

7.1.2 What are the roles of voice and choice in the shaping and stabilising technology?

Aymara and Quechua speaking indigenous farmers from the *suni* and dry *puna* in the Lake Titicaca basin, along with other social groups, such as indigenous people with skills as researchers and mechanical engineers with experience in wheat and barley, shaped quinua as an innovation for the international market. This sub-section discusses the role of these actors in this process.

Although, in the 1950s, quinua production became minimal or disappeared in many Latin American regions where it had been cultivated for thousands of years, some Aymara and Quechua indigenous communities[212] continued to cultivate it in the Lake Titicaca basin (see Ch.5 Sub-section 5.3.1). Also, Aymara and Quechua speaking indigenous people with skills as researchers, raised their voices to rescue quinua rescue. The different meanings given by indigenous people with skills as researchers served as inputs to the shaping of the hundreds of quinua varieties available in the Lake Titicaca basin to achieve stabilisation into some 'new varieties' that were introduced in the international market as a high protein content grain. This sub-section describes how different actors, including indigenous people with skills as researchers, became aware of the hugely reduced cultivation of quinua in the first half of the 20th century. They tried to apply modern techniques that imitated traditional practices for selective breeding and to control the saponins in the quinua grain. This section also discusses the role of mechanical engineers in this process.

The Peruvian government had been aware of the reduction in the area of production of quinua since the first half of the 20th century, but it was not until the 1960s that the reduction stopped. In the 1950s, Pulgar Vidal (1954 p. 174) reported that although the Peruvian Government's regulation forcing hotels and restaurants to include

[212] Aymara indigenous people continue to inhabit the Peruvian, Bolivian and Chilean territories. The largest Aymara population is in the Bolivian territory, particularly the regions of La Paz, Oruro and Potosí the west side of the country. In Peru, the Aymara population is mostly concentrated in Puno region, in the northern side of the Lake Titicaca. Quechua indigenous are dispersed in the lower territories of both Peru and Bolivia.

quinua in their menus at least once a week and to introduce a percentage of quinua flour in their bread, there was insufficient quinua to meet their requirements. A second initiative was implemented by a group of scientists performing the skills and routines learned from Jorge León, who headed the Andean office of IICA in Peru (see Ch.6 Sub-section 6.1.2). This group of researchers from Bolivia and Peru, met in Puno, Peru, in 1968 at the *Universidad Nacional del Altiplano*, in the First Convention of Chenopodiaceaes, a meeting of researchers in quinua and cañihua (*Chenopodium pallidicaule*), from Bolivia and Peru (Weber, 1978). Their aim was to enhance agricultural development in the Andean regions based on 'neglected' species.

León arrived in Peru in 1962 to replicate the establishment and maintenance of plant collections and the eventual diffusion of the use of what were considered neglected species, in order to avoid their complete loss. The skills and routines related to the establishment and maintenance of plant collections were established for maize and wheat in the USA, where León had studied. Maize and wheat research became a reference for agricultural research on crops throughout the continent. León considered his objectives feasible given that agronomists, such as Oscar Blanco and Carlos Ochoa, were already collecting and maintaining maize and potatoes, the main staples in Peru at that time. Also, León promoted the collection (e.g., gene banks) and maintenance of neglected species by students through his teaching at the UNALM, in Lima. A group of agronomists, who had graduated from UNALM, became teachers in universities in the highlands (see Ch.5 Sub-section 5.2.2). They and students from these universities, under the supervision of Blanco and Ochoa, became the main collectors and holders of quinua collections. The students used their skills and routines as farmers in their own production regions (Interview IP).

Thus, the Chenopodiaceaes Convention was an opportunity to gather together those researchers and students, many of whom already knew about León's work, to work on quinua and cañihua. The convention became a translation space (Callon, 1986) (see Ch. 6 Sub-section 6.3.2) since it gave recognition and voice to the participants, and allowed them to discuss the problems of quinua production and mobilise the resources to resolve them.

Many chroniclers and commenters had referred to the advantages and relevance of quinua for the Andean economy (Humboldt, 1849; Safford, 1917; Cieza de León, [1553] 2012; Cobo and Jiménez de la Espada, [1653] 1890; Ruiz *et al.*, [1793] 1940), and had researched quinua (e.g., the Argentinian P. Mazzoco (Mazzoco, 1934), Bolivia's Walter Ceballos (Cevallos Tovar, 1934) and Martín Cárdenas (Cárdenas, 1944),[213] and Pulgar Vidal (Pulgar Vidal, 1954) from Peru). However, the Convention was important to the extent that reported quinua production reduction and brought the interest of organisations as IICA in Peru. Hence, the researchers used international cooperation to call attention to the relevance of quinua and cañihua and their potential for the local economy.[214]

The convention gathered researchers from both Bolivia and Peru with experience in quinua, Humberto Gandarillas, from the Bolivian Ministry of Agriculture, and representatives from *Universidad Técnica de Oruro*, and the Peruvians Jorge Rea, C. Blanco Tapia, Angel Mujica, Mario Tapia, and Luis Lescano, the last of whom worked at the IICA (Interview IP). Other participants included the heads of the gene banks in Bolivia and Peru. Four quinua gene banks were established; three in Peru - in Camacani, Puno, headed by Luis Lezcano, in Cuzco, headed by Oscar Blanco, in Ayacucho, led by Julio Valladolid, and one in Cochabamba, Bolivia, headed by Humberto Gandarillas. Those researchers that had been working with IICA had gained skills and routines for implementing collaborative projects between local research centres and universities, with funding from international cooperation organisations. Similarly, those in charge of the gene banks learned how to obtain additional varieties (from the farmers), and learned how to identify, duplicate them to ensure seed viability, and to deliver seed to other researchers abroad. This delivery of seed helped to mobilise new funding for field trials and breeding programmes locally and abroad.

[213] Martín Cárdenas was a well-known Bolivian botanist, who collected and characterised quinua among many other species. Cárdenas learned about the collection and characterisation of plants from the Swedish botanist, Erik Asplund, and later British plant geneticist, John Gregory (Jack) Hawkes. Cardenas worked closely with Humberto Gandarillas, who became an important quinua breeder (see Rodríguez Rodríguez, 2005).

[214] Interviewee IP recalls that the Chenopodiaceaes Convention was an initiative of the *Universidad Nacional del Altiplano* to celebrate the 300 years' anniversary of the foundation of Puno city. Initially, the city government was not in favour of the initiative and considered quinua production as antique. However, the interest of IICA, an international cooperation institution, chancged opinions and it then supported the initiative.

Researchers with skills in chemical evaluation took advantage of the availability of seeds to compare quinua with other staples, and to compare among varieties. Thus, researchers raised their voices regarding the potential of quinua for hunger reduction, given its high protein content (White *et al.*, 1955; Chiriboga and Velásquez, 1957; Quiros-Perez and Elvehjem, 1957; Bruin, 1964).[215] Those skills and routines enhanced the development of several collaborative projects in subsequent decades, while conventions of researchers, indigenous Andean farmers and representatives from governmental agencies, and international cooperation become relevant for gathering new actors.

In the Second International Chenopodiaceaes Convention, held in Potosí, Bolivia, in 1976, Bolivian Humberto Gandarillas presented the 'Sajama' variety, which researchers considered the first breed (i.e., new variety) obtained using modern breeding techniques (Gandarillas *et al.*, 2015 p. 346).[216] This variety solved the problem of the bitter taste in the large grain quinua (over 2mm) (Gandarillas Santa Cruz and Tapia, 1976 p. 105).He crossed large grain quinua with quinua with a low saponin content. Although several varieties had been obtained from cross breeding different seeds, Gandarillas produced Sajama, which had all the desired attributes and *stability* over time (Gandarillas Santa Cruz and Tapia, 1976).

While indigenous Andean farmers considered the bitterness as defending against birds' attacks on the crop and used the saponin as a degreaser, researchers considered the post-harvest practice of removing saponins as labour intensive making quinua costlier than other grain post-harvest practices. Hence, researchers, such as Humberto Gandarillas, who had agency to shape the quinua based on skills as a breeder, prioritised the breeding of large grain quinua, which was what the local quinua dealers wanted, and crossing it with varieties with low saponin content. Sajama is a large grain, sweet grain

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[215] Discussions on nutrition and hunger reduction began at the end of the 19th century with the development of technologies that allowed identification and measurement of plant compounds and their relationship to nutrition. Some consider this nutritionalisation as being part of the agro-food system crisis (see Dixon, 2009).

[216] Indigenous communities maintained breeding practices based on movement of seeds through different zones (i.e., altitudinal vegetation zones, longitudes and altitudes).

And years later was adapted in field trials in Puno, by the Aymara speaking researcher Vidal Apaza,[217] and became established in that region (Interview BK).

Another solution of the bitter taste of quinua caused by saponin, was provided by a group of mechanical engineers, who devised a mechanised technique that imitated the scarification practiced by indigenous farmers for post-harvest. Indigenous farmers combined the post-harvest practices of toasting, crushing/grinding of the grains with stones or sand, and then washing and drying these grains. The, mechanical engineers focussed on the crushing/grinding and introduced machines used for other grains such as barley and wheat. However, the mechanical processing depended on a understanding of the non-mechanical variables such as the desirable saponin content for human consumption, which was controversial (Jancurová *et al.*, 2009 pp. 75-6).[218]

Three different meanings (i.e., of indigenous Andean farmers, mechanical engineers and researchers) can be identified in relation to the same attribute (i.e., saponin content) were based on the learning processes of actors who used the species. Gandarillas learned from his contact with indigenous communities in his native Cochabamba, from his training as an agronomist in a Bolivian university, and from Martín Cardenas. Based on Vavilov's findings (see Ch. 5 Sub-section 5.1.1), Gandarillas realised that the large variability of quinua was related to the breeding processes conducted by indigenous communities for thousands of years. His knowledge about scientific breeding techniques related to wheat and maize, common at that time across all Latin America, allowed him to imitate the mass selection performed by indigenous Andean farmers for thousands of years and combine it with statistical techniques to identify varieties with the desired attributes. A description of the meaning given by mechanical engineers is provided in section 7.2.

[217] Apaza, graduated in 1990 from a wheat training breeding programme in CIMMYT, Mexico, and took up research on quinua. Most wheat was imported, so the wheat breeding programme was considered less important by INIA and by the government. Apaza had to choose between breeding quinua or kañiwa. His decision was based on the size of the quinua flower, which although tiny, was bigger than the kiwicha flower which made its breeding more complex (Interview BK).

[218] The maximum saponin content for quinua allowed by the best desaponification technique was defined by bitterness. It was defined using a single quinua ecotype (i.e., quinua Real), although each quinua variety has a different saponin content and, also, the assessment was based on a particular measurement method (see Zavaleta Mercado *et al.*, 1982).

Actors meanings are translated into skills and routines. In the case of Gandarillas, his expertise was as an agronomist and his skills in cross breeding were accumulated in cooperation with Martín Cárdenas. Earlier writers had the skills for giving meaning to quinua, but not the agency to shape it. Although several shaping paths were feasible, its eventual shaping was the result of the meaning given to quinua (a grain with high protein content) and the agency (i.e., skills and routines) for shaping the quinua. In the next section, we address the question of how organisations and institutional arrangements framed the actors' meanings and agency.

7.2 Trade, languages and international research cooperation in the quinua innovation process

Indigenous Andean farmers, researchers, mechanical engineers and dealers cooperated in the attempt to appropriate benefits from the goods that emerged from the use of quinua. Institutional arrangements facilitated the creation or transition of different forms of organisations in which actors cooperated to address their individual needs.

After independence from Spain, many countries in Latin America passed from feudal regimes, where landlords had control over haciendas and mines, and inherited right to the indigenous communities' labour, to a freer movement of people and land (see Ch. 5 Section 5.2.1). Events during the 19th century, such as the trend towards unionisation in Europe and the USA, and indigenous movements claiming rights to the land or recognition of their language as the official one, supported this transition.

Although its triggers differed, agrarian reform spread across all the countries of Latin America. In Bolivia, it happened in 1952 during the first government of Ángel Victor Paz Estenssoro, and meant that indigenous people received the status of 'comuneros' with rights to sharing the land of the former haciendas, and participating in the country's social and political life (Richard, 1961). In the case of Peru, it happen in 1969 during the government of Juan Velasco Alvarado, and Tonet considers the alphabetisation in Spanish of indigenous communities of the 1940s and 1950s as the trigger for demonstrations demanding Agrarian reform(Tonet, 2015). This section explores the role of institutional arrangements and organisations in shaping quinua, from its near disappearance in the 1960s to becoming an internationally commercialised crop since the mid 1980s.

This section considers the organisational goals within which actors cooperated. Indigenous Andean farmers, researchers, mechanical engineers and dealers are multidimensional to the extent that they can participate in different organisations and operate under different institutional arrangements.

7.2.1 How do institutions and organisations affect the shaping and standardisation of quinua?

Several actors were involved in the shaping of quinua to avoid its near disappearance and to achieve its international commercialisation. In 1961, Bolivia and Peru produced 9,200 and 750 metric tonnes respectively of quinua grain, the lowest production in the period 1960 to 2010; in 2014 the figure for Bolivia was of 74,400 metric tonnes and for Peru it was a record 114,700 metric tonnes (FAO, 2017).[219] That same year, Bolivia exported 29,700 metric tonnes (IBCE, 2015a) and Peru exported 36,700 metric tonnes (Peru, 2016). This sub-section explores the role of institutions and organisations in the shaping and standardisation of quinua to achieve commercialisation in the international market.

In the 1960s, researchers, such as León, considered quinua as one of the group of neglected crops, that could be the solution to hunger in their places of origin and worldwide (León, 1964b). Other researches recognised that quinua grain had limitations because of its saponin content, despite its high nutritional value compared to other grains that are dispersed worldwide such as wheat and rice (White *et al.*, 1955; Ruales and Nair, 1993). Although other grains used threshing or scarification processes (always after winnowing and, typically, to remove the germ and prepare the grain for other processes), the saponin was not in the form of a husk, but was a cover attached to the pericarp, the outer shell of the seed.

Despite the meanings given by León and other botanists and chemicals researchers, these actors did not have the same agency to act on the shaping of the technology as did

[219] In 2014, Ecuador produced 3,700 metric tonnes of quinua (see FAO, 2017).

the indigenous Andean farmers, who produced and consumed quinua, and the breeders, agronomists and mechanical engineers who designed machines for scarifying the quinua. Those actors with agency made choices during the shaping of the species in an institutional context and pursued organisational goals and addressed individual needs.

Traditionally, indigenous Andean farmers, who cultivated quinua on their land, considered quinua to be a crop for self-consumption.[220] Again, traditionally, quinua grain was de-saponified using in-house techniques that varied from region to region and variety to variety, and were applied just before it was cooked. In the 1950s, a small amount of quinua grain was commercialised in local markets, or 'catos' and re-sold in larger cities in indigenous territories or in cities with indigenous migrants and mestizos. The use of quinua grain by indigenous migrants in cities involved adjustment to the skills and routines, of both researchers and dealers, who participated in the shaping and standardisation of de-saponified quinua grain.

For example, in Peru, quinua grain began to be commercialised when indigenous people migrated to cities and demanded crops, such as quinua, potatoes, barley, or oca. Other indigenous migrants got involved in commercialisation as dealers, linking production in the Puno region with areas of consumption in Puno city, Cuzco and Arequipa.[221] Quinua was bartered in 'catos' for clothing, meat, candles, bread, spirits and other commodities by indigenous people with skills as dealers (the first intermediary or *rescatista*, like rescuer). Then, a second intermediary (the *acopiador*, or gatherer) bought the quinua grain (for money) from the first intermediary and gradually increased the amounts acquired by visiting several local markets. The *rescatista* bartered quinua grain along with other local products. The money the *rescatista* received from the *acopiador* allowed the former to buy large amounts of products for bartering purposes in the *cato*.

Rescatistas and *acopiadores* exchanged quinua grain of different colours with different levels of saponins (Interview LA). The *rescatista* obtained a higher price from selling de-saponified quinua grain. The *rescatistas* collaborated with the indigenous people, who provide the service of washing the quinua grain in large amounts, the most

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[220] The agrarian reforms occurred in the 1950s in Bolivia and 1960s in Peru and triggered the indigenous farmers' decisions to cultivate quinua and other staples, as in the case of maca (see Ch.6 Sub-section 6.2.1).
[221] A description of the present quinua trading network in Bolivia is provided in Ofstehage (2010).

common system of de-saponification. The washing service replicated the skills of indigenous communities on a large scale although it remained a manual rather than a mechanical process. The washed quinua grain was sun dried (wet quinua grain can germinate within 24 hours after washing, or be attacked by fungus if the moisture content is higher than 20%).

In the 1950s, some indigenous people with skills as dealers installed small mills in Cuzco to imitate traditional indigenous skills for scarifying quinua grain; they adapted wheat mills and obtained pearled quinua, flour quinua and a quinua bran with saponins suitable for animal feed, washing clothes or making beer (Repo-Carrasco *et al.*, 2007 p. 273). In the 1960s, the Cuzquenian company, Incasur, commercialised pearled quinua in the city's central market where the main buyers were Cuzco citizens (Interview LA). Incasur implemented large washing and drying routines because the costs of doing this by hand and drying it on a small scale were very high.

The mechanisation of quinua grain processing was one of the items discussed by the participants in the international Chenopodiaceaes Convention. The second International Chenopodiaceaes Convention, held in Potosí, Bolivia, in 1976, addressed mechanisation with presentations from Ferrari Ghezzi y Cia and of an agro-industrial project (Tapia *et al.*, 1976). The convention and later following conferences were the mechanism to update the state of the art and to promote collaborative projects. For example, the Ferrari Ghezzi y Cia project in Oruro city, Bolivia (Ferrari Quevedo, 1976 In; Tapia *et al.*, 1976), reported on the washing/drying technique and was followed by others projects in Torres and Minaya (1980) in Juliaca, Puno, in Peru, and Valdivieso and Rivadeneira (1992; 1994) in Quito, Ecuador. Although each of those experiences was developed within different institutional contexts, their background was reports from the conventions and participation in collaborative projects proposed during the conventions.

Below, we describe the three projects related to washing/drying techniques and their commonalities.

In the case of Ferrari Ghezzi y Cia, in 1973, the company designed new process of pasta making that included scarifying and milling quinua grain machines and adapted scarifying machines used for wheat, to allow them to replace wheat flour by quinua flour to produce pasta. After the first commercial plant was established, the Bolivian government issued Supreme Decree 12187 dated 17 January, 1975, which mandated that all flour milling companies should be producing improved wheat flour with, at least, a 5% quinua flour content (Bolivia, 1975; Ferrari Quevedo, 1976). Although the percentage of quinua flour content was relevant since it defined the costs, the challenge of Ferrari Ghezzi & Cia in the implementation of the new process was to ensure a low level of saponin. The company implemented a dry phase, based on brushing the grain, removing 80%-90% of the saponin (Ferrari Quevedo, 1976). After the fourth pass through the Ferrari Ghezzi & Cia machines the saponin content was still of 0.74%, which implied that it was necessary to remove the rest by washing/drying processing. A saponin content of 0.74% was higher than Zabaleta considered acceptable for human consumption (i.e., between 0.06 to 0.12%) (Zavaleta Mercado *et al.*, 1982).[222]

Torres and Minaya, mechanical engineers hired to support companies in Juliaca, Puno, designed a machine with funding from the Venezuelan Fund Simon Bolivar, managed by IICA for the Peruvian Ministry of Agriculture and executed throughout the Agro-Industrial Research Institute (IIA for its Spanish name Instituto de Investigaciones Agroindustriales). The mechanical engineers adapted a wheat scarifier for use with quinua, from which it obtained a saponin content of 0.04%-0.25%, depending on the quinua variety or ecotype processed, and, as a reference, used the Sajama variety saponin content (0.08%) (Torres and Minaya, 1980 p. 24). They considered it important to avoid reducing the protein and fat content, and the losses of grain due to breakage caused by excessive friction. Later, Zavaleta (1992) compared the two machines available in relation to the protein and saponin content and he concludes that: (i) the scarification involved excessive leakage of grain quinua sprouts, which reduced the protein content, especially in the Sajama variety, but less so the Real Boliviana variety (Zavaleta Mercado *et al.*, 1982 p. 148); and (ii) neither, the Ferrari Ghezzi & Cia nor the Torres and Minaya machines resulted in sufficiently low saponin contents for human consumption – both needed and additional washing process (Zavaleta Mercado *et al.*, 1982; Bacigalupo and Tapia, 2000).

