Capacity Accumulation in Three Natural Resource-based Industries in Chile: The shifting roles and positions of doctoral graduates

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Declaration

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.

Signature:

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Table of Contents

List of Abbreviations and Acronyms

ASOEX	Asociación de Exportadores (Exporters' Association)
BCC	Banco Central de Chile (Chilean Central Bank)
CIMM	Centro de Investigación Minero y Metalúrgico (Research Centre for Mining and Metallurgy)
CINDA	Centro Interuniversitario de Desarrollo
CNIC	Consejo Nacional de Innovación para la Competitividad (National Council for Innovation for Competitiveness)
CODELCO	Corporación Nacional del Cobre de Chile (National Copper Corporation of Chile)
COCHILCO	Comisión Chilena del Cobre
CONICYT	Comisión Nacional de Ciencia y Tecnologia (National Science and Technology Council)
CORFO	Corporación de Fomento y Reconstrucción (Government Agency for Production Improvement)
CRUCH	Council of Rectors of Chilean Universities
D	Demand
ECA	Empresa de Comercio Agrícola
EU	European Union
FAO	Food and Agriculture Organization
FDI	Fondo de Desarrollo e Innovación
FIC	Fondo de Innovación para la Competitividad (Fund for Innovation for Competitiveness)
FONDECYT	Fund for Development of Science and Technology

FONDEF	Fondo de Fomento al Desarrollo Científico y Tecnológico
GCM	Great Copper Mining
GDP	Gross Domestic Product
HDCA	Human Development and Capability Association
ICTs	Information and Communication Technologies
IFOP	Istituto de Fomento Pesquero (Institute for Development/Enhancement of Fisheries)
INE	Instituto Nacional de Estadísticas
INIA	Instituto Nacional de Investigación Agropecuario (National Institute for Agricultural Research),
INTESAL	Instituto Tecnológico del Salmón SA (Technological Institute for the Salmon Industry)
IPRs	Intellectual Property Rights
ITT	International Telephone and Telegraph Corporation
KE	Knowledge Exchange
MECESUP	Fund for Improvement of Quality in Higher Education
NGO	Non-governmental Organisation(s)
NIS	National Innovation System(s)
NLS	National Learning Systems
ODEPA	Oficina para el Desarollo y la Producción Agrícola
R&D	Research and Development
S	Supply
SAG	Servicio Agrícola y Ganadero (Agriculture and Livestock Service)

SERNAGEOMIN	Servicio Nacional de Geología y Minería (National Service for Geology and Mining)
SI	System(s) of Innovation
SME	Small and medium sized enterprises
SONAMI	Sociedad Nacional de Minería (Confederation of Mining Enterprises)
SSI	Sectoral System(s) of Innovation
SLS	Sectoral Learning System(s)
UN	United Nations
UNDP	United Nations Development Programme
US	United States
VET	Vocational Education and Training
UNDP	United Nations Development Programme

List of Figures

List of Tables

UNIVERSITY OF SUSSEX

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SUMMARY

Understanding technical change in late industrialised economies is the general area of this thesis. There is a lack of research and policy advice on how industry sectors develop active technological learning, particularly in economies based on natural resources and in contexts of poverty and inequality. The thesis is framed by the challenges related to production and economic performance.

This thesis compares three natural resource-based industries in Chile - copper mining, fruit growing and salmon farming – focusing on the participation of doctoral graduates, taking a historical perspective. Doctoral graduates represent a small fraction of the population, but their importance in the advancement of knowledge and technological change is considered strategic. The thesis research questions are: how do doctoral graduates participate in the accumulation of producer capabilities in industry sectors; what factors are important for their participation; and what are the implications for public policy?

The thesis adopts the concept Sectoral Learning Systems (SLS) (adapted from Viotti, 2001) and applies the producer capability approach (von Tunzelmann and Wang, 2007; von Tunzelmann, 2009), which is an alternative approach to conventional production theory, to understand the practice of doctoral graduates in relation to technological change. Policy analysis and recommendations are based on the concept of system alignment (von Tunzelmann, 2010), which offers possibilities for governing systems in which agents may have contradictory views and positions. Throughout, the thesis is underpinned by Bourdieu's (2005) economic anthropological approach. His notions of field, habitus and capital are reinterpreted within the more specific science, technology

and innovation studies literature. This thesis constitutes an interdisciplinary endeavour that integrates approaches from different academic traditions such that all are essential for achieving the research findings.

In terms of methodology, the thesis draws on a historical study of coevolution of technology and governance for each of the three industries, complemented by in depth individual case studies. Through analytical inference, I locate doctoral graduates in the history of each field. The analysis is illustrated by the case studies of doctoral graduates' careers. By applying the producer capability approach, I deduce the likely accumulation of scientific capabilities by doctoral graduates in each field. The results of the comparison show that copper mining, fruit growing and salmon farming display similar patterns of development in relation to their respective incorporations into the technological revolutions in each industry field. In all three cases, the state played an important role in the emergence of these industries at the national and international levels. The establishment of these industries was succeeded by periods of high profits, adoption of new technologies and low levels of innovation, followed by intense process innovation and increasing competition, and finally a period of concentration and re-structuring characterized by the development of networks of suppliers and oligopolistic industry structures. Product diversification in the dominant technological paradigm appeared towards the last period.