[222] The meaning given by Ferrari Ghezzi & Cia to quinua as a raw material for producing flour was later abandoned since the Supreme Decree still allowed imports of wheat flour at subsidised prices (Bacigalupo and Tapia, 2000). Thus, it was more profitable for the company to purchase wheat flour than to buy quinua grain, which required scarification and grinding.

The Torres and Minaya machine was placed for offering the service in Juliaca, Puno, by the Peruvian Ministry of Agriculture to those companies or *rescatistas* interested in de-saponifiying quinua grain. The machine was replicated by a steel workshop set up to design machines tailored to individual companies, and the rescatistas organised themselves to offer the service and to commercialise de saponified quinua grain (Interview GA).

Valdivieso and Rivadeneira during their mechanical engineering training at the *Universidad Escuela Politécnica Nacional*, in Quito, built the machine with funding from a scholarship from the Canadian cooperation agency IDRC, through a project with the Ecuadorian National Institute of Agro-Livestock Research, (INIAP for its Spanish name *Instituto Nacional Autónomo de Investigaciones Agropecuarias*). The project was to install and operate a pilot plant for the production, gathering, processing and commercialisation of quinua, and other grains for the indigenous communities of Guamote, Chimborazo, Ecuador (Nieto and Vimos, 1994 p. 136). Although the machine reduced the saponin content of the quinua grain to 0.026% and a reduction in broken grains of 1.5%, which was considered very positive, the mechanical de-saponification and the pilot plant generally were affected by several problems. For instance: (i) the indigenous communities did not crop quinua commercially, so cropping had to be increased before the pilot plant could become operational; and (ii) there was no organisational arrangement in place for collecting quinua grain (Nieto and Vimos, 1994 pp. 242-6).

The three initiatives were reported on at different conventions. The learning from these projects were input for researchers and producers to became involved in further projects as representatives of the Bolivian and Peruvian governments, the IICA, and the IDRC, as partners together with representatives from other cooperation agencies as the USAID, the Rockefeller Foundation, the Danish International Development Agency (DANIDA), IBPGR, and the United Nations International Fund for Agricultural Development (FIDA). So, in the following years new projects were funded that compared and assessed quinua production and promoted quinua grain commercialisation, and enhanced the machines for the de-saponification of quinua grain.

The active mobilisation of resources and actors in which the group of participants in the first Chenopodeaceaes conventions, still has echoes. Some of the participants at the first convention (i.e., researchers or producers) are actually (2014) researchers involved in collaborative projects with several countries around the world (Interview IB), who continue to work on promoting quinua. Some of these individuals participated in the International Quinoa Conference, held in December, 2016 at Zayed University, Dubai, United Arab Emirates, organized by the International Center for Biosaline Agriculture (ICBA) in collaboration with the Ministry of Climate Change and Environment of the United Arab Emirates, Zayed University, the Islamic Development Bank (IsDB), the Arab Bank for Economic Development in Africa (BADEA) and FAO (IQC *et al.*, 2016). The 2016 conference was international and focussed on agronomic issues,[223] although the industrial stages were referred to, especially by the Chinese. Once there is sufficient surplus to commercialise, industrial production becomes interesting.

In the case of Peru and Bolivia it took two decades after the first Chenopodeaceaes Convention. Both countries now mostly use combined hulling and washing/drying techniques. The machines also hull the grain, which removes around 95% of the saponin and the washing stage reduces it to marginal levels. This is followed by centrifuging and drying of the quinua (Quiroga *et al.*, 2015 p. 219).

Desaponification is a requirement for commercialising quinua. Andean Technical Norms were agreed by the Andean Normalisation Committees, where the Ecuadorian Service of Normalisation (INEN for its Spanish name *Servicio Nacional de Normalizacion*), the Peruvian National Institute of Competence Defense and Protection of Intellectual Property (INDECOPI, for its Spanish name *Instituto Nacional de Defensa de la Competencia y de la Protección de la Propiedad Intelectual*), the Colombian Institute of Technical Standards and Certification (ICONTEC for its Spanish name *Instituto Colombiano de Normas Técnicas y Certificación*) and the Bolivian Institute of Normalisation and Quality (IBNORCA for its Spanish name *Instituto Boliviano de Normalización y Calidad*) participated. (Soto and Gutierrez, 2010). Those institutions took account of the voices of researchers, farmers and industries in their consultation on, preparation of and approval

[223] The conference included representatives from Peru and Bolivia where production was consolidated, but also Argentina, Chile, United Arab Emirates, India, Germany, the USA, Turkey, Burkina Faso, Algeria, Sudan, Pakistan, Uruguay, Tajikistan, Iran, Azerbaijan, Uzbekistan, Niger, Ethiopia, Kenya, Uganda, Zambia, Buthan, Germany, Lebanno, Morroco, Malawi and China, all of which are involved in research on quinua (IQC *et al.*, 2016). China has 7,300 hectares devoted to quinua, mainly in the provinces of Shanxi, Gansu and Qinghai. The main variety grown is Longli-1 (Ren, 2016).

of the technical norms in each country. The norms define what is considered quinua grain and the classification and requirements for its commercialisation. Along with the maximum humidity, protein, ash, fat, fibre and carbohydrate levels, they defined a saponin content of a maximum of 120 milligrams in each 100 grams of quinua grain (Soto *et al.*, 2010).[224]

Mechanical engineers and indigenous people with skills as researchers and dealers, performed their skills and organisational routines in the shaping and standardisation of quinua. Together with breeders of sweet quinua (i.e., with low saponin content), the mechanical engineers shaped quinua as a nutritious grain with more options for commercialisation in the international market. Those researchers cooperated in international conventions and conferences to update the state of the art, promote diffusion of quinua use and establish contacts for further collaborative projects. However, whether these activities were conducted on a sufficient scale to ensure innovation remains questionable. Other species were considered at these international conventions and conferences (cañihua was the second Chenopodiaceae that was considered at the first international convention), and the Peruvian government was keen to promote other species which derived-products had not been (perhaps yet) commercialised at the international level.[225]

The next sub-section considers language as an institution that affected the quinua shaping process.

[224] The Chinese National Standard Information Sharing Infrastructure (NSISI) published the first industry standard for quinua in China, which was approved by the State Administration of Quinoa (Ren, 2016).
[225] Interviewee KB recalled that, in the 1990s, during the Alan Garcia government, kiwicha production received attention from government. However, after a few years of heavy investment in promotion, subsidised production and research, the support programmes were discontinued. The organisations with collections did not receive more resources and the collections were lost. Interviewees LA and JA believe that government support does not ensure international demand, but rather provides incentives for people without the skills and routines in production needed to compete against the existing companies and, therefore, affects the free market and reduces existing companies' benefits.

7.2.2 What is the role of knowledge codification in the shaping of the technology?

This sub-section explains how language, codified or not, provides an institutional context, and a direction for the shaping process and increase the rate of standardisation of quinua. It is organised in line with quinua knowledge codification over the last 50 years.

Many Aymara and Quechua speaking indigenous communities began to have access to Spanish speaking education in the first half of the 20th century. Indigenous people, who learned skills apart from those as farmers, maintained use of quinua, but gave new meaning based on their own new skills. Some of those indigenous people learned to commercialise quinua grain, others learned to transform it industrially, and yet others conducted research on quinua. Language as an institution played a role in the codification of the underlying knowledge regarding the shaping of quinua. Quinua passed from being produced for self-consumption by indigenous communities, to being commercialised in *catos* and city markets around the Lake Titicaca basin and around the world.

Some of the skills of the Aymara and Quechua speaking indigenous communities employed in using quinua have persisted for hundreds of years. The underlying knowledge regarding how to define quinua, to reproduce it and to cook it passed from parents to children over the generations. Since neither Aymara nor Quechua were written languages, the expansion of Spanish education in the 20th century increased the chances of codification of the underlying knowledge.

Spanish was the official language in Peru and Bolivia during colonial times, meaning that access to education before the 20th century privileged Spanish descendants (i.e., mestizos and criollos), migrants identified as landlords of haciendas and mines, and government officials (see Ch. 5 Sub-section 5.2.2). The Catholic Church maintained schools in cities and large towns and some universities in the main cities, in which Spanish was the teaching language. Indigenous Andean communities in rural areas, the majority of the population, were marginalised from the education system until the first half of the 20th century, when the access to education in the Spanish language for indigenous Andean communities become a mechanism for accessing the rights that the state previously had denied to them. For example, ‘people who were educated in Spanish literacy forced the political elite to promote agrarian reform' (citing Oliart, 2011 p. 34; Tonet, 2015 p. 111). In the 2000s, 12% of Bolivian's population speaks only an 'original' indigenous language, and 48% are bilingual with an 'original' language and Spanish (López, 2005 p. 22).

Indigenous people with skills and routines for codifying knowledge in Spanish became scientists and researchers, and their previous skills as farmers facilitated and encouraged codification of the underlying knowledge related to quinua. More recently, this underlying knowledge has been codified in other languages (particularly English), along with knowledge on new ways of using quinua.

So, there were three tiers to the use of language in the process of shaping quinua. The first was when quinua was used exclusively by Aymara and Quechua speakers; the second tier involved the commercialisation of quinua grain among Spanish speakers, and the third was the inclusion of the English language.

First tier: Quechua and Aymara speakers' use

Quechua and Aymara speaking communities in Puno, Peru, and in La Paz, Oruro and Potosí, Bolivia, maintained the knowledge regarding the use of quinua for hundreds of years. Expectations about quinua use were stabilised by non-codified practices repeated by members of the community generation after generation.

The use of quinua involved knowledge on defining, cultivation, harvest and post-harvest practices along with the use of several other species. For example, decisions about which quinua variety to use and where and when to cultivate them, were based on knowledge about the weather conditions in the microenvironments around the Lake Titicaca basin. These decisions took account of the capability of the soil to retain moisture for the plant, saponin content, resistance to pests and diseases and culinary uses. Each indigenous Andean farmer had specific knowledge of the land and a set of seeds that ensured daily food needs, plus a surplus to cover special social occasions and other activities.

Harvesting of quinua was based on accumulated knowledge related to its cultivation, since harvesting times could vary widely.[226] The farmers cultivate more than

[226] Quinua's uses are not limited to the grains. See Section 7.1.

one variety of quinua. They had to judge the colour of the panicle for the reaping or cutting, and the weather conditions. Harvesting takes place when the quinua is sufficiently ripe ripe but not so dried out that the grains begin to be shed onto the soil. Harvesting of quinua like other gains needs dry weather. Before storing, the quinua plants is tied in sheaves or arcs to dry out further in order to ease threshing, winnowing and cleaning of the grain. Each community managed different forms of scarification based on the availability of stones, wood and water sources (Quiroga *et al.*, 2015).

Handling and storage required fine materials that prevented leakage of the tiny grains. These materials had been produced from alpaca since pre-colonial times. Indigenous Andean communities stored quinua for consumption during the rest of the year, with each variety of quinua grain (i.e., colour, saponin content) requiring specific culinary preparation. Culinary uses varied from region to region, based on the availability of complementary products and traditions.

Hence, the underlying knowledge in the use of quinua was contextual, and derived from knowledge of the variety used and factors, such as the weather at the time of planting and harvest, or the availability and mastery of tools suitable for harvest and post-harvest practices. The knowledge was passed down and, thus was restricted to community members. There are no instances of codification before the introduction of written Spanish[227].

Second tier: Spanish use

Spanish chroniclers of the region describe vast rural communities alongside small urban conglomerations around the political authorities in each region. The transition to urban areas was slow until the 1960s, when 53% of the Peruvian population and 73% of the Bolivian population were rural. Users of quinua in the urban areas included: Indigenous people who had learned research skills and routines and migrants who moved from rural areas to the towns.

One of the first research reports on quinua was by Martín Cárdenas, who was born in 1899, in Cochabamba, a Quechua speaking territory. Cárdenas attended a school

[227] The equivalent to the Quechua *kipu* is the Aymara *chinu*. However, further studies are required to learn about the underlying knowledge related with quinua if *chinus* or chants, or any other record or Aymara knowledge.

where he learned Spanish. He met the Swedish botanist, Eric Asplund, who visited Bolivia in 1920, to collect plants in the Lake Titicaca basin. Asplund recognised Cárdenas's interest in botany, taught him field work skills, introduced him to herbarium and library research, and presented him with the press he used when collecting plants. Cardenas's interest and the skills he acquired allowed him to be involved in expeditions led by the American, Henry Hurd Rusby, to the Amazonas Basin in the 1920s, and by the British J. G. Hawkes, an expert in potatoes and the American Hugh C. Cutler, an expert in maize, who led expeditions to the Lake Titicaca basin in the 1930s and 1940s (Rodríguez Rodríguez, 2005 pp. 66-9,97-8). Cárdenas taught botany and genetics in the *Universidad de San Simon*, in Cochabamba and influenced other Bolivian and Peruvian botanists such as Humberto Gandarillas and Jorge Rea.

Cárdenas initiated several collections, including one dedicated to quinua, and set up herbaria using skills learned from Asplund, which allowed him to propose characterisations of the different types of quinua in Bolivia (Cárdenas, 1944) and to introduce new techniques for characterising quinua and other plants based on counting their chromosomes. He was supported in this work by Hawkes (Cárdenas and Hawkes, 1948). Thus, two types of codification took place: First, when several types of quinua were collected, codification made it possible to compare their inflorescence (i.e., panicle shape) to define the variations, and to compare plant and seed colours to define their forms.[228] Cardenas was aware that this codification would allow him to solve an economic problem related to quinua: To select a white grain which was high yielding and had a low saponin content (Cárdenas, 1944 p. 4) (see Sub-section 7.1.2). Cardenas acted as a translator (Callon, 1986) (see Ch. 6 Sub-section 6.3.2) and he provided meaning to quinua (i.e., identifying an economic crop suitable for breeding for increased yield and low saponin content) and he mobilised the resources needed to answer that meaning (i.e., to solve the problem supported by codification). Cardenas's reports were written in Spanish.

[228] Cardenas proposed a preliminary quinua varieties classification based on two types of inflorescence (Cárdenas, 1944), or panicle shape: 'Three panicle shapes are common: (i)'amarantiform', when the glomerules are inserted directly in the secondary axes and have an elongated shape; (ii) 'glomerulate', when the glomerules are inserted in the glomerulate axes and are globose in shape; and (iii) 'intermediate', when the panicles express both amarantiform and glomerulate traits' (Rojas *et al.*, 2015 p. 65).

The second codification related to the number of chromosomes in a set of native Andean plants including quinua, potatoes, oca and olluco, among others, which had been taken from Bolivia to England by Cárdenas (Cárdenas and Hawkes, 1948; Rodríguez Rodríguez, 2005 p. 189).[229] Those techniques were unknown in Bolivia and constituted a further advance in quinua breeding, in projects that began to be implemented in the 1960s with the support of European and North American collaborative programmes. Experience with techniques and the availability of collections and well characterised varieties were the basis for further breeding projects funded by the collaborative programmes.

The codification of knowledge on the use of quinua in the first half of the 20th century was enabled by institutional arrangements that allowed access to Aymara and Quechua knowledge about the use of quinua. Chroniclers were supported by the Spanish Crown to travel the colonised territories and similar sponsorship enabled botanists from the new independent nation states to collect plants and animals. There are less than a dozen examples of codification like that performed by Cardenas in the first half of the 20th century, but this increased rapidly in the second half of the century in the form of undergraduate dissertations and postgraduate theses, scientific papers and articles on quinua from many Latin American countries. As explained in detail in sub-section 7.2.1, knowledge of quinua grain processing was enhanced by the scarification technologies reported in pieces written mainly in Spanish.

Use of the Spanish language by indigenous researchers allowed other forms of codification: In the 1990s the Peruvian company, Incasur, launched an advertising campaign based on a report from the National Aeronautics and Space Administration (NASA) (Schlick and Bubenheim, 1993), related to the inclusion of high content protein grains in its space missions. These included quinua and kiwicha (Interview LA). The advertisement was directed at children and suggested that eating quinua might help them to become astronauts.

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[229] Rodríguez Rodríguez (2005) refers to Cardenas's and Hawkes's study on quinua, potatoes, olluco and oca, which had been taken Cardenas from Bolivia to England during the WWII. He was supported by a British Council scholarship. The laboratory work was done by Dr. Koppel, a German researcher, who came to Cambridge as a refugee during the war. Cardenas and Hawkes wrote an article in Spanish (see Cárdenas and Hawkes, 1948 pp. 188-9).

Third tier: English speaking exchange

The experience of use of quinua grain by NASA coincided with reports published in the USA, Canada, and other European countries. In the 1980s, Stephen Gorad, founder of the Quinua Corporation, a USA company with an interest in health and nutrition, added quinua grain to his portfolio of macrobiotics, vegetarian and vegan food (Interview HA) (Bjork, 2011).[230]

The dealers and researchers interviewed considered that commercialisation of quinua grain in the last three decades to be more relevant in English-speaking countries, such as the USA and Canada, than in the production countries, where most quinua was produced for self-consumption by the indigenous Aymara and Quechua communities. Thus, in the last two decades of the 20th century, demand for quinua grain in Lima, the largest market for most agricultural products in Peru, was limited to chicks feed; it was described as *cholo* or *serrano* food (Interviews LA, PA, RA), pejorative terms suggesting that white people would consumer consuming it. Thus, quinua consumption in the USA, Canada, and some European countries, by vegetarians, vegans and people looking for alternative foods that would enhance health, was unexpected.

Consumption of quinua grain in the USA, Canada and other European countries was facilitated by codification of quinua knowledge. We have referred to two forms of codification in which Cárdenas was involved. Three general forms of codification can be identified to generalise the three tiers: One involves quinua as a grain for consumption, the second as a seed for producing plants and the third as a research tool. These three forms helped to characterise the level of codification in English language and help also to explain the role of codification in reducing the uncertainties involved in quinua use and stabilising consumer expectations, as the background to the introduction of goods derived from use of quinua.

As a grain for consumption, reports in English began in 1951 with the 'Report on milling, breadbaking, chemical and vitaminic studies of quinua and wheat grown in Peru'commissioned by the Bureau of Plant Industry (Fifield, 1951). In 1955, there was a

[230] Gorad's attempts to grow quinua commercially in Colorado, USA, during the last few decades have been unsuccessful, the company now imports quinua from Bolivia (see Ancient Harvest and Quinoa Corporation, 2016).

joint programme involving researchers from the Peruvian Ministry of Public Health, the Institute of Inter-American Affairs on behalf of USA Foreign Operations Administration, and the Department of Nutrition from the Harvard School of Public Health, in a comparison of the quinua nutrient content and protein quality between quinua, cañihua and milk (White *et al.*, 1955). The study highlighted the quality of quinua protein and opened a space for further studies, such as the that conducted by Quiros and Elvehjem from the University of Wisconsin, on the nutritive value of quinua grain protein compared to a formulation that included seven essential aminoacids, in rat diets (Quiros-Perez and Elvehjem, 1957). In 1964, Bruin, from the Chemical-Biological Laboratories of the Royal Tropical Institute in Amsterdam, Holland, provided a detailed study of the carbohydrates, proteins, minerals, vitamins and oils in three 'varieties' of quinua grain, and compared his findings with common cereals such as wheat, maize, oats and rice (Bruin, 1964).

This form of codification includes reports written in English on the scarification of quinua grain, which began in the 1980s, a few years after the first reports in Spanish. Ruales (1993) reviewed the first explicit references to saponin content in quinua and to scarification of quinua grain in the 1980s and beginning of the1990s (Ruales and Nair, 1993). Despite several patents issued since the 1960s, referring to saponin management in plants,[231] it was not until 2002 is that a patent was awarded that applies explicitly to quinua grain (Muir *et al.*, 1999 (2002)).

The scarification process (in which quinua grain is a research tool) had an important effect on the amount of protein (as a grain) and the presence of fungi, viruses and bacteria in the grain. Peñaloza *et al*. (1992) refer to this in their study of fermenting quinua with *Rhizopus oligosporus* Saito; they concludes that 'the hyphal infiltration was normally limited by the seed coat' (Penaloza *et al.*, 1992).[232] A more recent reference is to mechanical scarification as a determinant of increased productivity of quinua in Bolivia, which had an important effect on exports of quinua grain (Birbuet and Machicado, 2009).

[231] Patents include: Rothman and Wall (1957); Holt Thomas and Sabel (1960); Julian (1962); Jules and Pierre (1967).

[232] Although the scarification process is not discussed by Perañoza *et al.* (1992) in a study evaluating the tempe production inoculating quinua by *Rhizopus oligosporus* Saito, they to refer pH levels prior to inoculation as one of the determinants of spore germination and growth. They used a sweet quinua with a pH of 5.0, which showed a significant difference with another variety with pH of 6.5.

As a research tool, quinua was used to evaluate the presence of viruses and to understand heredity, providing the background to breeding techniques. Hollings and Stone (1965) at the Glasshouse Crops Research Institute, in Littlehampton, Sussex, used quinua as an indicator plant for carnation latent virus; Polák and Klir (1969) at the Central Research Institute for Plant Production in Prague in former Czechoslovakia, used quinua for the successful mechanical transmission of beet yellows virus; and Bos and Rubio-Huertos (1971), working at the Institute of Phytopathological Research in Wageningen, the Netherlands, used it to transmit the Passiflora latent virus. Martelli and Russo (1973) at the Istituto di Patologia vegetale in the Universita degli Studi in Bari, Italy, studied the infection of artichoke mottled crinkle virus in quinua. Simmonds (1965; 1971), working in the John Innes Institute in Hertford, England, collected quinua in Bolivia and studied its heredity, and Heiser and Nelson (1974), Department of Plant Sciences at Indiana University, obtained quinua hybrids to study the origin of cultivated chenopods. A high-quality chromosome-scale reference genome sequence for quinua has been published recently and is expected 'to facilitate the identification of the transcription factor likely to control the production of anti-nutritional triterpenoid saponins' (Jarvis *et al.*, 2017).

In the case of quinua as a seed 'Colin Leakey in 1980 introduced to Cambridge, England, materials from Chile, which adapted better than the Bolivian and Peruvian ecotypes. Leakey and Nick Galwey, also at Cambridge, carried out small scale evaluations in conjunction with John K. King and Sons Ltd of Coggeshall Essex. These resulted in processed UK-grown quinua appearing in the market in 1990' (Ridout et al., 1990). Galwey and the Peruvian Juan Rici evaluated 294 accessions that they had collected and brought to Cambridge in the 1980s, and published their results (Risi and Galwey, 1989b; a; Risi and Galwey, 1991). From Cambridge, quinua research spread to the Loire Valley in France, to Denmark, the Netherlands, Italy, Sweden, Poland, Czech Republic, Austria, Germany, Italy and Greece in European (1990s), to Brazil (1988), China (1988), Nepal (1988), India (1988), Bhutan (1998), Malasya (1998), Australia (1998), Denmark (2008), and Morocco (2008) (Bazile and Baudron, 2015). In the USA, similarly, quinua research extended after the first trials in Colorado, but also, attempts to produce quinua commercially.

Phenotype and genotype codification of quinua enhanced interest in it as a nutritional product with a high protein content, and increased enthusiasm for further research. The open exchange of seeds and plants allowed collaborative projects. The studies of heredity and plant pathology familiarised researchers in North America and Europe with quinua and, in this way, achieved outputs such as viable seed for further research and learning about its growth conditions (physiology). The researchers working on breeding and field trials had access to reliable reports on quinua in English. Those breeders and agronomist used their agency for cultivating and supplying quinua as 'an alternative source of high quality protein'. The breeders and agronomists were interested in the large variability of quinua and learning which would best fit to the environmental conditions in foreign places.

Codification of knowledge about quinua has become more complex and includes uses, comparative agronomic performance and phenotypic and genotypic information. It involves several languages other than the traditional Aymara and Quechua, the languages of indigenous users. Codification has been important for stabilising the meaning given to quinua and standardising the quinua grain commercialised. In general, institutions play a key role in the conditions surrounding actors' decisions about the shaping of the technology; these institutions affect the form of governance over the public and private goods that emerged from the shaped species.

7.3 Forms of goods governance and appropriation of benefits from goods from biodiversity

At the time that indigenous Andean farmers and researchers used quinua during the shaping process, public and private goods emerged. Some of those uses were innovation activities, which supported the introduction of goods into the market. The technological attributes of those goods and the institutional arrangements under which they emerged defined the form of governance over these public or private goods (see Sub-section 7.3.1). The technological attributes of those goods and the institutional arrangements under which actors and organisations operated defined how actors and organisations appropriated the benefits arising from these goods. This is analysed in Sub-section 7.3.2 which also describes the complementary means that constrained or enhanced the capabilities of actors (and organisations) to appropriate these benefits.

Although institutional arrangements, such as the Aymara and Quechua communal organisations and languages remained fairly stable, they were affected by the skills, organisational routines and technological change. Skills and routines allowed the actors to address their needs. However, actors can have involvement in several organisations and under complementary institutional arrangements. Thus, some indigenous people managed to address their individual needs with the pay-off obtained from cooperating within organisations different from the indigenous Andean communities.

Stabilisation of the meaning of quinua as a high protein content grain, and standardisation of scarified quinua, involved adjustments to the institutional arrangements and the creation and adaptation of organisations. Indigenous communities were empowered by the Agrarian Reform, which was facilitated by the use of Spanish as a *lingua franca*, which allowed Aymara, Quechua and Spanish speakers to communicate with each other and to cooperate. The migration of indigenous people to medium and large cities in Bolivia, Peru and other countries boosted demand for surplus of quinua and increased demand for food products that were considered to be health enhancers or substitutes (i.e., vegetarian and vegan demand); written Spanish and English facilitated the diffusion of the quinua underlying knowledge.

7.3.1 How were the public and private goods that emerged from the quinua shaping process, governed?

The governance of the goods emerging from the use of quinua are analysed in terms of: (i) the institutional arrangements under which actors and organisations exert their ownership, control or access; and (ii) the technological attributes that define how actors and organisations consumed these goods. The focus of the analysis is on the goods that emerged from the use of quinua and its associated knowledge. We described the forms of governance over four goods: (i) quinua grain for consumption; (ii) the set of quinua seeds; (iii) the codified and articulated (or not) knowledge on quinua; and (iv) quinua botanical collections.

Good (i): Quinua grains have been used in dozens of culinary preparations, which result in exhaustion of the grain, that is, it is consumed, which prevents others from consuming it. This applied to quinua grain used as food for self-consumption by indigenous communities. Indigenous farmers decided to commercialise their surpluses in the *catos* or city markets; once it was sold, the grain was not available for consumption by the indigenous Andean farmers. Indigenous Andean farmers began to produce and commercialise a large part of their production since the price they received for it allowed them to buy other products (Bellemare *et al.*, 2016; Cherfas, 2016). In all three cases the grain is governed as a private good, and the benefits to the farmer owning the grain are bounded by consumption of the grain or the income received for its sale.

Although indigenous communities used quinua grain as food, they also used it in many other forms to address their subsistence requirements. They had many other practices that complemented or addressed different needs (see Section 7.1). In all those cases, quinua grain was produced and accessed individually and was exhausted after its consumption; it was governed as a private good.

Good (ii): Quinua grain can be used as seed. The seeds or grain can be planted and is governed as a private good. However, their reproducibility allowed seeds to replicate quinua production and, thus, reduced its excludability and subtractability. Indigenous Andean farmers saved and maintained some seed instead of eating it. What was reproduced was the defining information (i.e., genotypical information), which gave identity to the quinua grain and passed from seed to plant and then to the grain.

Institutional arrangements based on trust and the kinship relations among members of the *ayllu* were related to traditional exchanges of seed, which stabilised some varieties and boosted the variability of many others. The exchange practices involved borrowing some seed that was then replaced after the harvest, plus some additional amount that compensate the favour (Interview AK, KB). The borrowers expected the lenders would return at least the same amount of seed after the harvest and, also, that they could, if necessary, borrow from their peers. The borrowed (or lent) seeds would be those available in the region, which were resistant to the weather conditions; so seed exchange was in the collective interest of disseminating seed with resilience, resulting in no catastrophic crop failures and yields not conspicuously inferior to the farmers' immediate neighbours, and suitable for the consumption (see Ch. 5 Section 5.1.1). Several varieties of seed fulfilled these requirements and the risks associated with different stresses (i.e., plagues and diseases, frost). Governance over the set of seeds in the *ayllu* territory was of a common-pool resource to the extent that mutual trust allowed common interest in viability and preferred technical attributes. The excludability property of the quinua grain was reduced thanks to its reproducibility as seed, and subtractability was defined by the exchange practice among ayllu members (see Ch. 5 Section 5.3.2).

In the last few years when large amounts of quinua began to be produced commercially, seed has been governed under a state-regulated private goods system (see Ch. 5 Section 5.1.1 and 5.3.2). The registration of quinua under the PBR system occurred in Denmark and Peru, and the Peruvian and Bolivian governments introduced and promoted protocols for the commercialisation of certified seeds reproduced from bred seeds provided by research organisations. These institutional arrangements displaced the traditional seed exchanges among indigenous community members.

Good (iii): The indigenous Andean communities' knowledge derived from controlling and replicating the cultivation of quinua in the Lake Titicaca basin for thousands of years, was governed until the 1950s, as a *local public good*. This knowledge was freely shared among the members of the community and included jargon and standards related to agricultural and post-harvest practices (i.e., type of soils and weather conditions, complementary factors for harvest and post-harvest practices), which explain the contextual character of this knowledge. For those who imitated use of quinua, cultivating it in other parts of the continent during the last few centuries, Lake Titicaca basin knowledge was not easily accessible, and each community developed its own 'language' to express standards related to the environmental conditions and traditions.

The name quinua is an example here. Although quinua is considered a Chibcha word, it is also owned by Runa-shini speakers to refer old food or *auquin*. The Chibchas from the Colombian territories also called it *suba* o *supha*, and the Runa-Chimi speakers used the name *llijccha*, a dialect Chinchaysuyo of the Runa-shimi language referred to *quiuna*, and the Collas called it *quinoa.* This las was adopted as the scientific name. The

Aymara called it *supha*, *jupha* or *hupa*, which are terms in use in only a few communities (Pulgar Vidal, 1954 pp. 1-6).

As mentioned in the case of maca, knowledge is contextual rather than absolute. Similar to the use by indigenous people of jargon and standards to which they refer without explanation, researchers maintained their own jargon and standards, which influenced access to knowledge by other actors.

In the last few years, the knowledge about quinua has increased. Its high protein content and freedom from gluten have been highlighted in relation to its commercialisation and recognised as positive for nutrition. Once Spanish and English became the *lingua franca* is related regions, the cost of knowledge codification was reduced. This allowed, several actors to be involved in the diffusion and decoding of this knowledge, which is governed as a *public good* in an international context. Under this form of governance, the costs of restricting actors from accessing the knowledge increase.

Good (iv): The quinua botanical collections are used mainly for research, but are also employed as instruments to diffuse the species as a commercial crop.[233] In principle, the available seed in a territory is governed as a *common-pool resource*, maintained by their holders who make them available for exchange among group members (i.e., the traditional exchange among ayllu members), under voluntarily agreed conditions. As mentioned before, this involves performance of individual skills to reproduce the seed to ensure its viability and availability.

During the 20th century, indigenous Andean communities cooperated with indigenous individuals with research skills, during the collection of quinua varieties. Quinua collection was consolidated in the 1970s and 1980s through funded collaborative research projects. Interviewees (AK, BE) stated that indigenous farmers did not ask for payment from researchers who collected varieties from their farms since they were of marginal value to the *ayllu* and, in many cases, the researchers had kinship linkages with the community, which facilitated their access to materials. These collections include varieties from different ecosystems, which allowed comparison of varieties and value

[233] In the USA the global collection of 'plant germplasm was initiated by the U.S. Patent Office as early as 1839' (Kloppenburg, 2004 p. 15); once they reproduced, the seeds were distributed throughout the country for sowing.

attributes, and enabled a ranking of outstanding attributes in terms of high yield or resistance to stresses.

The members of the *ayllu* did not expect to receive any seed in return because the small amounts of seed collected and the nature of the materials (i.e., leaves, roots) were inconsequential. Some researchers had access to seed from markets, purchased as grain. In the case of quinua, quinua bought as grain would not germinate[234] and also had no roots or leaves. In this case, seed collections were governed as private good under the control of the collectors.

In the 1970s and 1980s, researchers responsible for the collections in the USA, Europe, and even Peru received attention from international cooperation to the extent that they became 'guardians' of seed that climate change and certain agricultural practices might cause to become extint. The loss of biodiversity reported by Rachel Carson in her book, Silent Spring, contributed to give new meaning to the working collections of researchers[235] and those ex-situ collections across the world. Public resources were allocated for storing seed in gene banks: National agencies funded gene banks dedicated to maintaining and ensuring viability of seed. Some governments renewed their interest in maintaining species and preserving large biodiversity at the level of varieties. In the case of quinua, researchers in charge of the collections available in research institutions, such as INIA in Peru and Fundación PROINPA in Bolivia, added varieties from Chile, Argentina, Ecuador and Colombia. The Convention of Chenopodiaceae and Andean Crops promoted the interest and identified new actors. Maize and wheat were used as models and studies on protocol for storing in relation to humidity, temperature and other factors, were applied to quinua grain.

Indigenous people with skills as researchers cooperated in exchange of quinua seeds among Andean countries and participated in the collection of quinua varieties by foreign researchers. Seed exchanges operated under the institutional arrangements proper of the corresponding organisations. Indigenous people trained as researchers in Bolivian universities and research centres followed the pattern of American and

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[234] A common practice since 1980s in Peru and Bolivia is to commercialise quinua only after it had been scarified, washed and dried (see Sub-section 7.2.1), which compromised its viability.

[235] Breeders need different varieties for research. They generally focus on a small number of varieties, which are characterised in detail (Interview AG).

European universities where it was common practice until the 1960s to maintain breeding working collections for in house research and to save a portion of the harvest for distribution to researchers in other organisations. In principle, the limitation on distribution of seed to other researchers was the cost of transporting and delivering the seed. The collected seed was governed as a private good since researchers could agree (or not) to the access of other researchers to the seed and establish institutional arrangements for such access. Similarly, collected varieties that were, intentionally moved to Europe for use as seed or that maintained viability as an unintended consequence after collection (i.e., quinua seeds collected by university researchers for their taxonomical or chemical characterisation) were privately governed.

The trend for appropriating benefits from goods emerging from use of biodiversity depended on changes to the institutional arrangements (see Annex A). In 2012, Jack Kloppenburg, Professor Emeritus at the University of Wisconsin-Madison and 'plant breeders, farmers, seed companies, and sustainability advocates', launched the Open Source Seed Initiative (OSSI), which maintains quinua and another 50 types of crop seeds 'unencumbered from legal restrictions and free to be used, shared, saved, bred, and sold'. The initiative attempts to maintain fair and open access to plant genetic resources in order to balance the restrictions imposed by plant variety protection, licensing and patenting of living organisms (OSSI, 2016). In this case, these seeds are governed as a club good since there are no restrictions on sharing the seeds, such as PBR do, and providers define the conditions for seeds reproduction and commercialisation.

Goods arising from the process of shaping quinua have different forms of governance. The form of governance can change with the institutional arrangements. The next sub-section analyses how actors appropriated the benefits from the consumption of the goods that emerged from the quinua shaping process.

7.3.2 How do actors and organisations give meaning (value in use) to and appropriate benefits from biodiversity-based innovation?

The appropriation of benefits is based on the skills of actor and the pay-offs and rewards provided by each organisation to the actors for the performance of routines. This sub-section discusses how different actors appropriated benefits and analyses how those benefits were enhanced or constrained by complementary means.

The analysis focusses on the actors involved in the shaping process of the emerging goods. The expected benefits are the incentives that actors were offered during the shaping process. The analysis examines three particular actors and one organisation: (i) the indigenous Andean farmer - actor; (ii) the quinua grain dealers - actor; (iii) the quinua researchers – actor; and (iv) International Conventions and Conferences - organisation.

Actor (i) The indigenous Andean farmers. The benefits to the indigenous Andean people who produced quinua were derived from self-consumption of the grain and leaves. The benefit was derived from the value in use as a staple food that was affordable to produce and versatile in use. Also, the benefit derived by each member of the community from saving a portion of the harvested seed was that this covered the risks related to climate stress or other calamities.

Indigenous people, members of the *ayllus*, had the right to use the land to produce quinua. The adaptability of quinua to different environmental conditions allowed indigenous Andean farmers with land rights in Latin America to produce quinua and appropriate the benefits from the goods arising from its use. These land rights were complemented by relational means such as labour and technology for processing quinua.

In the last few decades, quinua grain has received meaning as an alternative to animal protein and as a supplier of aminoacids. It is a healthier food than meat. It has received meaning also as a gluten free product, which property is of considerable interest to celiacs. Those meanings allowed the increased commercialisation of quinua production. So, indigenous Andean people in the Lake Titicaca basin enhanced their benefits thanks to the broad scope of their knowledge.

Actor (ii) The quinua grain dealers. Standardisation of the mechanised desaponification process facilitated quinua's commercialisation in medium sized cities and for export. The mechanical desaponification was done by indigenous people who acted as intermediary dealers (i.e., *rescatistas* and *acopiador*). The desaponification of quinua by hand had implicit larger costs compared with other grains such as barley, where scarification was mechanised. The appropriation of benefits of quinua-derived products commercialisation was enhanced by mechanical desaponifiers that complemented the structural and relational means of the indigenous people with skills as dealers (see Sub-section 7.2.1).

Quinua grain passed from being a staple for self-consumption in the regions around the Lake Titicaca basin to being an important export product. In 2014, in Bolivia, quinua was the 9th most important exported product by value with US$117 million, while in Peru this figure was of US$197 million.

Actor (iii) The quinua researchers. Indigenous people with skills as researchers and experience in breeding techniques appropriated both morals and economic benefits from launch of breeds. At the beginning of the 1990s, indigenous researcher, Vidal Apaza, working for the Peruvian INIA, obtained the new variety 'Salcedo-INIA' by cross breeding the Sajama with local Puno varieties. Although Sajama was successfully cultivated in the La Paz region, in Puno, Peru, farmers stopped using it after a few seasons because of its susceptibility to mildew. Apaza's relations with researchers in charge of the collections facilitated access to quinua seeds. Apaza appropriated benefits by maintaining his research practices and introducing the Salcedo-INIA variety of quinua. In any case, Apaza's motivation was not to register the new variety under the PBR for being commercialised since INIA's policy does not have this option.

The researchers in the Andean countries continue to have the world's largest collections of quinua[236] and the benefits to those researchers in charge of these collection accrue in the form of access to funding, based on the arrangement of the NSI (i.e., collaborative projects where access to a large collection is rewarded by national or international funding).

In the last few years, the interest in quinua promoted by the FAO IYQ, has encouraged exchange of varieties and comparative studies. Researchers have found the IYQ important for promoting research in quinua (Interview BH, BF, IB). The exchange of varieties between Latin American collectors and breeders and their peers in North America and Europe, which began in the 1960s within collaborative projects, has allowed

[236] The USA Department of Agriculture, USDA (North Central Regional Plant Introduction Center at Ames, Iowa) has a medium size collection of 164 'accessions' in the USA (see Peterson and Murphy, 2015 p. 674).

the people responsible for the quinua collections to access financial resources for further collaboration. They provide seeds and advise on practices to grow varieties that might adapt to foreign environmental conditions. The plasticity of quinua allows it to adapt to several weather conditions enabling R&D activities.

The practice of researchers to anonymise varieties to avoid bias (i.e., the preference for a seed) or to facilitate the ordering (i.e., to provide a short name coherent with a particular classification) of these varieties, has allowed researchers and collectors control over their collections (i.e., governance as a private good - see Sub-section 7.3.1). Researchers in charge of collections can prioritise research problems and mobilise resources for project using materials from the collections. Relational means in the form of access to research networks and government authorities, enhance the appropriation of the benefits related to access to collections.