Doctoral graduates emerged as scientific suppliers to the industries, when these industries embarked on the phase of intense process innovation, which increased demand for scientific possibilities supplied by doctoral graduates. The level of demand often was related to industry subsidies, particularly important in the fruit and salmon farming sectors. Doctoral graduates participated in active technological learning in less mature technology contexts, and in systems where the dominant producers had the capabilities for improvement and innovation. Once doctoral graduates had a position as scientific suppliers, they actively maintained and enhanced their participation in the field. Doctoral graduates also participated in shaping the structure of the fields, and in influencing policy

The thesis derives policy recommendations to strengthen active learning, particularly in relation to new product development, based on the understandings and the lessons drawn from history.

Chapter 1. Introduction

This thesis aims at understanding how doctoral graduates participate in the accumulation of producer capabilities in industry sectors, which factors are important, and the implications for public policy. The research strategy consists of historical comparison amongst three industry sectors in Chile – copper mining, fruit growing and salmon farming.

Chapter 1 presents the context for the thesis. It describes the general characteristics of the three industry sectors in relation to Chile's economy (Section 1.1), provides a historical perspective on Chile's economic policy (Section 1.2) and public policy in relation to doctoral graduates (Section 1.3), and describes the population of doctoral graduates in Chile (Section 1.4). Chapter 1 concludes by describing the motivations for the thesis (Section 1.5).

Chapter 2 reviews the main theoretical sources drawn on for this thesis and discusses their application and the way that the different perspectives included are related. Chapter 3 presents the methodology used to study the sectors; it is based on secondary data and the development of individual case studies as examples to illustrate and inform the examination of the three industries. Chapter 4 introduces the empirical background to the individual case studies - the field of higher education, which is inter-related with the sectoral fields. Chapters 5 to 7 focus on copper mining, fruit growing and salmon farming respectively. The three chapters are organised along the same lines: they start by mapping the field from the perspective of historical coevolution of governance and technology; then locating doctoral graduates' experience within the field; finally, analysing practice in the field and its effects on the individual's capability accumulation. Chapter 8 presents a comparison of the three sectors in terms of their history, the horizons for doctoral graduates, and the alignment of systems and networks from the perspective of doctoral graduates. Chapter 9 concludes the thesis by referring back to the research questions and discussing the contributions, limitations and scope of the thesis. The concluding discussion refers to the study of sectors and doctoral graduates' careers, use of theory, and application of methodology.

1.1 Copper Mining, Fruit Growing and Salmon Farming in Chile's Economy

This section provides the local economic background to the sectoral studies. It provides descriptive economic data on the participation of the sectors in Chile's production output and exports. The episodes behind these data - as I understand them (see Chapters 5, 6 and 7) – reflect the characteristics described by the Chilean poet, diplomat and educationist, Gabriela Mistral: 'Something of a telluric speed has driven the development of modern Chile. Its evolution seems to be at a forced pace in the sense of urgency of the good forge when it needs to offer immediate service' (Mistral, [1934]1994, my translation).

Chile belongs to the group of middle income countries. It is a small, very open economy with good economic performance in the context of the Latin American region (OECD, 2012). International evaluations consider Chile's macroeconomic management and stability since 1990 to be important assets; its economic growth has had positive effects on alleviating poverty although the distribution of income remains very unequal (OECD, 2007, 2012). In 2009, Chile became a member of the OECD group of countries.

All three industry sectors – copper mining, fruit growing and salmon farming – compared in this thesis are important in the national and/or regional level local economies, and are export oriented. Table 1.1 shows total gross domestic product (GDP) and the share of these economic sectors in 2011. Table 1.2 shows total exports and share of exports by sector. Copper represents a majority of mining exports and fruit a majority of agricultural exports. Imports of copper and salmon are non-existent and imports of fruits are insignificant.

Table 1.1 Total GDP and Share by Selected Sectors: 2011

Population		17,269,525		
GDP $USm.	245,372	**GDP/capita $US.**		14,208
		% share of GDP		
Agriculture-Forestry	**Salmon***	**Mining**	**Manufacturing**	**Other**
3.0	1.0	16.6	11.9	68.1

*Chilean National Fisheries (SERNAPESCA) data

Source: Author's elaboration of BCC data.

Table 1.2 Total Exports and Share by Selected Sectors: 2011

Trade Indicators	Total Exports	Copper	Total Mining	Fruit	Total Agriculture	Salmon
US$m	81,411	44,438	48,865	4,274	4,947	1,853
Percentage (%)	100	55	60	5	6	2
	Total Imports					
US$mn	70,619					

Source: Author's elaboration of BCC data

Table 1.3 shows changes in the structure of production between 1960 and 2010. The manufacturing sector includes economic activities related directly to natural resources, for example, production of pulp and paper, timber and wood, food (which includes salmon). The growth of transport and communications can be explained in part by the processes of privatisation in the 1980s (affecting motorways and other infrastructure). The sector showing the highest growth is financial activities, which reached 18% in 2010, based on only internal demand. This sector share is high in international comparisons; the EU country average was 6% in 2010, and for the UK (which exports financial services) was 7% (OECD Statistics, 2012). OECD data for Chilean sector GDP does not match Chile's BCC's; however, in both cases, the dominance of copper and the relatively modest contribution of agriculture are clear. Policy discourse in Chile has been dominated by an increasing focus on clusters and export diversification in agriculture, forestry and manufacturing (see Section 1.2), whose share of GDP has shown a decreasing trend.