The anonymisation or re-naming of varieties is displacing indigenous names,[237] which is allowing new control over the quinua collections. The Quechua and Aymara names of varieties were displaced by the institutional arrangements. Humberto Gandarillas named the Sajama variety after a mountain near the city of La Paz. It was which was a combination of a Royal sweet variety, crossed with a variety from the La Paz region. Sajama later became known as Salcedo-INIA when it was bred by Vidal Apaza in field trials at the INIA research station, in Puno. Other bred varieties were given names related to INIA and the place they derived from, for example: INIA 431 Altiplano, INIA 427 Amarilla Sacaca, INIA 420 Negra Collana and Illpa INIA. When maize seed was bred in the USA, it was named in this way, and the method was adopted by other countries the. Anonymisation and renaming of varieties displaced the contribution made by indigenous communities to maintaining and breeding those varieties and adapting them to the different environments of the *ayllu* or community (Interview GA).

[237] Indigenous people with skills as researchers have followed the routines of university or research centre' providing reports about their R&D activities, but adapting their skills to the institutional arrangements. Different than in Europe, in which the reports began to be written mainly in English, in Bolivia and Peru those reports were done in Spanish, the official language in both countries. Neither Quechua nor Aymara reports have been included in the detailed compilations of literature available of quinua. Thus, at the international level, Quechua and Aymara references have been limited to few varieties named after the indigenous voice (e.g Collanta or Kollanta), culinary preparations (e.g., pesque) or tools, devices and other inputs related with the use of quinua.

The re-naming was justified by the organisations goals. In Peru, for example, if INIA researchers obtained a new variety, they needed to persuade farmers to change to using it instead of carry-on using ‘the same’ varieties that regularly farmers cultivated. The researchers followed the state protocols for ensuring the quality of the seed, which allowed them to reach a larger number of farmers. Once breeders at INIA had achieved several repetitions in which the stability of the attributes of the new variety was ensured, they grew the variety to obtain basic seed. This basic seed was sold to certified seed companies, which follow the routines for reproducing seeds under conditions that allow reproduction of large amounts of seed for commercialisation and homogeneity and identify of the seed. The seed companies sell the seed to the farmers. So, the seed company judges the quality of the seed and its chances to be preferred from other seeds in the region.

Scientific understanding of the role of insects, microorganism and viruses in the spread of diseases gave further value in use to the varieties collected by allowing researchers to recognise that seeds were vectors of diseases and had different tolerance of and resistance to them. Diseases free seeds were suitable for reproduction, and varieties tolerant or resistant to disease become inputs for further research and seed transboundary trade policies (e.g., free commercialisation of seeds with no reported diseases). Thus, scientific techniques that allowed researchers to check for the presence of diseases were a control mechanism. Finally, techniques such as hybridisation (i.e., homogenisation but with loss of vigour) and potential control obtained by property rights over the techniques for producing seeds, encouraged further research and patenting on quinua uses (Ward and Johnson, 1994). In this case, the appropriation of benefits was enhanced by rights-based and relational means typical of agrochemical corporations.

Organisation (iv) international conventions and conferences. Bilinguals (Aymara or Quechua indigenous language and Spanish) indigenous people with skills as researchers implemented routines for building research networks. These indigenous people participated in several collaborative projects funded by government agencies. They prioritised the research problems and searched for resources to solve these problems.

The benefits to those organisations were that they led to further conference with participation from new researchers. Those participants bore the costs and benefits of attending the conferences. These include the costs of submitting papers, and attending the conference. The paper presented provided information on the performance of projects and proceedings might be published (i.e., moral benefits).

Conventions and conferences provided participants with a mechanism to promote the diffusion of quinua as crop and find further opportunities to commercialise the product or to take part of collaborative projects (mainly government funded R&D projects) and international cooperation programmes. As in the case of maca, the movement of quinua enabled by collaborative projects extended the trials in quinua for bigger yields. Other benefits are associated with conservation of quinua diversity to avoid the risk of only a few varieties.

Indigenous people gained benefits from the export of quinua grain in their roles as farmers and dealers. Although the economic benefits were important, other rewards such as recognition for researchers and access to research funding were also important.

7.4 Summary

Quinua shows large variability as a staple plant in the Lake Titicaca basin, its region of origin and domestication. This variability is related to the thousands of varieties and different social practices of indigenous communities in Latin America. Despite efforts made in colonial and immediate post-colonial era to introduce quinua in other parts of the world, it is only recently that the meaning of quinua has reached a level of stability that has allowed quinua-derived products commercialisation around the world. Quinua grain is considered a staple with high protein content, suitable for replacing meat in diets, with high levels of aminoacids, trace elements and vitamins, and absence of gluten.

Quinua is an innovation that has reached the international market. The large variability achieved during hundreds of years of use (similar to potatoes and maize) ensured opportunities for its adaptation in other places. Before 1950, quinua use was not diffused around the world. However, since the 1980s, quinua grain has become an iconic export for Bolivia and Peru, and a reference in gourmet (i.e., vegetarian, vegan) markets in European countries, the USA and other developed countries.

Standardisation of quinua was achieved through the active roles of indigenous people who learned skills and followed routines as researchers and quinua dealers. These researchers imitated the skills of indigenous communities, particularly selection of varieties, and scarification and processing of quinua. The result is two main forms of standardisation: New varieties with large grains and low saponin content, and mechanised scarification of quinua.

Several goods emerged from the shaping process of quinua: (i) the quinua grain which is governed as a private good; (ii) the set of quinua seeds governed by indigenous communities as a local common-pool resource; (iii) codified and articulated (or not) knowledge of quinua governed as a local public good or a public good; and (iv) the quinua collections in universities and research centres, governed mostly as private goods when access to seed is costly and supply of seed is scarce.

Actors and organisations appropriated benefits from the goods that emerge from the use of biodiversity. They included the indigenous Andean farmers, who received economic benefit from the international commercialisation of quinua-derived products, and indigenous people with skills as researchers who acted as translators, prioritising relevant problems, such as saponin content in the grain, and mobilising resources via international cooperation to solve these problems.

8 Comparative Analysis and Policy Findings

This chapter summarize and discusses the findings from the three case studies of innovation of species from biodiversity. Diffusion of use of the species provided benefits for individual and groups. The innovation process was characterised in terms of the effects of actors' and organisations' voices and agency. The form of governance over the goods that emerged from use of the species defined the conditions for the appropriation of benefits. We discuss these aspects in order to address the thesis research questions. Sections 8.1 and 8.2 focus on the first research question: *How is biodiversity-based innovation shaped by the social practices of actors and organisations in an institutional context?* Section 8.3 address the second research question: *How do the forms of governance over public and private goods emerging from the shaping of biodiversity-based innovation affect the appropriation of benefits?* Each of these sections follow the structure of the sub-sections in the case study chapters.

8.1 The biodiversity-based innovation process

In chapter 4, the example of the Jersey cow was used to analyse to what extent the SCOT approach, employed by Bijker (1995) to analyse manufactured artefacts, could be used to examine the species from biodiversity. The SCOT approach was extended to incorporate additional elements to respond to critiques of the approach and to explain the unequal distribution of benefits arising from the use of biodiversity. The extended theoretical approach resulted in a more complete framework for analysing the shaping process of the three species, from the state of use and 'domestication', to a 'novel' state.[238] The approach assumes a variation-selection perspective (Nelson and Winter, 1982 p. 43).

This thesis research shows that, compared to manufactured artefacts (the original focus of SCOT studies), the species studied showed a level of resistance or obduracy to

[238] See introductory section in Ch. 4 for what this thesis considers to be innovation (i.e., the combination of an artefact from nature and its underlying knowledge), and how novelty is achieved in the context of biodiversity.

being shaped. This obduracy is related to the species' natural capability to reproduce genotypic information and retain phenotypic characteristics. Mutations, genetic drift, gene flow and natural selection introduce small degrees of variation to the reproductive process. Also, some actors exert forms of selection (i.e., mass selection or biotic stress resistance). Therefore, variation and selection occur through the breeding of the species that takes account of intent and constraints (i.e., cultivation/husbandry).

Clonal and sexual reproduction are the two general forms of reproduction that explain variation. In the case of the Jersey cow, this species was bred (by sexual reproduction) within many of the hundred cattle breeds from Europe. The political distance of Jersey from France, the levies imposed on imports of cattle from France and the social preference for 'pure breeds', provided the conditions for establishing the identity of the Jersey cow. Quinua produces sexually and achieved large variability over the last few thousand years following its domestication, based on its ability to reproduce with wild relative plants (see Ch. 7 Section 7.1). This allowed its emergence as a crop in various regions throughout America. In contrast, maca is a biannual plant with two separate, but complementary life cycles associated with the weather conditions of the wet *puna* where it originated and was domesticated (i.e., Junin and Pasco regions of Peru). Its domestication process is unclear; it may have involved wild relatives' species from the Brassicacea family. Also, given its continued 'uncontrolled' variability of colour, to what extent maca is completely domesticated is unclear. Compared to other artefacts, the socially constructed nature of living artefacts is highly context-specific. Technologies used for the (re)design of one species are not necessarily suited to other species; our knowledge is often limited to understanding the species, its possible expressions (i.e., the range of variability) and the social choices that bounded the development of capabilities to design some species and not others.

In each of the three case studies, the history of use began long before the shaping process discussed in this thesis, and actors gave meanings to the species based on their accumulated and retained knowledge. The capability of actors to shape the species is the result of a learning process that can involve other species. In the case of the Jersey cow (discussed in Section 5.1), this learning began in the Middle East, north Africa and Europe based on experience with other dairy producer species such as auroch, goat, mare, ass, camel and sheep (Diamond, 1997 p. 701; FAO *et al.*, 2015 p. 7). The actors in each region experienced their own learning processes; in Europe, a preference developed (with its associated meanings, routines and skills) for cows that provided either milk or meat. On the island of Jersey, farmers gave meaning to dairy cattle from which the Jersey breed derived. In the Andean region, the learning process involved the larger biological variability at the level of species and varieties from which actors learned and applied their skills. In the case of maca (Ch. 6 Section 6.1), the learning process involved potatoes, olluco, oca and mashua, and Andean camelids which feed naturally on maca. The meaning given to maca which encouraged its use despite it being a low yielding species compared with other species, was as a therapeutic plant. It allowed for humans to survive in the tough conditions of the wet *puna*. Chapter 7 Section 7.1 discusses that the learning process in the case of quinua involved wild relatives from the Chenopodiaceae family and species such as maize, kiwicha and cañihua, which gave its meaning as a versatile staple crop.

The point of departure of the shaping process on which this thesis focusses, occurred when the actors' performance of certain skills and routines allows actors to locally produce goods (mainly for self-consumption). At that point, the goods were rarely commercialised. A several decades long shaping process included a range of actors and their meanings. The technological attributes of the species, related to the form of reproduction or the type of plant were one aspect of the shaping process. Despite the obduracy of the species, human intervention (i.e., voice and agency) generated variation with the result that human needs and the species were shaped together;[239] the path of shaping enhanced human welfare. Section 8.2 explain how the organisational goals and the institutional context provides direction and increase the rate of the shaping process. Section 8.3 discusses how the goods that emerge from the shaping process, and the actors and organisations appropriated benefits.

The shaping process of species is likely to be affected by the introduction of new institutional arrangements such as the CBD and the Nagoya Protocol. However, their use is so well established that the social practices (i.e., knowledge underlying each species) are difficult to govern. Practices, such as exchange of seeds as an expression of the

[239] The little prince in Antoine de Saint-Exupéry's book, referenced at the beginning of this thesis, species (i.e., the rose) 'tamed' humans or affected humans' performance of skills.

collective interest or maintenance of a pooled resource within indigenous communities, increased the cost of enforcing laws to restrict exchanges across national borders or to prevent individuals from distributing seeds abroad. The geographic and social does not allow a specific focus for a restrictive enforcement effort – many farmers are engaged in diversification of the varieties cultivated in order to manage risks or pursue their ideas and these activities are spread over different altitudinal vegetation zones. Although indigenous people have explored many of the vast number of species with which they coexist, the nature of consumption or use is subject to change with new technologies such as genetic re-combination or new perceptions of the values of a species such as pharmaceutical properties. On the one hand, it might not be necessary to shape the species to suit these new forms of consumption – it may be sufficient that they are sampled and then reproduced by techniques such as chemical synthesis or cell culture. On the other hand, some desirable properties may arise from *in vivo* features of the species in which case shaping will occur. It remains an interesting question whether this would support localisation.[240]

The three cases were selected strategically because they have common and contrasting aspects that help to ensure robustness in our conclusions. All are elements from biodiversity (species or breeds) which products passed from being locally use to be broadly commercialised (i.e., biodiversity-based innovations). Methodologically, the historical case was used as a heuristic example from where the theory emerges. Also, the first stages of the Jersey cow shaping process occurred under quite strict isolated conditions, so it was possible to simplify assumptions and how the shaping and diffusion processes took place. The maca case helped to validate on a plant the theory presented on an animal, while maintaining the isolated conditions in the first stages of the shaping process. Finally, the quinua case challenge the theoretical framework by flexibilising the isolated condition, which is more common in plants than the strict isolation that happened in maca.

[240] We can speculate that familiarity with similar already cultivated species might provide a local advantage to shaping a previously unexploited species or the new species to be cultivated may benefit from local ecological conditions ranging from climate to the population of microorganisms.

The following two sub-sections will provide a comparative analysis of use of the species and the actors' capabilities to shape the species, in order to explain the variation that allowed selection. They consider the tension between social practices and implementation of the CBD and the Nagoya Protocol.

8.1.1 Biodiversity-based innovation

As has been shown, species can have different meanings (see Ch. 3 Section 3.1). These meanings are linked to the actors' skills and routines associated with their use. The thesis provides evidence of the different meanings of species and the associated social choices.

Chapter 3 discussed how the relative isolation of the island of Jersey allowed the shaping process of the Jersey cow to be traced up to the 19th century. Maca was shaped in similarly isolated conditions (the Lake Junin basin was a 'natural corral' for camelid herding which is closely associated with maca domestication). Quinua involved a broader context. It was produced in many regions of Andean South America in pre-colonial times and was introduced into Europe in colonial times, but had disappeared from several regions by the 1950s However its main production is in a few regions of Bolivia, Peru and Ecuador. Thus, all the case-studies involve local production, mainly for self-consumption, and a shaping process, which led to commercialisation at the international level. Isolation allows identification of the factors that affected the shaping process and other relevant aspects.

Table 5 presents the three cases at the beginning of the shaping process in terms of human use.

TABLE 5 THE THREE CASE STUDIES. BEGINNING THE SHAPING PROCESS

Case Study	Starting point	Where	Main use
Jersey cow	1750 – 1800	Jersey Island	Husbandry and milking for rich milk production for self-consumption
Maca	1960 – 1980	Junin and Pasco regions, Peru	Cultivation for producing nutritious roots for self-consumption
Quinua	1960 – 1980	Lake Titicaca basin and central Ecuador	Cultivation as staple with versatile applications for self-consumption

Source: The author

The results of the three case studies confirm our expectations (literal and theoretical replication) (Yin, 2009). The innovation process in all three cases is characterised by a starting point in time related to the users and their meanings. The cases differ in the size of production (dairy products, staple crop and therapeutic crop), and the underlying production knowledge (i.e., sexual and annual reproduction vs biannual and mixed reproduction), which affected diffusion of the use of the 'shaped species'.

8.1.2 Choice in the shaping process

The technological attributes of species, as living organisms that can reproduce, derive from subtle changes which enabled selection. Actors use agency and voice in attempting to address their individual needs. This thesis analyses the social practices involved in actors' performance of their skills and attempts to satisfy their needs. Table 6 presents these social practices, skills and needs.

TABLE 6. ACTORS, SOCIAL PRACTICES AND SKILLS FOR ADDRESSING NEEDS

Case Study	Actor and Social practice	Skills	Addressed needs
Jersey cow	Jersey farmers; tethering	Moving the cow as much as once every two hours during the day	Food availability thanks to intensive use of land (for growing vegetables) and surrounding pasture for rearing cattle. Tethering shaped a gentle and docile breed.
Maca	Indigenous Andean people; control altitudinal vegetation zones	Visiting the wet *puna*, to which humans are not well-adapted	Food availability: Several staples from *qechwa* zone and Andean camelids and maca from wet *puna* zone
Quinua	Indigenous Andean people; diversification in varieties and uses	Cultivation of several species and hundreds of varieties	Food availability with low risk of shortage since different varieties were available at different points of the year and surplus for social occasions and social works

Source: The author

Social practices involving use of the artefact are performed to address individual needs. The choices made by social groups are the result of a learning process and accumulation of skills to address individual needs. In the case of the Jersey cow, Jersey farmers used cattle to produce milk with a high solids content, which was valued as a source of butter. In the case of maca, indigenous Andean farmers considered it a fertility and stamina enhancer, and believed it helped them to withstand the tough conditions in the wet *puna*. In the case of quinua, indigenous Andean farmers identified it as staple based on its resistance to conditions of drought, common in the dry *puna* and *suni* zones.

Attempts to restrict actors' access to species, reduced their chances of giving them meanings that addressed their individual needs and organisational goals. The CBD and the Nagoya Protocol should not be seen as restricting access to the species, but rather as promotingvariation in the meanings and human needs that are addressed.

Governing frameworks, such as intellectual property rights systems, that restrict access to technologies by increasing their costs and restricting their replication, are problematic. Such frameworks are difficult to implement in the case of living organisms (i.e., species), due to the technological attributes of species. At reproduction, species undergo subtle changes, which can be unintentional or intentional (i.e., due to human agency). This makes it difficult to separate *what* part of a species is the creation of a human mind and what is not (in manufactured inventions or artistic works this distinction is clear). It makes it costly to differentiate species where access is approved and where it is restricted.

The implementation of governing frameworks can reduce the possibilities for variations that could provide welfare. Control, replication and imitation of the use of species in different contexts or environments is based on actors' accumulated and retained knowledge, and individual needs and organisational goals. Restricting access to species from biodiversity implies restricting social welfare. Restricting access to species implies losing opportunities to improve social welfare.

In the case of technology, intellectual property regimes in developed countries imply higher net costs and restricted access to the technology for developing countries. The success of IPR systems is related to the bargaining power of developed countries in the definition and implemention of such regimes, and the cost of that implementation.

Implementation of the CBD and the Nagoya Protocol by biodiverse countries, many of which are developing countries with low bargaining power, seems impractical.

8.2 Institutions and organisations

Given the motivation to explain the unequal distribution of the benefits arising from the use of biodiversity (see Ch. 1), this thesis discusses aspects that go beyond the micro level of individual actors' decisions and considers the macro and meso levels in evolutionary (Nelson and Winter, 1982) and institutional economics (Hodgson, 1988; North, 1990) approaches. We have discussed the organisational routines and institutional arrangements which are subject to change as the result of a learning process. The collective choice to diffuse or not the use of the biodiversity-based innovation is a bargain among the actors. Actors' decisions consider the expected benefits from these decisions, while institutions help to reduce the costs of participation in the shaping of the biodiversity-based innovation.

The biodiversity-based innovation requires a combination of something from nature and its underlying knowledge. The underlying knowledge is related to the actor's social practices in a learning process of accumulating and retaining knowledge. This thesis shows that *biodiversity-based innovation is shaped by social practices; not necessarily by changes to the nature of the species, but by changes to the underlying knowledge of the species*.

The thesis shows that actors cooperated within organisations and that those organisations helped to increase the rate and define the direction of the shaping process. These organisations were built around a long history of institutional arrangements. For each of the three case studies, this history was discussed in terms of the creation/consolidation of the nation-states and markets, and the diffusion of languages. The creation of nation-states affected the commercial use of the species by defining the size of the market and the relative costs of goods. The creation/consolidation of markets involved a variety of actors (from barterers to professional dealers), trading routines and costs. The diffusion of languages involved to cover the costs of learning the standards and models of the language compared to the benefits expected from adopting a *lingua franca* for trade or a standardised language for knowledge codification.

Patterns of social structure affect organisations and institutional arrangements. Technological and institutional changes are related to: (i) higher-yields from agriculture due to cultivation/husbandry rather than hunting/gathering, and (ii) high-class social groups exerting power to govern the nation-states. High-class social groups define the institutional arrangements governing ownership and rights over land and other complementary means; these arrangements are preferred to self-defence, direct confrontation and war. Control, access and ownership over complementary means provide the conditions for the appropriation of benefits (i.e., the rights to control and to benefit from what is grown on the land) and can affect the shaping process. In the case of Jersey, the lands were governed privately. Jersey had an equal parts inheritance law, which allowed a more even distribution of land (i.e., smaller farms) compared to the oldest-son-heritage that prevailed in England (see Ch. 4 Section 4.2.1). This last characteristic contributes to explains the practice of tethering common in small farms, instead of herding typical of larger farms.

In South America, two large indigenous communities, the Inca and Aymara, survived colonisation and maintained their presence and social practices in the Andean highlands. Although independence came at the beginning of the 19th century, it was not until the Agrarian Reform in the mid 20th century that indigenous communities gained equal civil rights and ownership over land. The *ayllu,* the basic local government structure discussed in the two Andean case studies, controlled several altitudinal vegetation zones, which explain how indigenous communities had control over *qechwa* zones while maintaining presence also on the *puna* (i.e., wet *puna* in the case of maca and *suni* and dry *puna* in the case of quinua). In general, the ayllu lands are now complementary means that are governed privately by the indigenous people.

In the last 250 years, the trend towards the consolidation of nation states has made trade superior to war. The challenge to the implementation of the CBD and the Nagoya Protocol is how trade can be maintained as an institution in which the actors cooperate. The common interest in trade is increasing social welfare by promoting competition (as opposed to monopoly). The two Andean species exemplify two different and contrasting perspectives from which nation states are attempting to implement the CBD and the Nagoya Protocol.

The next two sub-sections compare the institutions and organisations involved in the shaping and standardisation of the species under study, with an emphasis on the role of language. They conclude by highlighting the options available to nation states for implementing of the CBD and the Nagoya Protocol.

8.2.1 How did institutions and organisations affect the shaping and standardisation of the innovation

Chapter 2 referred to the actors directly involved in the shaping process and those who did not have an opportunity to be consulted (or involved), but were affected by the innovation (output). This thesis differentiates the meanings actors gave to artefact in terms of their voice (i.e., the 'what' is their position) and agency (i.e., 'how' they affected the artefact). Actors can voice their opinion by using the artefact, or problematising it, or can exert their capability to 'act' or not, on the artefact (see Ch. 3 Section 3.3) (Hirschman, 1970; Bishop, 1989; Barker, 2000). The thesis shows that the ability to differentiate meanings is explained by: (i) the pattern of the social structure, once a percentage of the population is able to produce enough food for the whole population, this allows the others to participate in other activities. The performance of specialised skills, such as research or trade, teaches the actors about the values in use of species which are different from the values given by the farmers; (ii) the creation of organisations specialised in other activities than the production of food for self-subsistence. Actors cooperate and choose the benefits to those performing these other activities. The concepts of voice and agency enable identification of several actors, their performance of skills and routines, and the expected benefits from such performance.

Although the expected benefits may be associated with the commercialisation of derivative products or diffusion of use of the species, those who raise their voices do not necessarily expect direct benefits from commercialisation. For example, organisations such as the RJA&HS benefited from the organisation of shows and the patronage of the British Crown. Also, researchers expected benefits in the form of public recognition for their publications or the development of new products. An example of this is the researchers who mechanized scarification of quinua and published on the therapeutic effects of maca differentiated by colour (See Ch. 6 Sub-section 6.3.2).

In each of the three case studies, there were some triggers for the rearrangement to the ways that the actors coordinated their efforts. This increased the rate and defined the direction of the shaping process. In many cases, activities that previously were marginal became professionalised. In the case of the Jersey cow, the visit at the beginning of the 19th century of the cattle dealer and British dairy expert, Michael Fowler, resulted in the creation of the RJA&HS. In the case of the two Andean species, local concern about reduction in the use (i.e., production) of the species compared to other more broadly cultivated species, as wheat and barley, resulted in researchers from Bolivian and Peru organising themselves to discuss this concern. León, through the IICA, supported the Convention of Chenopodiaceaes (for quinua) and the International Congress on Andean Crops (for maca), and both scenarios were used to share the research activity in crops such as quinua and maca. Production of quinua decreased during the first half of the 20th century and of maca during the 1960s and 1970s. León was in Peru as the representative of an organisation whose goal was to promote yield increases in line with what had been achieved with maize and wheat. León support helped to specialise researchers in maca and quinua, and not only in maize and wheat. In the case of maca in particular, the ETC Group warned Begoña Venero about the granting of patents covering the use on maca to the USPTO; this convinced Venero and others to create the Maca Group.

The organisations that took part in the shaping process are presented in Table 7.

TABLE 7 MAIN ORGANISATIONS IN THE SHAPING PROCESS OF THE THREE CASE STUDIES

Case Study	Organisation	What did these organisations do	When it began
Jersey cow	The RJA&HS	Shows and herd book	1834
Maca	The Maca Group or CNB	Legal status analysis of granted patents	2002
Quinua	Convention of Chenopodiaceaes or conferences of quinua	Conventions and proceedings	1968

Source: The author

The cases show how the performance of skills and organisational routines defined the shaping paths for the species. At the beginning of the Jersey cow shaping process, farmers were reluctant to consider the external attributes preferred by dealers to define the breed; their meaning was directed to the production of rich milk, rather than of animals for commercialisation. Once the RJA&HS' mechanisms considered external attributes, a new shaping path towards commercialisation began. In the case of maca, universities and research centres provided incentives for research, and encouraged Francisco Gonzales to study root colour differences related to the benefits for human consumption. However, there is no clear understanding about how to control homogeneity in the colour of the root or how to explain the variability (see Ch. 6 Sub-section 6.3.2). Quinua shows large variability (i.e., varieties with different saponins content, size and colours) from where social practice of diversification occurred (i.e., culinary uses differentiated by variety) (see Ch. 7 Sub-section 7.1.1). Researchers shaped quinua by performing their breeding techniques. They were aiming at a large sized grain, which was preferred by the market, and a low saponin content. Further shaping occurred when researchers, supported by organisations such as IICA and international cooperation agencies, investigated scarification and washing techniques for reducing the grain saponin content (see Ch. 6 Section 6.2.1).

Standardisation of species depended on stabilising the meanings. In principle, Jersey cows became standardised as the results of shows, since cattle were evaluated on a points scale, which simplified the meanings of farmers and cattle dealers. Animals that did not fit the standard were slaughtered. In 1866, the herd book was introduced and further standardisation occurred, since animals were registered and reproduction was encouraged using the foundation stock. Farmers were reluctant to measure milk yields, which were low compared to other breeds such as the Holstein-Friesian. In the second half of the 20th century, cheese makers solved by rhetorical closure (Bijker and Pinch, [1989] 2012 p. 37) to the problem; for them the high solids content of the milk was paramount and made their separation less costly (Perchard, 1998) (see Ch.4 Sub-section 4.2.1).

In the case of maca, the first stage towards standardisation was drying the root, which began when the Peruvian government promulgated the Supreme Decree N° 039-

2003-AG (Perú, 2003) in 2003. This law 'prohibits exporting botanical or vegetative seeds, or sub products in its natural state or with primary transformation, to promote its export with higher added value' (author's translation from Spanish). In 2008, indigenous Andean farmers, researchers and processors agreed the Technical Quality Norms for toasted maca flour (Indecopi and CNT 066, 2008b) and gelatinised maca flour (Indecopi and CNT 066, 2008a).

Finally, in the case of quinua, standardisation occurred with the redefinition of the problem in terms not of low production, but in relation to the saponin content in the grain. Several actors became involved in shaping the species towards larger grain size and reduced saponin content. Andean Technical Norms were agreed by the Andean Normalisation Committees, and particularly the Peruvian INDECOPI and the Bolivian IBNORCA.

Each organisation operated under an institutional context. The RJA&HS received support from the Crown and, since Jersey was a UK dependency, commercialisation of the Jersey cow expanded smoothly to British colonies around the world. Jersey farmers cooperated in the expectation of receiving greater benefits from commercialisation of the 'pure breed'. The commercialisation of maca and quinua crops imitated what had happened in the 19th century with other major staples from the highlands that began to be traded in cities such as Lima, Peru, and La Paz, Bolivia. The monetisation of trade proved more efficient than traditional barter and reduced transaction costs; and actors had the opportunity to accumulate the benefits from commercialisation. Latin American indigenous communities used maize, quinua and potatoes for thousands years. Since colonial times, wheat and barley were considered staples. Wheat and barley offered benefits comparable to those from maize, quinua and potatoes. All these species, both native and introduced, persisted on the continent although areas to quinua cultivation began to be replaced by introduced species in regions of the central Colombian Andes. In the 20th century, the learning process related to mass selection and seeding techniques accelerated as a result of public and privately funded research. Improvement to maize and wheat varieties enhanced the rewards from the cultivation of those crops (i.e., high yields and lower cost), which reduced the comparative rewards obtained for quinua, maca and many other traditional crops. Organisations, such as the Convention of

Chenopodiaceaes promoted R&D in quinua, imitating what happened in wheat and maize. Bilateral and multilateral research programmes related to maca and quinua and funded by government agencies and international cooperation agencies, were enabled by the availability of indigenous people trained as researchers in species such as potato, wheat and maize.

The analysis in this sub-section of organisations and institutional arrangements is in line with a NSI approach. The extended theoretical approach proposed in this thesis is reinforced by theory triangulation (see Ch. 3 Section 3.2); NSI approaches describe organisations and their interactions, and the institutional arrangements explain the rate and direction of the innovation. However, it is suggested that the NSI approach is not sufficient to explain the innovation process. For example, kiwicha and cañihua are two species that have received attention from the Peruvian government and research centres in recent last decades, but they have not reached the international market and remain only locally produced. These are innovation attempts where interactions between organisations did not make them successful. They need to be explained in terms of meanings. The disappearance of quinua from central Colombia since the 1800s, and from Europe after its introduction in colonial times, shows that the contextual character of the shaping process and the unintentional circumstances and unintended consequences need to be studied and considered in an analysis of the innovation process.

8.2.2 Role of knowledge codification in shaping the species

The movement and exchange of species occurred in tandem with the movement of actors with knowledge and reports on the species. After the arrival of Spaniards in the 15th and 16th century, movement of species between America and the rest of the world was together with exchanges of codified knowledge. This included reports of Spanish chroniclers and researchers interested in introducing the species to Europe. Their reports encouraged commercialisation of the species derived products based on their values as food and their benefits for health.

Codification of knowledge in the island of Jersey occurred when cattle dealers and farmers defined the attributes of the perfect Jersey cow and the perfect Jersey bull, based on a points scale. This scale was in use in England and was in the English language and it was introduced to Jersey in English rather than French or Jèrriais. The codification of knowledge occurred in tiers for each of the three cases studed.

Table 8 presents the main stages or tiers of knowledge codification in the three case studies.

TABLE 8 TIERS IN THE CODIFICATION OF KNOWLEDGE OF THE THREE CASE STUDIES

Case Study	First Tier	Second Tier	Third Tier
Jersey cow	The points scale, which codify defining and ancillary information	The herd book, which codify defining and ancillary information	The 24-hour butter test, which codify the defining and basic information
Maca	Quechua speaking use, articulated but marginally codified defining and ancillary information	Spanish speaking use, with details of defining, ancillary and basic information	English speaking exchange, with details of defining information and recently of basic and ancillary information
Quinua	Aymara and Quechua speaking use, articulated by marginally codified defining and ancillary information	Spanish speaking use, with details of defining, ancillary and basic information	English speaking use, with details of defining information and recently of basic and ancillary information

Source: The author

More detailed codification (defining, ancillary and basic knowledge) (see Ch. 4) occurred in particular languages, in which the costs of knowledge accumulation are low because standards and models for delivery and receipt messages already exist. Accumulation of knowledge in Aymara and Quechua was restricted to defining and ancillary information for the maca and quinua cases. Similarly, in Jersey, underlying knowledge about the Jersey cow in Jèrriais was limited to Jèrriais speaking farmers. Attempts by outsiders to accumulate knowledge involved high learning. Thus, English speakers, as outsiders, preferred to adapt skills and routines in English.

More complete forms of codification for defining, basic and ancillary information occurred in the *lingua franca*, Spanish (and to a lesser extent English) in Peru and Bolivia, and English in Jersey, which was of British. The use of a *lingua franca* facilitated codification of uncodified knowledge which allowed bilingual users to accumulate new skills and routines as dealers or researchers and, therefore, to gain benefits from codification. The *lingua franca* helped to link actors in bilingual (or multilingual) environments, but involved a transition from local descriptions to scientific generalisations (see Ch. 3 Section 3.3.2).

In Bolivia and Peru, bilingual users acted also as translators, able to unravel and assign meanings to the species and mobilise resources to solve problems. These allowed to raise their voices and exert agency to shape the species.

The underlying knowledge related to several species in biodiverse developing countries is uncodified or unarticulated; the holders of the knowledge are generally indigenous people lacking codification skills and routines, who would not benefit from its codification (i.e., high costs of codification compared to the expected benefits). This thesis shows that the codification of knowledge facilitated the shaping of species towards commercialisation by helping to reduce the uncertainty among actors/users of the artefact, stabilise the expectation of consumers, and build trust among those involved in the exchange of information on species and emerging goods. Articulation and codification of knowledge is convenient for the shaping process since it helps to reduce meaning to information.

The three case studies identified that actors – especially those with a long history of use – are involved in the shaping process, but can lose their previous control over the artefact and the underlying knowledge. The Jersey cow is an extreme case because production in the island of Jersey is marginal compared to production worldwide. Some reports suggest loss of control by indigenous Andean farmers in the case of maca and quinua which now are being produced in China.

The three case studies highlight the alternatives available to nation-states in implementing the CBD and the Nagoya Protocol. While the Jersey cow and quinua cases are based on a quite *open access* to the species, in the case of maca the Peruvian government restricts access to seeds to limit reproduction abroad. Although the ban on exports of maca seed seems to be effective to the extent that Peru is still the largest exporter of maca worldwide, and the Peruvian government has put in place several mechanisms to restrict commercialisation of maca seeds, the crop is becoming important in some regions of China.

In the case of the Jersey cow, the Island's government ensured the identity of the breed by restricting imports of foreign cattle, but was eager to promote commercialisation of the Jersey cattle. The case of quinua is similar in that both Bolivian and Peruvian governments were enthusiastic about promoting IYQ, and the diffusion of quinua use worldwide. Thus, in contrast to the case of maca, whose restricted access is in line with the CBD and the Nagoya Protocol, in the case of quinua it is an interest of the Peruvian and Bolivian governments for the diffusion of the use of the species. What occurred in the Jersey cow could risk loss of control of the species and the benefits arising from the cattle commercialisation. However, the Jersey cow case and the quinua case differ in that their shaping paths were affected by the species' technological attributes. The Jersey cow case was standardised and other variations of the breed that did not fit to such standard disappeared (i.e., were slaughtered); there is no other wild familiar species or other breeds in Jersey that could have generated variation. In the case of quinua, standardisation is associated to a preference for a few varieties with large grains and low saponin content, but hundreds (perhaps thousands) of varieties and wild relative species of quinua, persist especially in the Lake Titicaca basin.

The direction taken by the Peruvian government in the case of maca makes its sustainability problematic and goes against the trend towards maintaining trade and competition in order to promote social welfare. One of the risks associated with this perspective is that farmers from Junin or Pasco regions can move, taking with them their underlying knowledge, to find places (e.g., in China) where it might be possible to increase maca yields and the social benefits from its diffusion in use. The approach in the case of quinua, despite the risk of losing control over the species as happened in the case of the island of Jersey and the Jersey cow, seems more realistic and sustainable since it was accompanied by innovation management strategies (see Section 8.3). The reduction in the costs of transport and communication increase the chances of this happening.

The use of a *lingua franca*, in this case Spanish, English and Chinese, rather than a rural language, such as Jèrriais, Aymara and Quechua, increased the expected benefits from the codification of underlying knowledge. A *lingua franca* was useful for standardisation and increasing the scope of commercialisation. However, a *lingua franca* can be also reductionist since the process of generalisation proper to science, breaks this connection to the context. Rural languages add variation and richness to the underlying knowledge since the actors maintain the vocabulary adapted to local conditions. Rural languages are descriptive, rather than being used for generalising.

The section analysed the forms of governance over the goods that emerged from the shaping process and the actors' appropriation of benefits based on the two perspectives in the implementation of the CBD and the Nagoya Protocol and the possibilities of maintaining a more equal balance between a *lingua franca* and a rural language.

8.3 Forms of goods governance and appropriation of benefits from the goods from biodiversity

This thesis motivated by the notion that biodiverse countries should achieve greater benefits from their resources and enjoy more equitable sharing of the benefits arising from use of biodiversity. It addresses the actors (and organisations) shaping of biodiversity-based innovation and their social practices, in an institutional context (first research question) based on evidence from three case studies. The commercialisation of goods emerging from the shaping processes produced greater benefits for the actors and organisations. The second research question is related to the idea that benefits accrue to individuals or groups depending on the forms of governance over the goods emerging from the biodiversity-based innovation process.

The three case studies in this thesis provide examples of forms of governance over different goods and how actors and organisations appropriated the benefits. The appropriation of benefits is characterised by two aspects: (i) the actors' roles and the technological attributes involved in the shaping process, which defines the form of governance for the emerging good, and (ii) the actors relative bargaining power over complementary means and how it defines (and enforces) institutional arrangements governing the commercialisation, control and ownership of the goods emerging from the shaping processes.

Sections 8.1 and 8.2 discussed the difficulties related to implementing and enforcing aspects of the CBD and the Nagoya Protocol that restrict access to or reproduction of species from biodiversity. An open access perspective is coherent with a preference for trade and competition as a mechanism to increase social welfare. Voluntary observance of access to resources from biodiversity, according to mutually agreed terms, and trust in the sharing of benefits, proportionally more benefits to those with higher bargaining power (i.e., control over complementary means and capability to bargain over institutional arrangements). The consolidation of a few *lingua franca* worldwide and the disappearance of rural languages, combined with reduced transport and communication costs reduces the costs involved in moving people, their seeds and their knowledge, which further reduces the chances of nation states in biodiverse countries from enforcing the CBD and the Nagoya Protocol.

In Ch. 8 Sub-section 8.3.1 and 8.3.2 we explore the forms of governance over the goods emerging from the shaping process, and the appropriation of benefits for actors and organisations involved in the shaping process. In Sub-section 8.3.2 we conclude highlighting the possibilities for appropriating benefits deriving from innovation management strategies implemented by nation states, related to the CBD and the Nagoya Protocol.

8.3.1 How are public and private goods emerging from the biodiversity-based innovation process governed?

Chapters 1 and 2 justified study of the form of governance over goods rather than the public or private character of goods. Although these concepts are linked, the focus on governance emphasises the actors who appropriate benefits, recognises the actors' abilities to raise their voices and exert their agency in the shaping process.

This thesis emphasises that the technological attributes of species and the local public character of the underlying knowledge accumulated and retained by indigenous people and researchers, are intertwined with the form of governance. This distinguishes this research from that that recognises the broad public character of knowledge and species collections (*ex-situ* or *in-situ*), claimed by CGIAR research and gene banks (Pingali, 2012), but without considering the user perspective. It extends work that consider mainly technological attributes (Halewood, 2013), rather than technological attributes and actors' capabilities to use species. Thus, the form of governance lens is preferred to analyse the goods emerging from the shaping of the species and the appropriation of benefits because it considers the actors who make decisions about the goods emerging from the use of the species, and who practice their skills and routines under particular institutional arrangements.

Each of the three case studies discusses different forms of governance over the goods emerging from the shaping process - see Table 9.