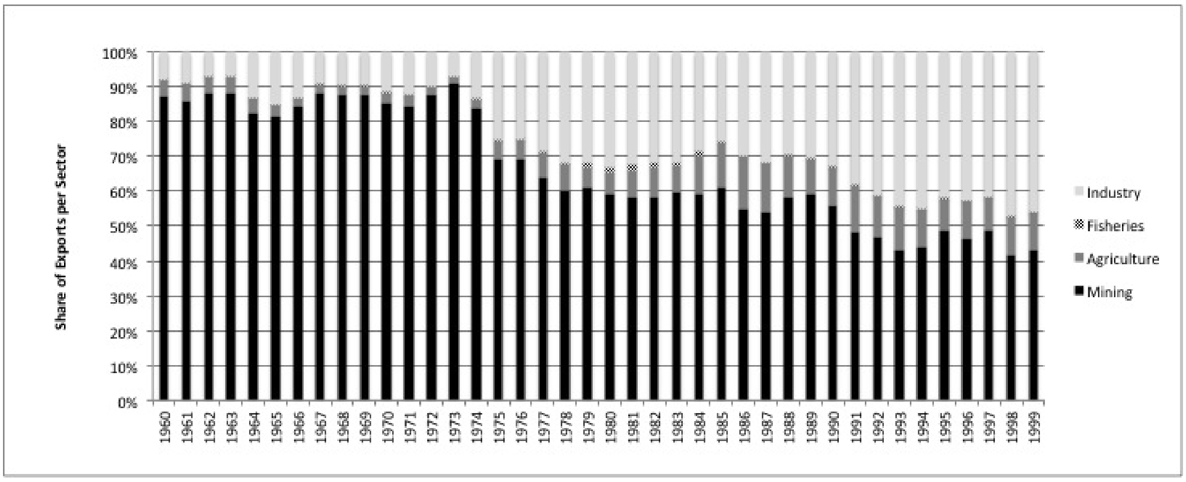
Table 1.3: Chile's GDP by Economic Sector (percentages 1960-2010, selected years)

Economic Sector	Percentage of GDP					
	1960	1970	1980	1990	2000	2010
Agriculture and Forestry	11	8	8	9	7	4
Fisheries	0	0	1	1	2	1
Mining	8	7	7	10	11	7
Manufacturing	23	26	22	19	16	15
Electricity, Gas and Water	2	2	2	2	3	2
Construction	8	8	5	6	5	7
Commerce	18	17	19	16	19	12
Transport and Communications	4	5	6	8	10	12
Financial Activities	3	5	10	14	15	18
Real Estate	7	7	6	5	4	6
Public Services	6	5	5	4	2	4
Personal Services	11	11	10	8	6	12

Source: Author's elaboration of BCC data.

The composition of exports has changed over time and has reduced the disproportionately high dependence of Chile on copper mining (Figure 1.1), although copper continues to be Chile's main export earner, with a share of 50%-60% between 2000 and 2010 due to higher copper prices. Although the export share of copper has decreased, the volume and value of copper exports have grown since 1960 (see Ch. 5).

Figure 1.1 Total Exports by Economic Sector: 1960-99



Source: Author's elaboration of DB Central Bank, Chile data.

The three industry sectors are not close geographically. The country of Chile is a long strip of land on the south west coast of South America, flanked on the east by the Andes mountain range and on the west by the coastal mountain range. Its unusual geographical layout includes a huge diversity of climates and geography. Chile extends roughly from 17^{o} to 56^{o} south (excluding Chilean claims on Antarctica). An equivalent location in the northern hemisphere would run from north of Edinburgh in Scotland, to Timbuktu in Mali on the southern edge of the Sahara desert. Copper mining in Chile is located primarily in the desert in the north of the country; the best fruit growing conditions are in the central valley half way down the country's length in an area characterised by a Mediterranean climate; salmon farming is conducted in the fiords in the far south of Chile.

1.2 Chile's Economic Policy

This section provides some background to economic policy – macroeconomic management and central government industrial strategy - generic for the three sectors in the study. Chile's economic policy in 2011, whose origins can be traced back to 1973, is the relevant context for the policy recommendations in this thesis.

Chile can be described as a liberal economy, that is, an economy ruled by markets in which the state compensates for market failures. According to Collier and Sater (1996: 364), 'the Chilean road to capitalism'[1] started with the military dictatorship under

[1] Here, 'capitalism' is synonymous with 'liberal economy'.

General Pinochet. When the military took power in September 1973, it sought expert advice on economic policy. The experts were a group of economists inspired by the University of Chicago's Economics Department, nicknamed 'the Chicago boys' (Collier and Sater, 1996: 365; Meller, 1996: 193). Their advice was influential during the early years of dictatorship; members of the group were appointed to the Ministries of Finance and Economics, and to the State Planning Office, ODEPLAN.

The Chicago boys believed that state intervention in the economy produced distortions and inefficiencies, which they observed had been growing in Chile since the 1930s, reaching a peak during the 1970-73 socialist government (Meller, 1996). The Chicago boys wanted to remove state intervention and advocated an open economy. Their immediate measures to stabilise and reactivate the economy were abolition of price controls and currency devaluation; followed in 1975 by 'shock treatment' to control inflation (reduction in public expenditure by 75%, tightening of money supply, and trebling of interest rates) (Collier and Sater, 1996; Meller, 1996).

Despite the deep recession in 1975-76 caused by application of the 'shock treatment', the restructuring of the economy went ahead. It was characterised by: restoration of some of the land property confiscated as a result of the 1962-1972 agrarian reform;[2] privatisation of state-owned and state-controlled companies (since 1974); a sharp reduction in import tariffs; liberalisation of the laws governing foreign investment (Law DL600, 1974); introduction of a tax on consumption (IVA); a new currency; and liberalisation of the labour market (Collier and Sater, 1996; Meller, 1996; de Ramon, 2003).The privatisations allowed financial groups to take advantage of the favourable conditions accompanying the sale of companies and lower prices than the international market value, which had implications for the state in terms of loss of patrimony through subsidisation of the privatisation process. Established financial groups flourished and new ones emerged, most gaining their power through control of the banking system and production for export (Monckeberg, 2001).

The economic restructuring appears to have reduced inflation, increased GDP by 7% per annum between 1976 and 1981, and resulted in more diversified exports (Collier and Sater, 1996; Meller, 1996). These positive economic indicators increased

[2] The agrarian reform was a process of expropriation of large expanses of land (See Ch. 6).

expectations and optimism that Chile was entering an era of prosperity until 1981 and 1983 when the economy slumped into a recession that was much deeper than in the early military period and was comparable only to the depression of the 1930s (Meller, 1996). Chile's banking system almost collapsed and the BCC took control of all the banks and assumed the debts of those that were liquidated (Collier and Sater, 1996; Meller, 1996). To escape the recession, the Ministry of Finance implemented macro-economic measures and policies designed to promote exports and provide benefits to local producers within the general neo-liberal framework (Collier and Sater, 1996).

The privatisations continued throughout the 1980s and pension schemes were transferred to the private sector. Although the state retained control of some companies, including the main copper company, CODELCO (Corporación Nacional del Cobre de Chile - National Copper Corporation of Chile), the privatisation programme accelerated and included some big state companies. The programme of privatisations was aimed at reducing the size of the public sector (Meller, 1996).

Foreign debt escalated in the early years of the dictatorship; external credit was reduced drastically after 1982 and following the economic bonanza of the late 1970s (Meller, 1996). In 1982-83 GDP fell by 15%, unemployment rose to 30%, and salaries were cut. Efforts to repay Chile's external debt resulted in a shortage of foreign currency: the adjustment programme was focused on external debt reduction, but overlooked the internal disequilibrium it provoked (Meller, 1996).

During the recession, several reforms were introduced, including health, education and pensions. They represented deep and permanent economic transformations. The reforms introduced between 1973 and 1990 occurred under special 'conditions', such as a closed parliament, restrictions on political activities, and repression of human rights. As several authors and political figures have pointed out (Meller, 1996; Correa et al., 2001), it is difficult to imagine such reforms taking place in a democratic regime.

By 1985, Chile had embarked on a period of renewed economic growth (Collier and Sater, 1996; Meller, 1996). Castells (2005: 57, 58) distinguishes two models: 'authoritarian-liberal-excluding', in the last period of the dictatorship 1985-1989, and 'democratic-liberal-including', in the new democratic period starting in 1990. Castells describes both as ‘liberal’ since both emphasise the roles of the market and an open economy for economic growth.

Meller (1996) concludes his economic history of Chile in the years 1890 to 1990, by outlining the ideas that he considered prevailed at that time. These included widespread belief in: the importance of macroeconomic equilibrium and public budgetary control; role of government as a macroeconomic contra-cyclical agent; the benefits of an open economy; and the role of the private sector as the production agent. Meller believed that questions remained about the role of the state in relation to its participation in the market and the scope of its regulatory power. Reducing poverty and inequality are concerns that he considers have yet to be translated into action.

From the recovery of democracy in Chile in 1990, to March 2010, the country was governed by a coalition of centre-left parties known as the ‘Concertación’, which was victorious in five presidential elections. As Collier and Sater (1996: 384) describe it:

> The Concertación’s economic aims were summarised in the phrase ‘growth with equity’: its programme accepted the market economy as a reality (though with further privatisations suspended) and stressed both the containment of inflation and the continued promotion of exports, but it also placed emphasis on addressing the *deuda social*, the ‘social debt’ inherited from the Pinochet regime.

Technology and innovation as a strategy for economic growth rose up the political agenda in 2004, resulting in the creation of a new fund for innovation, and the creation in 2006 of CNIC (Consejo Nacional de Innovacion para la Competitividad – National Council for Innovation for Competitiveness). The public budget law (Law 20,083, 2005), which became effective in 2006, created the Fund for Innovation for Competitiveness (Fondo de Innovación para la Competitividad - FIC), based on a new tax on copper production, to be used to foster economic competitiveness and growth. In 2005, President Lagos commissioned the preparation of guidelines for a long-term national strategy of innovation for competitiveness, to strengthen the NIS and orientate the use of public resources to encourage innovation (CNIC, 2006).