TABLE 9 FORM OF GOVERNANCE OVER GOODS EMERGING FROM THE SHAPING PROCESS OF THE THREE CASE STUDIES

Case Study	Privatisation	Common-pool resource	Toll or club good	Public good
Jersey cow	Dairy products and meat Cows used for milking and jeifers for selling	The foundation stock	Siring service in the parish	General knowledge of dairy Codified articulated knowledge disclosed by Jersey farmers to the RJA&HS (1)
Maca	Maca roots for consumption or commercialisation Publications protected by copyright Maca botanical collections with high cost to distribute materials	Set of seeds in the wet *puna* exchanged among *ayllu* and community members	Maca botanical collection easily shared among researchers	'Andean Viagra' concept (2) Codified articulated knowledge disclosed by researchers to their peers or by indigenous Andean farmers among their ayllu or community (1)
Quinua	Quinua grains for consumption or commercialisation Seed 'new varieties' protected by PBR Certified seeds commercialised under the state-regulated system Quinua botanical collections with high cost to distribute materials	Set of seeds exchanged among *ayllu* and community members	Quinua botanical corrections easily shared among researchers Quinua seeds under the OSSI	'High protein content and gluten free condition' used in commercialisation Codified articulated knowledge disclosed by researchers to their peers or by indigenous Andean farmers among their *ayllu* or community (1)

(1) Contextual rather than absolute, and scope increase with the articulation or codification in the *lingua franca*.
(2) Other knowledge that become easily accessible and with high costs on its restriction
Source: The author

Section 4.3 (Ch. 4), 6.3 (Ch. 6) and 7.3 (Ch. 7) and Annex A show that privatisation became a trend in the 20th century. This trend is exemplified by implementation of forms of protection of codified knowledge by copyright, of 'new plant varieties' by PBR, and of commercialisation of certified seeds rather than traditional exchange.[241] These goods, which formerly were governed as common-pool resources were affected by this privatisation since actors and organisations implemented routines for gaining benefits, which do not consider the collective interest and make collective action unnecessary. Also, the technological changes (i.e., improvements to communication and transport common to the three case studies)[242] make it costlier to restrict newcomers' access to goods that previously were restricted to a small number of users. The trend towards privatisation as form of governance over the goods emerging from use of biodiversity has affected the balance of the bargaining power; some actors manage to accumulate benefits and to increase their bargaining power, but some do not.

The case studies also show the contribution made by forms of governance of common-pool resources, club goods and public goods, at the local level, to generating variation from which selection is possible. Experience of those forms of governance contribute to evaluating the perspectives of policy-makers and actors in biodiverse countries in relation to the governance of the goods emerging from the use of biodiversity. These forms of governance evolve together with technological changes and institutional arrangements.

8.3.2 How do actors and organisations give meanings to and gain benefits from biodiversity based innovation?

Appropriation of benefits is preferred to ownership for explaining welfare for two reasons: First, the interest is in discussing the unequal distribution of benefits arising from biodiversity; second, because the control over or access to biodiversity expected from biodiverse countries is not sufficient to differentiate those countries from non-biodiverse

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[241] This includes the modern techniques of artificial insemination, embryo transplantation, genotypification and certification, which displaced the siring service. See fn. 91.

[242] The development of and improvement to the transport and telecommunications infrastructure are evident in all Latin America countries. Since 1990s, mobile subscriptions have increased from being marginal to including 1.1 subscription per person in 2015. The same year, in Bolivia, the ratio is of 0.92 per person and in Peru is of 1.1 subscriptions per person (WB, 2017).

countries in terms of the accumulation of benefits (i.e., benefits to biodiverse countries vs non-biodiverse countries).

The robustness of proposed extended theoretical approach, in which the appropriation of benefits is explained by the form of governance of the goods emerging from biodiversity, is enabled by theory triangulation (discussed in Ch. 3 Section 3.2). This is because, as other authors have recognised, institutional arrangements, such as property rights (e.g., patents), contribute to explaining the appropriation of benefits (Sternitzke, 2010). However, this thesis claims that other elements are also relevant. For instance: (i) the species technological attributes such as its reproducibility and form of reproduction; and (ii) the value in use gained by the relative bargaining power over complementary means such as rights-based illegal access to the species (e.g., biopiracy) or relational means such as the access to skilled labour (e.g., kinship linkages that enable help from which indigenous people). The value in use that actors (and organisations) define for the use of the species derives from the relationship of actors and characteristics of the species used. For example, Peruvian government officials gave the value in use of biopiracy to foreign use of maca (i.e., non authorized use as stated in the Andean Decision 391), supported in the unique origin of the plant in the Peruvian mountains; however, it was not the case for quinua in which the origin in shared with other Andean countries. Instead, both Peruvian and Bolivian governments agreed that the International Year of Quinua would be an opportunity for promoting quinua production without any reference to seed restriction (Interview BA), and as a grain to be grown in regions with poor soils and tough weather conditions (IQC *et al.*, 2016).

Table 10 summarises the values in use and the complementary means that affect actors’ appropriation of benefits for the three cases.

TABLE 10 ACTORS' APPROPRIATION OF BENEFITS, VALUES IN USE AND COMPLEMENTARY MEANS

	Jersey cow			Maca			Quinua		
Skill / Routine	Actor	Value in use for fulfilling a purpose	Complemen-tary means	Actor	Value in use for fulfilling a purpose	Complement-ary means	Actor	Value in use for fulfilling a purpose	Complemen-tary means
Cultivation/ husbandry	Jersey farmers	Dairy and meat as food for the family Nutritive food that limit the risk of diseases. Exported heifers as source of income	Property rights over the land, ensured by fences.	Indigenous Andean farmers from the wet *puna*	Fresh and dry roots as food for the family Maca as fertility enhancer and resistance to *puna* conditions Commercialised maca products as source of income	Property rights over the land Capital and knowledge for commercial production	Indigenous Andean farmers from the Lake Titicaca basin	Grains as staple Grain as alternative to meat protein and with well-balanced aminoacids content Exported grain as source of income	Property rights over the land Capital and labour to perform the commercial production
	Bull owner	Bull as source of income from the siring service or from export	Viable population						
	The whole set of Jersey farmers	Foundation stock as set to reproduce pedigree stock							
Commercialisation	Cattle dealers	Heifers and sires as merchandise to be exported	Vessels and steamboats to transport the cattle	Maca dealers	Maca flour and gelatinised flour as source of income	Knowledge on transporting to Lima, processing and marketing Capital for mechanisation Geographic indication 'Maca Junín – Pasco'	Quinua dealers	Quinua grain as source of income	Knowledge and capital for transporting to medium and large size cities, process mechanisation and marketing Capital for mechanisation and export

	Jersey cow			Maca			Quinua		
Skill / Routine	**Actor**	**Value in use for fulfilling a purpose**	**Complementary means**	**Actor**	**Value in use for fulfilling a purpose**	**Complementary means**	**Actor**	**Value in use for fulfilling a purpose**	**Complementary means**
Events organisation	The RJA&HS	Animals that fit to the points scale as pure breed Shows as source of reputation and trust	Regulation (approved points scale or levies) to be enforced	Maca Group or CNB	Maca seeds and roots as resources from biodiversity that requires approved access from Peruvian government	Knowledge and access to authorities for enforce the Decision 391, which regulate CBD and Nagoya Protocol	International Convention and Conferences	Plant as research input and subject to diffusion in use	Access to authorities and research networks for ensuring funds, mobilise actors and publishing.
Research				Maca researchers	Roots as research input from which moral benefits	Knowledge and access to authorities for ensuring funds and publishing	Quinua researchers	Seeds and parts of the plant as research input from which moral and economic benefits New varieties as form of moral recognition	Knowledge and access to authorities and research networks for ensuring funds, exchange of seeds and publishing

Source: The author

The three case studies provide examples of the appropriation of benefits. Benefits arising from the use of biodiversity accrue to individuals or groups, and complementary means enhance the actors' abilities to appropriate benefits.

From the perspective of the biodiverse countries', it is important to consider actors who maintain close contact with the species. The two Andean case studies provide examples of indigenous people who learned skills as researchers or dealers, which increased their opportunities for appropriating greater benefits from use of the species compared to their initial situation as indigenous people with farming skills. These new skills of researchers and dealers gave them opportunities to articulate (voice) the meanings given to maca and quinua. This was because Aymara and Quechua were subnational languages, which made the costs of communicating with indigenous relatively high and reduce the audience reached compared to communication in a *lingua franca*, in this case English or Spanish. The rewards derived from codifying the knowledge in the *lingua franca* were marginally higher than if the knowledge was codified in the Aymara or Quechua language. This applies also to the use of Jèrriais rather than in English in the case of the Jersey cow.

Although use of a *lingua franca* for knowledge codification may increase the scope of governance over that knowledge (i.e., more actors, which will increase variation and the opportunities to innovate), it has some risks. The three cases show that historical users (i.e., indigenous communities in developing countries and farmers in the island of Jersey) can be excluded from the benefits of their innovation if they lack the skills and organisational routines to codify and decode the knowledge or the complementary means to enhance their capability to appropriate benefits.

Skills allowing articulation and codification of knowledge are not enough to enhance the capability to appropriate benefits. Standardisation of the species towards commercialisation shows the actors involved. In the three case studies, standardisation occurred through agreement within voluntary standards setting organisations. The definition of standards exemplified the bargaining power of actors and organisations. In the case of the Jersey cow, at the beginning of the shaping process standards were decided by the Jersey farmers and dealers. However, this bargaining power changed once

Jersey farmers lost control over access to the species, that is when farmers in other countries such as the USA, Australia and South Africa, were able to establish their own foundation stocks for reproduction. This was accompanied by loss of capability of the Jersey people to define the standards.

In the two Andean case studies, farmers' representatives, dealers, researchers and industry representatives involved in transforming and commercialisation were invited to define the standards. Rather than defining by itself, the Peruvian government in the case of maca and the Peruvian and Bolivian governments in the case of quinua, convoked these actors for defining the standards,[243] which shows a trend to reducing the *intrusiveness* of the state in the economy. In both cases, no single actor had the bargaining power to define standards through market competition.

A challenge for policy-making in biodiverse countries is maintaining bargaining power as producers, and defining standards at the time the use of species is diffused. This is exemplified by China's cultivation of maca and quinua. The definition of standards is related to both the capability to produce, and the complementary means required to achieve those levels of standardisation.

The three case studies illustrate two perspectives related to nation-states' implementation of the CBD and the Nagoya Protocol: *Restricting access* to species from biodiversity which reduces the possibilities for variations in social practices for using the species, and *trade*, which is likely to increase variation and selection and facilitate biodiversity-based innovation.

The quinua case shows the need for innovation management strategies implemented by nation states regarding the CBD and the Nagoya Protocol. These strategies are additional to the traditional appropriation of benefits by the actors that commercialise goods, and that would benefit actors with complementary means to enhance their capability to appropriate benefits. It is expected that the benefits follow the trend of unequal distribution and that indigenous farmers might lose control over the

[243] The other three forms of standardisation are government promulgation, market competition embodying unsponsored standards, and market competition embodying sponsored (proprietary) standards (David and Greenstein, 1990).

seeds and underlying knowledge without appropriate policies. Traditional policies of taxing the rich and redistributing wealth through social policies, might be complemented with innovation management strategies that support the emergence of goods and the appropriation of benefits to achieve:

(i) equilibrium between researchers' scientific knowledge and knowledge held by indigenous communities and farmers. There need to be a balance between a reductionist scientific approach in a *lingua franca* (i.e., Spanish, English, Chinese, etc.), which considers quinua as a source of food for the world's population based on its high protein content and gluten-free character, and accumulating and retaining indigenous knowledge about the large set of quinua varieties. This implies the need for a policy to preserve and promote the use of Aymara and Quechua alongside other languages. Farmers, researchers and dealers with skills and routines in tourism and language teaching, for example, could appropriate benefits from goods (and services) associated with exporting underlying knowledge related with the large set of quinua varieties.

(ii) improved seeds for commercialisation. Promoting breeding activities based on experience with commercial standardised crops, such as wheat or maize, but learning from the unintended consequences accompanying standardisation. This thesis suggests that genetic erosion and disappearance of or reduction in the areas used to grow species and varieties that compete with commercial standardise crops, are unintended consequences that need to be avoided. Therefore, scientific research to improve yields, associated with diversification (i.e., use of a larger set of varieties adapted to local conditions, and multi-cropping with complementary species) should be based on an understanding of the local context in which improved seeds will be used. This context-based research is a challenge for the NSI in biodiverse developing countries, given the low level of investment in R&D.

(iii) sets of seeds and varieties available for breeding. Wild species and the set of varieties can increase over time and it is clear that the environmental conditions of the Andean countries contribute to increasing their variability. Actors from Andean countries could benefit from roles as farmers, dealers or researchers while facilitating this increase.

In the case of the Jersey cow, English was preferred to Jèrriais. Other world regions adapted the skills and routines involved in use of the Jersey cow. The challenge related to maca is to promote the use of these three innovation management strategies alongside a trade and competition approach, to implement the CBD and the Nagoya Protocol. The reduced transport and communication costs will make it expensive for the Peruvian government to restrict actors from moving with their seeds and taking with them the underlying knowledge.

9 Conclusions and Summary

This thesis proposed a framework for analysing the shaping process related to biodiversity-based innovation and the appropriation of the benefits arising from the goods that emerged from that process. Chapters 2 and 3 presented the theoretical approach, and Chapters 4, 6 and 7 presented the three case studies. A comparison of the three case studies and a discussion of the theoretical implications was presented in Chapter 8.

Chapter 9 summarises the contribution of the thesis and it is divided into four sections: the first section provides an overview of the whole thesis, the second section details the contribution to the literature, the third section offers the implications for policy, and the fourth section discusses some limitations of this research and suggests some directions for future research.

9.1 Summary

This thesis argues for the need for a more comprehensive discussion on use of biodiversity in relation to enhancing benefits of this use for biodiverse countries and promoting more equitable sharing of these benefits. To that extent, the thesis informs the debate on the implementation of the Convention of Biological Diversity (CBD) and the Nagoya Protocol goals of a fair and equitable sharing of benefits arising from the use of biodiversity. The findings from this doctoral research reveal that biodiversity-based innovation is a social shaping process that has resulted in large benefits, which are not always shared in an equitable way. The cumulative capability to use species from biodiversity gives meanings that contribute to the species shaping process, with organisations and institutional changes providing direction and increasing the rate of the shaping process. In showing how innovation takes place and how the appropriation of benefits occurs, this research contributes to studies on science policy and innovation in relation, especially, to biodiversity-based innovation.

In order to achieve these conclusions, the thesis begins by introducing the Convention of Biological Diversity (CBD) and the Nagoya Protocol as representing changes to the governance of biodiversity. Chapter 2 presents the theoretical approach, which draws on evolutionary (Nelson and Winter, 1982; Edquist, 1997 Ch. 1) and institutional economics (Hodgson, 1988 pp. 140-144; North, 1990), both of which inform and extend a question that is central in the sociology of technology: That is how are technology (innovation understood as an output) and social practices shaped collectively? Sociological approaches have been proposed by scholars from the Social Construction of Technology (SCOT) tradition (Pinch and Bijker, 1984; Bijker, 1995). SCOT studies focused initially on physical objects or artefacts (e.g., bicycles and refrigerators). Chapter 3 presents the research design and the unit of analysis (species) used to define cases. The examination of a species (or a breed within a species) adds to the SCOT literature. Taking species as the unit of analysis allows us to trace what occurs around a well-established concept including the different actors and knowledge areas.

Chapter 4 applies the SCOT approach to naturally occurring biological organisms using the historical case of the Jersey cow. The Jersey cow is a breed within the species *Bos Taurus* or modern taurine cattle, which long-lasting valuation has been well-documented. Information (in the English language) on the Jersey cow breeding process is readily available. This case study is interesting since Europe is not particularly rich in biodiversity. The isolated character of Jersey delimited the scope of the breed at a point in time when it was being bred locally and allow us to identify its shaping as a 'technology', and the broader diffusion of its use. The Jersey cow is used to introduce the theoretical framework and the analysis. The SCOT approach is extended with institutional and evolutionary economics to explain how the sharing of benefits among actors occurs during the shaping process.

Chapter 5 introduces the two Andean case studies. It extends and deepens the research design to include different forms of biological reproduction, patterns of social structure and a historical and contemporaneous background. This extended research design is applied in chapter 6 to maca and in Chapter 7 to quinua. Maca, originally from Peru, is a root crop with nutritional and, allegedly, fertility enhancing properties. It was domesticated in Peru and only a few world regions have conditions favouring its production. Maca is commercialised as flour and used as a raw material; some of its underlying knowledge is protected by patents. The Peruvian Government is disapproving of this patent protection mostly because, this knowledge is the traditional knowledge of Andean indigenous communities. Quinua has great potential as a staple food crop. The United Nations Food and Agriculture Organization (FAO) declared 2013 to be the International Year of Quinoa on the basis of its unique and nutritious character. The cereal quinua is gluten free, but has high protein and essential amino acids content. Three Andean countries (Bolivia, Ecuador and Peru) report exports of quinua grain (FAO, 2017), although dozens of countries around the world are engaged in performing agronomic testing for its commercial production.

Chapter 8 provides a comparative analysis of the three cases, and identifies the science and technology policy issues related to implementation of the CBD and the Nagoya Protocol. The case studies demonstrate the innovation process of species from biodiversity. Benefits arise from the diffusion of the use of the species, which accrued to individuals or groups. The characterisation of the innovation process highlights how the voices and agency of actors and organisations affected the shaping process. The governance over the goods that emerged from the use of the species defined the conditions for the appropriation of benefits.

9.2 Thesis contributions

The thesis contributes to the SCOT approach by considering living organisms (species, breeds, varieties) as artefacts shaped by social practices. Unlike manufactured artefacts, living organisms show a level of obduracy to the shaping process: First, because of technological attributes related to their reproduction by which defining information passes from generation to generation in a range of quite predictable forms (i.e., inherited DNA following genetic laws); and second, because of the limited understanding and limited capabilities of actors to intentionally modify specific characteristics. Our finding highlight the limitations of the SCOT approach in the context of biodiversity based innovation. We proposed an extended approach that includes evolutionary and institutional economic aspects.

The extended approach is useful for giving a more complete account of the shaping process at the micro, meso and macro levels. The thesis proposes a tailored theoretical approach, useful for understanding contemporary discussions of biodiversity-based innovation and the distribution of benefits in biodiverse countries. Organisations and institutional arrangements can provide direction to and increase the rate of the shaping process and, thus, enhance individual actors' capabilities to shape the species.

This thesis adds to debates in science policy and innovation studies, where innovation is seen as being inclusive or democratised (i.e., not confined only to inventors/innovators or firms) (STEPS Centre *et al.*, 2010; Cozzens and Sutz, 2012; Martin, 2012), and scholars have begun to pay attention to the challenges related to socially responsible innovation (Stilgoe, 2015; Martin, 2016) rather than growth as the aim of innovation. By focussing on the agricultural sector, this thesis is responding to these challenges since food production and consumption are closely related to growth as a linear quantity, and the distribution and quality of growth. Based on these three elements (i.e., (i) who have voice and agency in the shaping process, (ii) what is a relevant challenge to tackle and (iii) which are relevant scope of study on policy making), this thesis provides elements for guiding debates on inclusive innovation. For example, in the case of the biodiversity-based innovation, not only researchers take part of the shaping process, but also indigenous people who have had close and long-term contact with species from biodiversity. Also, organisations of users who raise their voice in favour of (or against) a crop and its derivative products, push (or restrict) the demand for them, and in this way define the direction and rate of growth of the shaping process.

This thesis contributes to discussions that connect innovation to studies on use of biodiversity. It shows that the shaping process is influenced by unintentional circumstances (i.e., environmental conditions and those derived from the form of reproduction of species), but has unintended consequences, such as loss of biodiversity (i.e., genetic erosion, and disappearance or reduction of areas of species or varieties that compete with other introduced crop species) due to the diffusion in use of the 'shaped species'.

9.3 Recommendations for policy making and practice

The thesis offers a background and a framework of analysis that could be useful in the context of policies related to use of biodiversity. The proposed theoretical approach explains how biodiversity-based innovation occurs and how the appropriation of the benefits arising from use of that biodiversity takes place, and with this theoretical approach it is possible to analyse the implementation of biodiversity use policy. The case studies show the lack of (or at least weak) ability of biodiverse countries to enforce the CBD and the Nagoya Protocol, given the high costs of excluding actors from using the species from biodiversity (i.e., maintaining control over the species). The situation that happens for seeds and any other reproductive material of species from biodiversity, also occurs with knowledge. In the case of underlying knowledge of indigenous populations, the local scope becomes extended because of the decisions of a single actor; at actor's attempts to address individual needs, they learn new skills and routines, and give access to that knowledge to others. The loss of control over the underlying knowledge occurs through the individual or collective learning by local indigenous communities of lingua franca and of skills such as research or commercialisation. Institutional arrangements, such as markets, and organizations and their interactions, including research centres and universities, define the direction to and increase the rate of the shaping and, therefore, the benefits arising from the use of biodiversity.

Given that, several options for the development of policy are suggested:

(i) influencing the ownership, control over and access to biodiversity (e.g., eliminating/reducing the requirements for accessing the species from biodiversity);
(ii) influencing the codification and articulation of knowledge (e.g., defining incentives for the disclosure of underlying knowledge regarding the species from biodiversity);
(iii) strengthening the organisations and institutional arrangements related to the performance of skills and routines regarding the innovation process (e.g., defining subsidies for research on the species from biodiversity); or
(iv) regulating the complementary means that enhance the capability to appropriate benefits (e.g., promoting the performance of actors that encourage linkages among actors).

The three case studies show the limitations involved in combining policy objectives. For example, decentralised forms of governance, such as those that occur when species are dispersed across several countries, under the control of actors with low bargaining power at the national level, are likely to lead to limited access to biodiversity and low benefits.

Recognising the tension between the different options and objectives (e.g., the two opposite perspectives in the implementation of CBD and the Nagoya Protocol in the case of maca versus quinua), this thesis provides information for stakeholders and adds to the democratic debate among different actors, including policy makers, about possible policies and their implementation.

Regarding the first policy option, the policy perspectives are between two opposite options: *restricting* access to (attempt to maintain control over) species from biodiversity which reduces the possibilities for variations in social practices for using the species, and *promoting trade*, which is likely to increase variation and selection and facilitate biodiversity-based innovation (see section 8.3.2). As discussed in Chapter 1, one of the aims of the CBD and the Nagoya Protocol – to enable greater benefits for biodiverse countries (i.e., growth) from biodiversity, and more equitable sharing of benefits (i.e., social welfare) from the use of biodiversity - is consistent with several objectives, such as: (i) enlarging the population of beneficiaries; (ii) increasing the amount of benefits; and (iii) ensuring an equal access to biodiversity and its underlying knowledge. A combination of options and objectives is possible. In any case, the scope of "fairness" in which this thesis has focused is how more equal benefits for biodiverse countries versus non-biodiverse countries can occur. Therefore, how a larger population of beneficiaries and of benefits in biodiverse countries can take place is a policy objective to be considered, which is consistent with a more open access to biodiversity.

One input to this debate is the consideration that species show particular levels of obduracy during the shaping process. This obduracy is related not only to the technological attributes of the species to replicate its genotype but also to the limited capabilities of the actors. Thus, when government decides to fund organisations that perform research routines, to provide rewards (or sanctions) or to implement *ad hoc* rule-enforcement systems that affect the costs of the shaping process, they should consider the learning process with different species. For some species, a broad and continuous learning process has occurred, while for other species it has not. Thus, the learning process that has often taken place with one species cannot necessarily be used with other species. An example here is kiwicha – when the Peruvian government tried to implement a similar shaping process to that used in wheat or maize (supporting INIA as a breeding research organisation and promoting investment and exports), these policies struggled because, in the case of the research, the breeding techniques were not easily imitated, given the small size of the flower. It can be extremely difficult and costly to implement a research strategy similar to that applied to wheat or maize, to a locally produced species (e.g., the case of maca in the 1980s), where the performance of research routines might be imitated using knowledge with other species with similar technological attributes (e.g., potatoes). The Peruvian government also tried to increase production and exports of maca; the indigenous farmers did not have the skills to replicating on several hectares their actions related to *sharpos* of no more than 100 square metres.

Also, the unintentional circumstances and the institutional arrangements in which the shaping of species takes place, are the background of policy perspectives such as the reference to biopiracy. The two Andean case studies show two opposite perspectives about biopiracy. While in the case of maca any non-authorized movement of reproductive material outside of Peru is considered biopiracy, in the case of quinua there is active promotion of distribution of seed varieties internationally. The identification of Peru as centre of origin of maca has been enough to justify the interest of the Peruvian government in paying the costs of restricting access to reproductive material (and in this way to advocate for the anti-biopiracy discourse), while the shared centre of origin and domestication of quinua between Peru and Bolivia around the lake Titicaca basin and the shared centre of dispersion in most Andean territories (from Colombia to Chile and Argentina) makes it impractical to create access restriction (and therefore little attention is given to the biopiracy discourse).

Further than informing how the discourse regarding biopiracy arises, the thesis challenges the consensus represented by United Nations' Nagoya Protocol and the trend for privatisation of biological resources through the World Trade Organisation's TRIPS agreement. These institutions' aim to achieve fair and equitable sharing of benefits from genetic resources is often interpreted as involving restrictions in access. Actors from developed countries have higher relative bargaining power when actors from developing countries define and enforce the institutional arrangements governing commercialisation, control and ownership of the emerging goods. Institutional arrangements that are based upon the Nagoya Protocol's call to achieve a more equitable sharing of benefits might be better targeted on enhancing the commercialisation of biodiversity-based products in ways that allow developing biodiverse countries to benefit along with their developed country partners.

Based on the findings from the case studies, a second policy option of influencing the codification and articulation of knowledge is suggested. To implement this option, innovation management strategies for maintaining an equilibrium between researchers' scientific knowledge and knowledge held by indigenous communities and farmers (see Ch. 8 Sub-section 8.3.2) are consistent with the interest of this thesis in explaining how to achieve a more equitable sharing (compared to present practices) of benefits between actors involved in the shaping process. This finding applies at the national and international level. Both researchers, in many cases identified with urban areas and developed countries, but also indigenous communities and farmers, identified with rural areas and developing countries, are both capable of taking part in the shaping process.

Species standardisation has been associated with increased benefits, but also with unintended consequences. In each of the case studies, references were made to unintended consequences that diminished welfare. First, loss of control of the cattle by Jersey farmers and smuggling of maca seeds to China, which reduced the respective bargaining power of the Jersey farmers and the indigenous Andean farmers and dealers to appropriate the benefits from the commercialisation of their own production. Second, standardisation of crops/cattle that are commercialised or whose use is diffused worldwide is associated with greenhouse gas emissions (especially in the case of cattle) (McMichael *et al.*, 2007), genetic erosion (van de Wouw *et al.*, 2009; FAO *et al.*, 2015), monoculture and, therefore, risk of pest and disease outbreaks (Francis and Sanders, 1978; Wilby and Thomas, 2002). How these unintended consequences arise, should be considered in the policy making process. These unintended consequences are the result of actors' decisions and social choices and can be avoided. Therefore, careful examination of the paths of shaping offered by several case studies, involves learning to identify potential unintended consequences of the biodiversity-based innovation process that diminish social welfare. The case studies might be inspirations for policies to avoid, minimise or compensate such unintended consequences at an early stage when accountability and control are possible.

Regarding the unintended consequences, a third policy option of strengthening the organisations and institutional arrangements related to the performance of skills and routines in the innovation process is proposed. This should follow innovation management strategies aimed at achieving an equilibrium between scientific research to improve yields, the current predominant focus of agricultural research organisations, and the diversification of crops with species and a set of varieties adapted to the local context, in which indigenous communities have maintain skills and routines (see Ch. 8 Sub-section 8.3.2). In general, developing countries, which have focused their knowledge policies around the NSI concept, in specialised research organisations and institutional arrangements such as in the codification of scientific knowledge, should take up the challenge of opening the scope to other organisations that maintain and diffuse knowledge, their knowledge forms (traditional knowledge) and values (non codified or non articulated knowledge).

The case studies show that one function of government in the shaping process is the promotion of codification of knowledge by increasing the reading and writing skills of indigenous users (i.e., ability to communicate in the *lingua franca*), and the strengthening of open markets and privatisation. However, this can result in the 'picking' of a few species that seem promising (i.e., prioritised ones), thereby, reducing the chances of accumulating and maintaining the knowledge about other species. Both of the contemporary case studies provide examples – a focus on maca led to some other indigenous species (e.g., camelids) being relatively neglected; in the case of quinua, it affected kiwicha (or the introduced species barley and wheat, displaced as a research priority by the Peruvian government). The relative neglect of the species (and the possible loss of underlying indigenous knowledge) can be countered by indigenous users' maintaining skills and routines regarding the 'neglected' species and the associated uncodified knowledge. These two forms of knowledge are 'embodied' by different language speakers. Therefore, this involves maintaining a balance between promotion of a *lingua franca*, such as Spanish or English, and maintaining the rural languages spoken by the holders of local indigenous knowledge (i.e., Aymara and Quechua speakers).

The analysis of unintended consequences reveals other options for policy, such as conservation of biodiversity (in accordance with the CBD and the Nagoya Protocol), which would involve values in use for biodiversity, such as emergency supply (i.e., insurance), aesthetic or recreational (Gurr *et al.*, 2003).[244]

Finally, a fourth policy option of regulating the complementary means that enhance the capability to appropriate benefits is suggested. To implement this option, innovation management strategies driven by a long term perspective are needed. Thus, a tradeoff exists between consolidating a short term growth of benefits based on a shaping process in which few actors with the bargaining power define and enforce institutional arrangements that ensure such benefits and a long-term perspective addressing sustainable growth and a more even sharing of benefits arising from the use of biodiversity (see Ch. 8 Sub-section 8.3.2).

9.4 Limitations and further research

Triangulation enables more generalisation. The multiple case study research design entailed the use of several sources of data to address the research questions. Two approaches to case study selection were followed - selection of a staple (quinua) and of a nutritious/medicinal plant (maca). The findings from these cases could be and corroborated by using similar approaches to collect more data, or could be enriched by different approaches. One possible approach would be the use of case studies of foods with characteristics different from those of staples or nutritious foods, such as their aesthetic attributes (e.g., the Andean crop *Physalis peruviana*). Another approach would be to study species that have remained local and commercialised only at the subnational level (e.g., the Mexican staple *Physalis philadelphica*), or in which the success can be qualified in terms of diffusion of use but not commercialisation (e.g., *Physalis peruviana*, or kikuyu grass, both considered as a weed rather than a crop). A third approach might

[244] Sukhdev *et al.* (2010 p. 7) extended such values in use (benefits) at the level of ecosystems.

be to explore the extent to which familiarity with similar already cultivated species is advantageous for shaping previously unexploited species or how new cultivated species can benefit from local ecological conditions. Finally, it might be possible to exploit the reservoir of genetic diversity remaining after standardisation, which would require local capacities (and knowledge).

Also, the three case studies deserve to be observed in the long term because, in a dynamic context, the three species could be subjected to new meanings that lead to more variation and selection (further stages of stabilisation).

On the other hand, this thesis identified codification as a key element of the shaping process, to the extent that it reduces the costs of exchanging meanings and simplifies the informational character of the meanings given by actors. Future studies could provide a more structured method for characterising the codification of knowledge in terms of the type of knowledge (i.e., defining, ancillary or basic) and the types of language that could be used for articulation (i.e., rural or a *lingua franca*). Characterisation of the codification of knowledge could be an input into the stages that actors follow and how they affect the appropriation of benefits.

The thesis argues also that there is a need for a better understanding of how the patterns of distribution of the benefits occur, moving the focus from explaining the effects (i.e., percentage of people suffering from poverty or undernourishment) to explaining the causes.

Finally, a critical and realistic perspective about the governability (i.e., ability) to enforce policies, and the extent to which such enforcement can affect social welfare would involve further research.

Annex

A. Forms of appropriation in the last century

Forms of appropriation of the benefits from the use of biodiversity emerged in the 20th century. These forms, derived from technological changes and institutional arrangements and complementary means constrain or enhance the capability to appropriate benefits. We present the technological changes and institutional arrangements related to each of the five forms of appropriation of benefits it studied and their effects on social welfare.

A.1 Plant breeders' rights (PBR) protection of new plant varieties[245]

PBR is a *sui generis*[246] form of intellectual property protection specifically adapted to the process of plant breeding, recognised by the UPOV. 'The UPOV plant variety protection system came into being with the adoption of the International Convention for the Protection of New Varieties of Plants by a Diplomatic Conference in Paris on December 2, 1961' (UPOV, 2011). The system provides compensation for investments in breeding *new varieties* of plants that produce improved, and higher quality yields or plants with resistance to certain plant pests and diseases. The protection entitles the breeder to authorise: (i) production or reproduction (multiplication); (ii) conditions for

[245] Due to the biodiversity of plants, they are ranked in systems of divisions and subdivisions. The broadest classification unit is 'species'. For UPOV, species denotes 'a group of organisms' that share 'a large number of heritable' attributes, but that cannot inter-breed by natural means with other species. Plants can vary widely. Farmers and growers chose plants that were well adapted to local natural and social conditions. Their worth is based on repetitive selection practices performed by indigenous communities and farmers for thousands of years. However, understanding of genetic laws in the 18th century allowed more systematic plant breeding. The concept of plant variety refers to specific desired attributes within a species. The UPOV Convention defines plant variety as 'a plant grouping within a single botanical taxon of the lowest known rank, which grouping, irrespective of whether the conditions for the grant of a breeder's right are fully met, can be (i) defined by the expression of the characteristics resulting from a given genotype or combination of genotypes, (ii) distinguished from any other plant grouping by the expression of at least one of the said characteristics and (iii) considered as a unit with regard to its suitability for being propagated unchanged' (see UPOV, 2011).

[246] This is a *sui generis* system that is distinguished from the traditional patent system by'the absence of a test for inventiveness or merit test for new varieties, the relaxed requirement for novelty and the unique method of disclosures' (see Rangnekar, 2000) P.53.

propagation; (iii) sale; (iv) marketing; (v) export; (vi) import; and (vii) stocking of the seed of the protected variety or any propagating material, for any of the purposes mentioned in (i) to (vi) above. Lack of protection can lead to free riding; it might be easy to reproduce a variety without compensating the breeder (UPOV, 2011).

Benefits appropriation is achieved through the licensing out by the breeder (e.g., a university or a research centre) to an intermediary user (i.e., usually a seed company) to allow it to reproduce and commercialise the protected variety. Protection is a rights-based means while breeding knowledge and access to authority are structural and relational means that enhance the appropriation of benefits through PBR. Similar to the case of cultivation/husbandry, access to land, capital, market and labour are means that support the appropriation of benefits derived from the revenue obtained from reproducing seed and selling the product (raw or as a processed good) to a final consumer.

Rangnekar (2000) provides a critical review of studies on the relationship between PBR protection and further investment and finds no evidence that implementation of PBR protection in the 1960s encouraged investments (i.e., new firms in plant breeding programmes or private R&D expenditure) to obtain further varieties (Rangnekar, 2000 pp. 31-6). In the USA, there was a rapid increase in investment in the 1960s, previous to the introduction to the PBR protection law, 'due mainly to those firms with older plant breeding programmes, possibly in anticipation' of the law (Butler and Marion, 1985 cited in Rangnekar (2000)). Private breeders in countries such as the USA and the UK, before the creation of the PBR protection system, benefited from government public research, whose results were made publicly available. PBR protection allowed private breeders to appropriate the benefits from public research. However, the introduction of the PBR system coincided with a dramatic reduction in public research on breeding (Rangnekar, 2000 p. 53).

At the international level, developed countries with strong corporate breeding and scientific institutions, farmers had access to new improved varieties, while in developing countries farmers continued to use lower yielding seeds and had very limited access to protected varieties suited to local conditions (Srinivasan, 2003 p. 537). In some developing countries PBR 'did facilitate access to improved foreign varieties but contributed little to food security' (Singh, 2007 p. 398).

A.2 Patentability of live matter: From plants to microbes

The patent system is a form of intellectual property protection for inventions. It was agreed at the 1883 Paris Convention on Industrial Property (Bodenhausen and BIRPI, 1968). The Paris Convention was a first step towards helping creators 'ensure their intellectual works were protected in other countries' (WIPO, 2016). The 1994 Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) , which sets minimum standards for many forms of intellectual property in international trade, based on the Paris Convention and other important agreements, was the mechanism that introduced widespread protection and currently more than 110 members of the World Trade Organization (WTO) subscribe to TRIPS. In the case of plants, Article 27.3(b) in TRIPS requires WTO member states to introduce forms of intellectual property rights in plants through patenting, PBR or an 'effective *sui generis* system' (WTO, 2016), while maintaining the patentability of micro-organisms, and non-biological and microbiological processes.

The patentability of microbes had a legal decision when the TRIPS were approved. It resulted from a long appeals process (Chakrabarty v. Diamond) in the US courts, which in 1980, decided that genetically modified bacteria were patentable. Commentators, such as Kloppenburg, consider that this decision led to the decision on the patentability of any form of 'live' invention 'as long as it meets the criteria of novelty, utility, and non-obviousness (inventiveness), and as long as it is a product not of nature but of human manufacture' (Kloppenburg, 2004 p. 262). Novelty is evaluated by patent examiners based on searches in knowledge databases. Several patent applications based on plants used traditionally by indigenous communities, have been submitted by universities and private companies to the USPTO, the European Patent Office and the Japanese Patent Office. It has been acknowledged that, only some indigenous knowledge is articulated and codified in local databases and these are not used by patent examiners. Also, the mechanisms available to indigenous communities to challenge the granting of a patent are complex and costly (see Indecopi, 2003).

Similar to the PBR, patent protection is seen as providing a means to compensate inventors by imposing a time limited period when exploitation of the invention would be rewarded. The inventor (or the applicant) has access to the structural and relational means of the authority that grants the patent (i.e., national patent office), and access to capital and market, which enhance the inventor's capabilities to appropriate benefits. Patent protection grants to the inventor or patent applicant the right to license the invention or to prevent others from producing, using, selling, importing, or distributing the patented invention.

The patentability of live matter has been criticised because it has reduced the exchange of genetic resources from biodiversity, which are fundamental for continuous breeding. 'New improved varieties are the result of crosses of locally adapted material' (Rangnekar, 2000 p. 46). The enactment of PBR legislation and introduction of patenting were used as pretext to limit public breeding programmes efforts (Kloppenburg, 2004 p. 323). They imposed high costs of entry to the market for new entrants. For example, a new entrant had to bear the costs of developing parental breeding material to obtain new breeds whereas, in the first half of the 20th century, those costs had been borne by the public sector (Rangnekar, 2000 p. 49) and 'expropriated' by the private sector, along with the benefits from the use of those materials. Both the PBR and patenting of live matter systems, overlook the breeding efforts of indigenous people and farmers, over thousands of years of domestication, based on mostly unarticulated.

A.3 The patentability of compounds of biodiversity

In the USA, the patentability of compounds from units of biodiversity is based on a broad interpretation of the USA Patent Act, which denies the patentability of *discoveries*. It states 'that an invention that makes *practical use of a discovery* can be patented' (Parry, 2004). This means that both the *processes* used to isolate a natural substance and the *compounds* obtained from such isolation are patentable.

While patentability of processes is common in many countries and is part of the TRIPS (Article 27.1), compounds generally are patented as formulations, which are combinations of more than one compound. The pharmaceutical industry has long experience of patenting pure and mixed forms of natural compounds and appropriating the benefits from their commercialisation.

Several organisations have access to the structural and relational means, such as the access to the authority that grants the patent, and access to capital, markets and knowledge, all of which enhance their ability to appropriate the benefits from biodiversity. Access to knowledge is related to the chemical extraction of compounds, their identification and their replication, while access to capital and market enhances the ability to produce compounds on a large scale and to commercialise them as both raw materials for industry or as processed good for final consumers.

Plants compounds used in drugs are commonly discovered in the course of follow-up ethnomedical uses. Thus, traditional knowledge associated to the use of the plants is considered, but not rewarded, which is similar to the situation related to live matter patents. Ethnomedical-based approaches to identify plant compounds favour the random collection of plants because 'one can rationalise that any isolated active compounds from the plants are likely to be safer than active compounds from plants with no history of human use' (Fabricant and Farnsworth, 2001 p. 74). However, implementation of the CBD has increased the costs of ethnomedical approaches. So, industrial approaches, based on 'random collection, followed by automated, robotized, *in vitro* screening' are being implemented by industry (Fabricant and Farnsworth, 2001 p. 74). These approaches differ in their requirements for pursuing industry's goal of obtaining synthetic derivatives that a less toxic and more effective.