In the presidential elections held in December 2005, all the candidates included in their manifestos an explicit section on innovation and development. Despite their many differences, these manifestos had a common understanding of innovation-science-technology as critical for economic growth, and of Chile as falling behind in these areas. State intervention to foster innovation, science and technology was understood as supply driven, that is, led by the private sector.

The new president, Michelle Bachelet, started a legal nomination process to appoint a permanent council, CNIC, to be responsible for the national innovation strategy. She appointed Nicolas Eyzaguirre, Minister of Finance in the previous government, to be Director of CNIC. Eyzaguirre was a strong figure and his appointment sent the message that Chile's innovation strategy was a relevant project. CNIC was set up in 2006 first on a temporary basis before being made legally permanent (CNIC, 2007, 2008).

The first volume of the national strategy (CNIC, 2007) identifies market and state failures as the justifications for state intervention. In light of the historical process, these were probably the safest areas about which to make propositions. This first volume of the national strategy makes some tentative inroads into the areas of state regulation and market participation. The proposed policy introduced the idea of selectivity through the identification of strategic clusters. The first volume of the strategy provoked responses from several sectors, which, despite some being criticisms of the content, validated the idea of a national strategy for innovation and the creation of an entity to coordinate efforts around it. This was the first attempt by the Concertación governments to devise a national strategy. It was stated in terms of economic targets (e.g., doubling GDP by 2015) rather than in terms of a visionary project, leaving the initiative for the direction of growth to the private sector.

The second volume of the strategy (CNIC, 2008), the proposal on policy implications, was accompanied by the appointment of a new Director of CNIC, Eduardo Bitrán. He had been a member of the CNIC board from its inception[3] and was well known for his ideas about innovation efforts being focused on traditional, natural resources sectors. Despite a greater focus on selected clusters, the strategy continued to be supply driven. There was not an explicit vision for cluster development; the direction of evolution was defined by default.

[3] Eduardo Bitrán was Director of the government agency for production improvement (CORFO) 1990-1997, Director of Fundación Chile, a prestigious institution for technology transfer 1997-2006, and participated in CNIC in his capacity as Minister of Public Works from 2006.

This thesis proposal was originally formulated in 2008 and developed further in 2009. The research strategy of comparing strategic sectors resonates with policy discourse and attempts to engage in policy debate. The OECD (2007, 2009) reviews of CNIC performance and strategy suggest that CNIC should play a key role in accelerating Chile's economic development, by orientating public resources to strategic sectors and activities, and by providing wider advice on innovation policy. At the time of writing the thesis proposal, CNIC was the natural policy audience for research on industrial development.

In March 2010, after 20 years of Concertación governments, the conservative candidate, Sebastian Piñera, ascended to the presidency (term March 2010 to March 2014). According to Piñera's programme of government, innovation policy was expected to remain in place unchanged. His government programme was presented as a continuation of the economic model, accentuating the characteristics of a liberal economy (Piñera, 2009: 15).

President Pinera appointed Fernando Flores as CNIC Director. Flores was a minister in President Allende's government in 1972. He was a senator, entrepreneur and politician who supported Piñera's presidential candidature. Piñera's government programme underwent review as a result of the reconstruction necessitated by the major earthquake that occurred on 27 February 2010. The CNIC programme funding was halved, and the programme lost its central position in the national priorities.

From March 2011[4], there were demonstrations and demands from social movements for solutions to the problems in society – and particularly demands for high quality, free education at all levels. The conflicts with and interrogation of the prevailing economic model was anticipated by several historians and social scientists (Salazar, 1999a and 1999b; Correa et al, 2001; Moulian, 2002; Garretón, 2007; Domedel and Peña y Lillo, 2008). They were critical of the success claimed for the economic model based on their observation of the social discomfort, prevalence of inequality and loss of institutional

[4] There had been public manifestations related to similar demands before, for example the 'March of the Pinguins in 2006' (Domedel and Peña y Lillo, 2008), but the social movement of 2011 has been consider the most significant since 1990 (Mayol, 2012).

legitimacy. Some concluded that the model was broken and that it was time for a deep revision of economic and social policy (Mayol, 2012).

The policy scenario at the time of writing this thesis implies a positive climate for critical debate and new policy propositions. While the model is considered successful and has been defended as such, space for scrutiny of its assumptions, achievements and future impacts has been limited. This thesis proposes an alternative interpretation of economic production, grounded on understanding the learning processes involved, and leading to sectoral policy recommendations rather different than the prevalent prescriptions. Even though CNIC and innovation policy had lost priority, there is wider interest in examining policy and even in re-considering the dominant model. There are also emerging policy issues that could offer space to join the debate (e.g., the future of Lithium production or the funding of higher education). Crisis may provide good opportunities to engage in policy debate.