Sterckx (1998) criticises the patenting of compounds from living organisms for ethical reasons. He considers that the isolation of a natural element using technical means is not an argument for their patentability given that the act of isolation does not change their 'naturalness' (Sterckx, 1998 p. 124). He considers patenting of compounds from living organisms to be ethically problematic since it could lead to patenting naturally occurring compounds in human beings. Since the act of isolation transmutes a 'naturally occurring phenomenon' to a 'non-naturally occurring phenomenon', Sterckx considers this to be a discovery, which is a category that is excluded from patentability.

A.4 The commodification of bio-information.

Information technologies translate some commodities into highly mobile informational forms. The information embodied in or represented by a physical object (such as a book or a compact disc), becomes available in new forms. Those forms can be replicated, combined and modified more easily than their physical counterparts. Similarly, biotechnologies can enable biological materials to be 'stripped down, or rendered, in new more artifactual or even purely informational forms (i.e., codified forms): As cryogenically stored tissue samples, as extracted DNA, as cell lines, MRI scans, or sequenced DNA codes onto databases' (Parry, 2004 pp. xviii-xx). These new artefacts provide genetic and biochemical material and information or 'bio-information', of interest to the life sciences industries.

Following the broad interpretation of the USA Patent Act regarding the patentability of inventions that make *practical use of a discovery*, in 1995, the United States Board of Patent Appeals decided that not only were multiple varieties of plants patentable but also 'the individual components of these varieties: DNA sequences, genes, cells, tissue culture, seeds and specific plant parts as well as the entire plant' (*Ex Parte Hibbert*) (Parry, 2004 p. 89). This decision supported patentability of the use of any form of 'living organism' capable of allowing such practical use.

Thus, companies in the life sciences sector have access to structural and relational means, such as access to the patent authority, and access to capital, market and knowledge, which enhance their ability to appropriate benefits. Access to knowledge allows codification and decoding of the information related to the individual components of plant varieties, and use of this information for breeding or the development of new compounds. Access to capital and markets allow the production of compounds on a large scale for commercialisation.

The immaterial character of biological materials, which are easily transferable, copied or replicated using information technologies, raises the question of unauthorised use of, replication of and modification to information-based products (Parry, 2004 p. xix). In this case, actors in developing countries that are the providers of raw materials became more substitutable.

A.5 The CBD and the Nagoya Protocol: The public or private form of governance of benefits to be appropriated

The Nagoya Protocol is derived from the UNCED Agenda 21 declaration, which culminated with approval of the Convention of Biological Diversity. The Convention considers the environment and development in tandem rather than separately. Thus, the environment and biodiversity are understood as 'crucial for development', as resources suitable to be developed economically which deserve to be conserved (Parry, 2004).

State sovereignty is a rights-based means to allow appropriation of benefits and assigns gives to a national authority of legal-access maker. The CBD considers that biological resources include genetic resources and states that attempts to access and use genetic resources are subject to PIC from the contracting party, and MAT between the provider and user of those resources. These conditions relate to: (i) access to and use of the resources; and (ii) the benefits which should be shared by the parties.

The CBD balances two opposing positions, debated by the FAO since the 1970s, on the role of biodiversity in food and agriculture. Some countries advocate for open access to biodiversity, which ensures inputs to obtain new products (e.g., *new varieties*) for commercialisation. They argue that genetic resources constitute 'a common heritage of mankind, [that] consequently should be available without restriction' (FAO, 1983). In turn, these countries offer technologies (i.e., high quality seeds commercialised by private breeders or seed companies) and knowledge (i.e., public and private funded agricultural research centres), which, they claim, increase crop yields and reduce hunger around the world. The innovative condition of those technologies and knowledge are rewarded through institutions that ensure and defend PBR and the appropriation of benefits from using those technologies (i.e., UPOV and patents). On the other hand, biodiverse countries claim that there is no 'common heritage' and argue for sovereign control over biodiversity combined with cooperation and exchanges in relation to particular resources (Mgbeoji, 2003) (see Ch. 1 Section 1.1).

The CBD exploits the FAO's principle of 'common heritage of humankind' and reaffirms the sovereign rights of *nation states* over their biological resources. The CBD requires that states ensure the benefits from the use of biodiversity are shared in a fair and equitable way, although it does not define the scope, which could be several actors or organisations (i.e., states) or individuals. Critiques of this lack of scope in the CBD led to discussion and approval of the Nagoya Protocol two decades later. The Protocol is claimed to be a 'transparent legal framework for the *effective implementation* of one of the three objectives of the CBD: The fair and equitable sharing of benefits arising out of the utilization of genetic resources' (CBD, 2017a emphasis added).

There are two competing interpretations of the CBD and the Nagoya Protocol. Some assume a 'common heritage of mankind' model that accompanies an institutional design, and that intellectual property rights do not apply to natural products, although 'modifications' to natural products can be awarded intellectual property rights protections. The CBD and the Nagoya Protocol have changed the institutional arrangements and suggest the need for 'historical reparations' on the basis of the reaffirmation of territorial sovereignty over biodiversity. This is a very broad interpretation of the CBD and Nagoya Protocol and is unlikely to be enforceable.

The alternative interpretation is forward-looking in relation to the exploitation of biodiversity. It is interested in and committed to ensuring 'that contemporary collecting programmes are less exploitative than their forerunners' (Parry, 2004 p. 96). The Nagoya Protocol tries to maintain a balance between access to and benefits from biodiversity by preventing foreigners (i.e., non-authorised users) from 'borrowing' resources from biodiversity without fair and equitable sharing of the subsequent benefits with the provider country (or countries) of those resources, but without restricting the access to those resources in such a way that it could limit the opportunities for innovation. Also, since most of the efforts and most of the rewards are due to theto innovation rather than to the discovery, the protocol promotes cooperation between developed countries and biodiverse developing countries, and promotes capacity building in the latter.

In the case of implementation of regulations, Ribot and Peluso (2003 p. 170) indicate that nation states tend 'to be selective along a number of economic or social lines' since only some actors develop skills for understand the regulation, how to apply it and the other structural and relational means to apply it (i.e., capital or market). Also, 'legal, customary and conventional authorities may also compete or conflict in the sense of overlapping jurisdictions of authority' (Ribot and Peluso, 2003 p. 170), as in the case of indigenous people whose relation to biodiversity precedes the law, for which they are entitled to particular rights. Finally, NGOs and scientists are able to create knowledge that constrain the appropriation of benefits (Ribot and Peluso, 2003 p. 169) from biodiversity by individuals, by considering such knowledge as ‘national commons’ or public goods.

Appendix

A. Standard Interview Guidelines

English Version [in *italic* those elements adapted regarding the species, organisations, or reported background to the question]:

‘I am conducting my research based on the assumptions that at the time we use biodiversity, public and private goods are created and those define the conditions for social welfare and wealth generation. Regarding his/her background as [*mention the name of their role*] in [*mention the name of the organisation*], I wonder about your experience about [*mention the species in which they have experience, maca or quinua*]. Please, in your answer consider the process in the last two or three decades’.

Topics to ask.

i. SPECIES USED. The organisation in which you work has reported [*research results/sales/production*] on [*the species*] in the last [*mention the period of years*]. In fact, you have [*Example, mention the experience, such as their role in the International Year of Quinoa*].

• Question: Is this [*Example, such as increase of production and productivity*] a motivation for [*name of the organisation*] in its work on the species? Why is that the main motivation for working on [*the species*]? How different was this process of what has happened with [other species, such as maize or potato]?

• Question: Has this motivation changed in the last three decades?

• Question: From where and from whom did [*name of the organisation*] obtain the quinua materials? Which collection of [*the species*] material does [*name of the organisation*] have?

ii. USES. [*name of the organisation*] maintain [the species] [*Background of the current use, such as collection, is promoting the use and is researching on adaptation of material to different agro-ecological conditions*].

• Question: Which uses [*name of the organisation*] does not give to [the species]? In situ conservation, social promotion, marketing, commercialization, providing free samples, for example? Why?

• Question: Which other kind of [main activity] is [*name of the organisation*] doing around [the species]? (agronomic, genomic, breeding, transforming, economics, social impact)

• Question: How has [*name of the organisation*] obtained the knowledge about [the species]?

iii. ADVANTAGES AND PROBLEMS. [*Reference to reported organisations experience and problems regarding the use of the species, such as resources for research and development are limited*]

• Question. Have [*name of the organisation*] had any advantage or problem at the time that that use [the species]? If yes, which are them? (internal or external interest / opposition, other priorities as maize or rice or potato, similarity / differences to model plants, researchers with / without experience, susceptibility / tolerance / resistance to diseases, recalcitrant / orthodox seeds).

• Question: Have that perception changed in the last decades? If yes, how the perception has changed? Are different materials [coloured or not, accessions, breeds, traits, taxon] of the quinua been involved in this change? Have [*name of the organisation*] changed the form you make research about [*the species*] in the last decades? Why did [*name of the organisation*] change the perception of those materials?

iv. GOODS: PUBLIC OR PRIVATE? As I understand, the main products that [*name of the organisation*] has been involved around [*the species*] [*mention reported experience of emerging goods from the use of the species*].

• Question: Is it evidence of the public or private character of those goods or services? Why do you consider this public [or private] condition of the good (service)?

• Question: How each of those products has changed during the time? For example, the number of adapted varieties / articles / materials in the collection has increased during the time or the character as now they are more public/private, or the emphasis has changed (i.e., varieties are now adapted to coast or passed from agronomic to genetic modified crop)?

• Question: Who is involved in the production /delivery of the varieties? Are all of them [*name of the organisation*] researchers? Have you received support from producers or farmers? Have you used field trials?

v. BENEFITS.

• Question: Which benefits do [*name of the organisation*] has from making [*the organisation main activity*] of [*the species*]? How those benefits have changed during the time? Is any benefit for the breeder / experimental station / research group for obtaining a new adapted variety? Or any benefit for those who write articles in international journals?

• Question: How do [*name of the organisation*] clients [*consumers, farmers or producers*] achieve the benefits from your products / services? Which are the requirement for your clients (users of your product or service that you produce) for obtaining the benefits of the product or service that you produce (minimal amount of land, education, technical assistance)?

vi. OTHER USERS. Background about reported organisations with the same use of the species. Example. Five Universities in Peru report studies of [*the species*], and some research centres abroad report more results, especially in Bolivia.

• Question: How different is [*name of the organisation*] from other research centres that work in [*the species*]? Opportunities: Class (access to assets, knowledge), race, gender, ethnic (language), geographic dimension; Output (quality of life): Income, wealth, education, health.

• Question: How those differences are related with the way that [*name of the organisation*] make research in [*the species*]?

• Question: How equal/unequal do [*name of the organisation*] consider are the benefits that [*name of the organisation*] obtain or that researchers obtain?

vii. VARIETY. The most commercialized [*the species*] is variety [*name of variety*].

• Question: Who was a key player in obtaining that variety? It was a public organization/private company who lead the process? Which was the role of that key player? How it happened (step by step)? [institutional design]

• Question: How standardized is this product? Can this variety be commercialized freely by anyone who has seed available?

QUESTIONS FOR SNOW BALLING

Which countries / companies / organizations / users are using [*the species*] in other way that you consider is important for this research?

Do you know somebody or any reference that will be important to know?

B. Codes and profile of the interviewees

FIGURE 1. INTERVIEWEES BY SPECIES

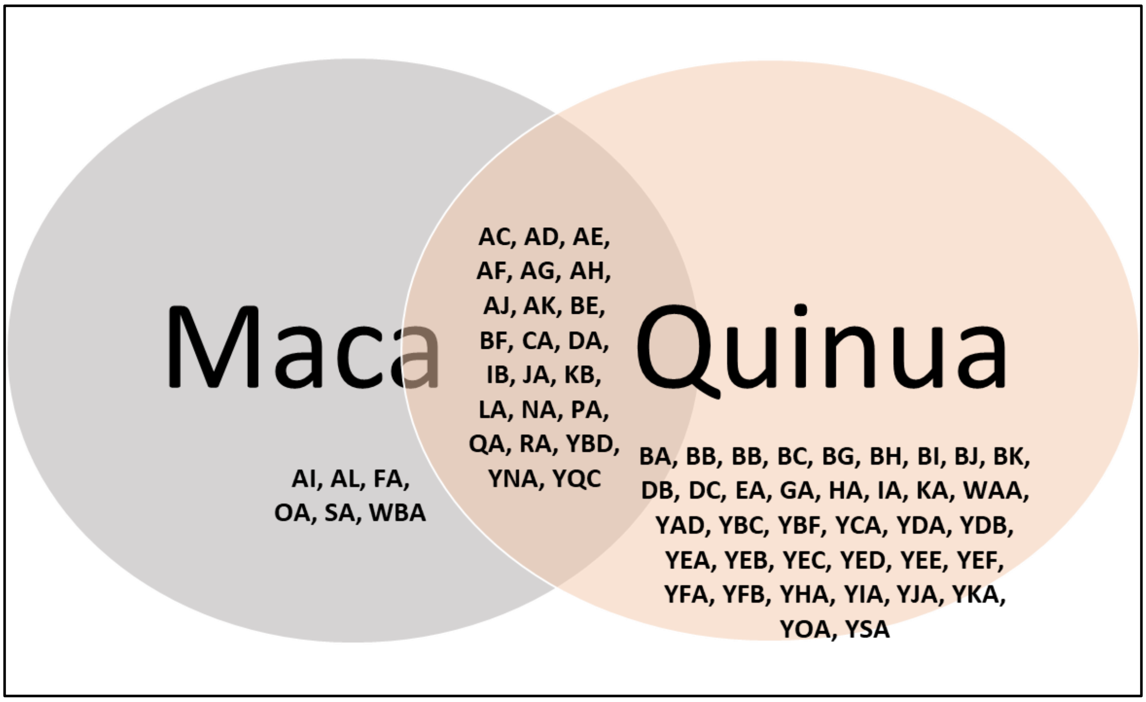


FIGURE 2. INTERVIEWEES BY COUNTRY

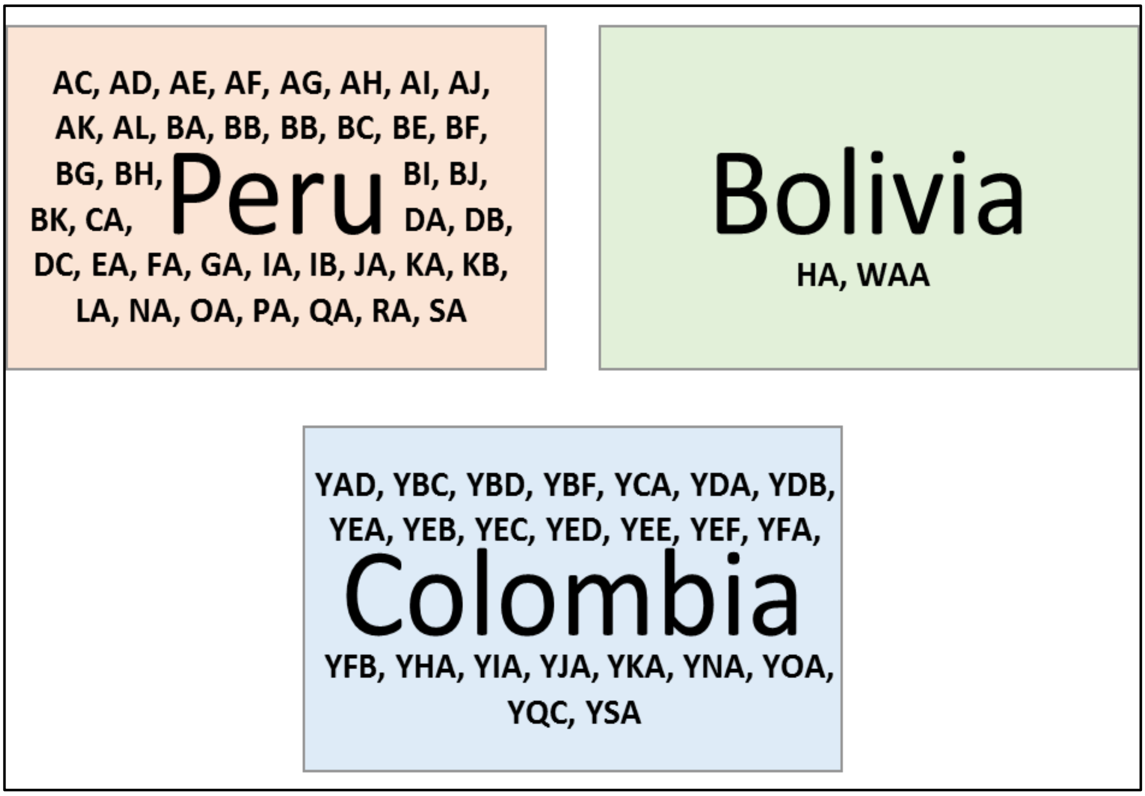
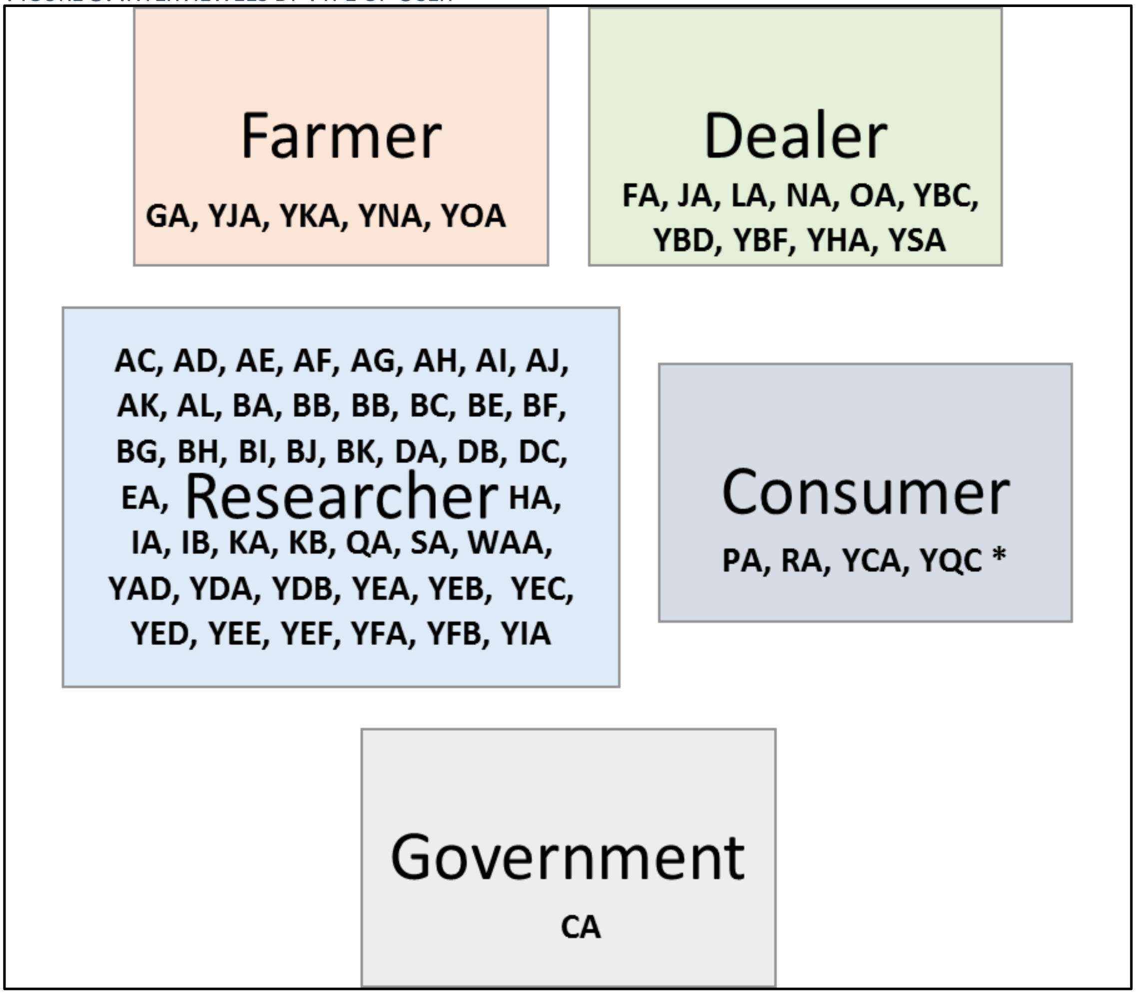


FIGURE 3. INTERVIEWEES BY TYPE OF USER



* Include specialised consumer, such as chefs.

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