1.3 Public Policy and Doctoral Graduates

This thesis takes a doctoral graduate perspective to the study of industry fields. In the case of Chile (and other countries), encouraging greater participation in postgraduate education is high on public policy and funding agendas. Public policy shapes the composition of doctoral graduate populations and directs their actions through incentive mechanisms. This section provides policy backgrounds to the study of doctoral graduate involvement in the industry fields.

In Chile, public funding for doctoral studies aims at augmenting the number of doctoral graduates in the labour force. Funding is provided in the form of scholarships and grants for doctoral study and research, in the expectation of returns in the form of increased national competitiveness. Chile’s policy makers assume that more doctoral graduates will imply better economic performance, based on innovation (CNIC 2007, 2008).

One of the targets of the national strategy for innovation and competitiveness is to increase the numbers of doctoral graduates working in Chile, in the expectation that this will increase local research capacity, and the transfer and diffusion of knowledge (CNIC, 2007, 2008). The first volume of the strategy (CNIC, 2007) includes increase in doctoral graduate numbers as part of the general human capital development project. The policy guidelines differentiate between professional and technical education -

which brings higher economic returns, and research degrees. It states that professional and technical education should be encouraged through the provision of student loans, while encouragement for research degrees – doctorates and research-based master degrees - should be in the form of student scholarships (CNIC, 2007). The argument for this provision is based on market failure in recovering investments in research training.

The second volume of the strategy (CNIC, 2008) published in 2008, was built on reactions to the contents of the first volume from the chancellors of traditional universities (CRUCH, 2007). The second volume, in a chapter on ‘science for development’ rather than under the heading ‘human capital’, discusses doctoral graduates in relation to the strengthening of Chile’s scientific capacity. It aims at a productive ‘scientific community ... with sufficient numbers to allow the country to take on the challenge of advancing to a new stage of development’ (CNIC, 2008: 71, my translation). The strategy considers: investment in advanced human capital; retaining researchers by increasing the funding for research; and creating incentives to attract scientists from abroad to reinforce local capacity and international networks. It states that providing scholarships as opposed to loans for doctoral studies, is not a sufficient incentive to foster substantial entry into research degree programmes at the rate the country needs (CNIC, 2008).

As a result of an analysis of the strengths and weaknesses of the national innovation system (NIS), CNIC (2007) concludes that it is fragmented, lacks coordination and has some contradictory goals. CNIC (2008) proposed to integrate all the programmes for postgraduate scholarships and to administer them under one agency, CONICYT (Comisión Nacional de Ciencia y Tecnología – National Science and Technology Council). It proposed to make accreditation a condition for awarding scholarships for national postgraduate programmes. Following the proposals of the Commission of Ministries for the Administration and Adjudication of Postgraduate Scholarships, CNIC (2008) recommended that all scholarships, from all programmes, should be equivalent in terms of their benefits and procedures.

The recommendations were implemented by various policy decisions made in 2009. The number of scholarships increased from 2007 and in 2009 all postgraduate scholarships were centralised within in one programme, ‘Becas Chile’, operated by CONICYT. All programmes were reviewed to make the benefits equal. The number of postgraduate scholarships awarded in 2009 was 1,744 (CONICYT, 2010) – an increase from a historical level of around 500. CONICYT's budget doubled between 2008 and 2010 (CONICYT, 2010).

Scholarships are the main component of CONICYT's 'human capital' programme alongside small programmes for: hiring foreign researchers on temporary contracts to support research teams, an initiative launched in 2009; subsidies to companies for funding new postgraduates recruits for the first year; and funding for short stays in international research centres for postgraduate students and academics (CONICYT, 2010). The programme of the new government (2010-2014) supports this increase in doctoral scholarship awards and hiring of international researchers (Piñera, 2009:30).

1.4 Population of Doctoral Graduates in Chile

This section provides descriptive data on the composition of the population of doctoral graduates in Chile. In the present thesis, doctoral graduates are defined as individuals who have been awarded a doctoral degree by an accredited national or international higher education institution.

The most recent information available on doctoral graduates in Chile is from a 2008 Council of Rectors of Chilean Universities report (CRUCH, 2008). Since doctoral studies are high on the policy agenda in Chile, CRUCH set out to collect information on the population of doctoral graduates, and its report shows that the total stock of employed doctoral graduates in Chile in 2007 was 6,225, mainly in the higher education sector. It estimates that 80% work in universities, 12% work for private companies, some 5% work for government, and the remaining roughly 3% work for non-governmental organisations (NGO).[5]

The report provides some general demographic data from a survey of a sample of the population in employment, chosen as being representative of doctoral graduates working in Chile (CRUCH, 2008). The average age of the survey group was 45 years, with an average age of 36 for completing degree study. According to the survey, the

[5] Survey respondents were classified as working for the education system according to economic sector classifications. The concept of cluster used in policy is not part of the statistical system in Chile.

majority (75%) of doctoral graduates are male; their work places are concentrated in the country's capital and the three regional capitals; they are specialised predominantly in natural sciences (46%) and engineering and technology (19%). Three quarters of the individuals in the sample had undertaken their studies abroad and a majority (90%) were Chilean.

Doctoral graduates present high rates of employment (above the national average according to census data). A high proportion (95%) of doctoral graduates in the sample had permanent full-time contracts, showed low levels of job mobility and identified research as their main activity. They reported high levels of job satisfaction in terms of responsibility, intellectual challenge, independence, contribution to society and social prestige. Almost all considered their jobs to be strongly related to their area of specialisation. They reported lower levels of satisfaction with their working conditions: the majority were not completely satisfied with their salaries and benefits. Women in the sample received salaries that were considerably lower than those received by male graduates.

These descriptive statistics match higher education policies for doctoral education; for example, the programme of scholarships until the 2000s was orientated to study abroad and privileged science and technology disciplines (see Ch. 4). Several characteristics of the data, for example, distribution by work place and levels of satisfaction, are similar to those observed internationally (Auriol, 2007 and 2010). Policy directed to incentivise doctoral study resulted in the number of scholarships awarded increasing fourfold in 2008 (Bachelet, 2009) and enrolment in national doctoral programmes increasing 20% between 2005 and 2006 (CRUCH, 2005, 2006)

1.5 Motivation for the research

The thesis has its origins in my personal story as an informed practitioner in technology and innovation management, a university lecturer, and a friend and acquaintance of many who have undertaken doctoral studies at some point in their lives. My country, Chile, is relatively poor and, therefore, the pressure for wealth creation is stronger than in some other contexts. Therein lies my interest in exploring production and work as sources of wealth, social inclusion and personal satisfaction.

My reading and practice have developed into personal reflection on the field of innovation studies which is aligned to the perspective adopted in this thesis of studying production and associated learning processes as complex social learning phenomena, in which context is crucial. I chose to embark on the adventure of exploring new possibilities of dialogue across different disciplines to examine an older question of how technology learning and innovation occur.

I chose to focus on doctoral graduates and industry in part from my observations of how innovation policy is formulated and promoted with very little debate. On the one hand innovation scholarship understands innovation as a complex phenomenon that is by no means explained by linear relationships. On the other hand, policy makers pay lip service to non-linear models, and deliver policy based on underlying assumptions including that more doctoral graduates will imply more innovation outputs. My intention was to critically explore and challenge that particular assumption.

I am conscious that engaging in this discussion in the context of innovation policy, which focuses on how innovation occurs rather than why shall innovation be of any importance, implies – to a certain extent - subscription to the belief that innovation is desirable for society. I am interested in production and learning. I believe learning and transformation are part of social life, whether or not the results can be evaluated as improving or diminishing societies. I am interested in these phenomena because they occur and because they transform every one of us and our contexts of interaction.

Other motivations for choosing to focus on doctoral graduates include the assumption that, compared to other workers, they have greater freedom to pursue employment they value. Section 1.6 shows that doctoral graduates in Chile - and internationally - report high job satisfaction and low rates of unemployment. The area of production and learning that interests me more is jobs. Jobs offer opportunities for social inclusion and enjoyment of life, and provide access to consumption. I am interested in jobs that 'give life and provide a living' (Mistral, [1931]1979, my translation).

My doctoral research was funded by the Chilean government programme for doctoral scholarships. My proposal was regarded as interesting because it referred to a relevant policy area – expansion of the doctoral graduate population –understood as related to education. I was awarded a scholarship to study the relation between doctoral graduates and industry in the Department of Education at the University of Sussex. I was fortunate to be co-supervised by the Department of Education and SPRU – Science and Technology Policy Research, in order to develop an interdisciplinary research project.

Chapter 2. Theory

This chapter identifies the four main theoretical building blocks supporting this thesis. Section 2.1 discusses the literature on technological change and economic growth and my arguments for adopting the comparatively less diffused National Learning Systems (Viotti, 2001) as a framework. Section 2.2 introduces the problems of neoclassical production theory for understanding practice. It argues that the producer capabilities approach (von Tunzelmann and Wang, 2007; von Tunzelmann, 2009) could constitute an alternative base to build an evolutionary theory of production. Section 2.3 introduces Bourdieu's (2005) economic anthropological principles as a basis for understanding the roles and positions of doctoral graduates within Sectoral Learning Systems in the processes of production and technological change. Section 2.4 presents the concept of systems and networks alignment (von Tunzelmann, 2010a) as a theoretical tool for understanding the struggles within fields, and the drivers that might explain the evolution of systems and networks over time. Section 2.5 provides a summary and discussion of the novelty of the theoretical approach.

2.1 Technological Change in Late Industrialising Economies: National Learning Systems

Economic growth is a natural goal of industrialising countries, whose pursuit involves the introduction of policies to foster technological change. Technology and innovation are considered central for economic growth by several economic approaches (Verspagen, 2005). In neoclassical economics (Samuelson and Nordhaus, 1998), technological change is an exogenous phenomenon that explains growth not accounted for by other factors (i.e., capital, labour). Since the 1980s, discussion on economic growth has been dominated by two approaches: new (or endogenous) growth theory, and evolutionary (or neo-Schumpeterian) theory. New growth theory (Romer, 1986), which draws on neoclassical economics, is a competitive equilibrium model that assumes that knowledge and technology are inputs to production that can have increasing marginal productivity. Evolutionary theory often is based on historical analyses and the development of patterns explaining the relationship between technology and economic development (e.g., Dosi, 1982; Nelson and Winter, 1982; von

Tunzelmann, 1995; Freeman and Soete, 1997; Freeman and Louca, 2001). It suggests that technological change can explain uneven temporal patterns of economic growth.

Both approaches include a role for science and technology policy to foster technological change that could have an impact on economic growth. However, there are differences in the way that these theories understand the nature of the phenomena. For neoclassical economics and new growth theory, the relationship between technological change and economic growth is of clear cause and consequence; technological change is steady and production possibilities unbounded. Innovation and technological change are explained by investments in Research and Development (R&D). The evolutionary approach considers historical circumstances, the complexity of relations over time, and uneven patterns of technological change. Evolutionary scholars criticise the strong assumptions and simplistic understanding of technology and production of new growth theory, which make their models unrealistic – a criticism to which I subscribe.

Evolutionary ideas gave birth to the concept of National Innovation System (NIS). NIS is an analytical framework that has found wide application in academic and policy contexts; however, it is broad and its concepts are understood differently by different authors (Edquist, 2005). NIS is the arrangement of all of a particular country's organisations and institutions, the relationships among them, and other important factors that contribute to national technological change and innovation processes (Lundvall, 1992; Nelson, 1993; Freeman, 1995). NIS analysis gives great importance to the institutions in the system. Although the idea of 'institutions' is open to interpretation, it comprises the parts played by such factors as social values, norms and beliefs, which Nelson and Sampat (2001) call 'social technologies', in shaping economic development.

NIS focuses on scientific and technical activities, particularly though no solely R&D, aimed at innovation. The idea was constructed primarily from experiences in industrialised countries. Therefore, the NIS framework focuses on the institutions and factors related to high technology and frontier innovation, both of which are largely absent in early industrialising countries (Viotti, 2001). Viotti argues that the nature of technical change is different in less industrialised countries which, in turn, implies different determinants and connections between technical change, growth and development; therefore, he questions the applicability of NIS for those countries.

Viotti (2001) proposes National Learning Systems (NLS) as a framework to study the processes of technological change in industrialising countries. For Viotti (2001), the most important process in less industrialised countries is technological learning, which is at the base of the incremental innovation and diffusion that characterise these countries. He distinguishes between automatic learning resulting from production, and active learning based on deliberate efforts to learn, and identifies the factors that favour one or other approach to learning. At the aggregate level, he distinguishes between economies dominated by firms with passive learning strategies, conforming passive learning systems, and those where the dominant firm strategy is active, conforming active learning systems.

Viotti's criticism is persuasive and NLS appeals as a promising framework for this thesis. There is a more recent stream of the systems of innovation (SI) literature that stresses differences among industry sectors. Based on the evolutionary literature and extensive empirical work, Malerba (2004) identifies important differences across sectors in terms of structures, actors, institutions, policies, technological regimes and patterns of innovation. Malerba proposes the notion of Sectoral Systems of Innovation (SSI) as an analytical framework that focuses on knowledge and the technological base, agents and networks, and institutions. SSI aligns with NIS in placing primary attention on the innovation process; therefore, Viotti's concern over its relevance for industrialising countries applies also to SSI.

This thesis uses Viotti's NLS approach to the analysis of industrialising economies, but adapts it to include consideration of sectoral differences. I employ the idea of Sectoral Learning Systems (SLS) to refer to the learning systems described by Viotti, but in the context of industry sectors rather than countries. As in Malerba's (2005) definition, SLS are defined by a generic product in the consumer market rather than by a particular technology used by producers to target that market; for example, the textiles SLS, according to this definition, would include both cotton and synthetic materials although their production uses very different technologies. Demand for textiles present high substitution elasticity whereas demand for technology is quite inelastic because producers are locked into one technological option. In the case of fruit production, to take a case that forms part of the thesis, there is high substitution of apples and oranges on the demand side, but not on the producer side; this is discussed in Chapter 5, Section 5.3.

SLS correspond to the configuration of agents and their relations in the particular historical circumstances affecting their practice. SLS include the agents and institutions involved in the production and consumption of the product (supply and demand chains), the technologies, the aggregation of technologies, spillovers and their relationships whether formal – for example, market exchanges, or informal – for example, knowledge exchange, and which depend on the relative power positions of the of agents at a given historical time.

Industry sectors can be understood as Bourdieu's field: their boundaries occur where any of the elements in the configuration has an effect on and is affected by the field. For example, to identify the boundaries of the copper SLS it is necessary to investigate which agents affect or influence the production of copper, which decisions are relevant for shaping the production of copper, and so on (see Ch. 2 Section 2.4 and Ch.3, Section 3.2). The logic of practice related to technological change within these fields is the logic of production, which is discussed in Section 2.2. The thesis focuses on one particular agent –doctoral graduates within SLS – which form part of the configuration and occupy a position relative to other agents in the field. Industry supply and demand chains are obvious cases in point.

2.2 An Alternative Production Theory: Producer Capabilities Approach

The dominant theory to understand production is neoclassical production theory, which is based on the assumption that firms always try to maximise economic profit with the resources available (Samuelson and Nordhaus, 1998). The maximum production from each level of inputs is represented by a production function. Each product or service has an associated production function which depends on the state of technological development. Von Tunzelmann and Wang (2007) point out that production theory in neoclassical economics has several limitations in that it ignores time, it does not recognise the diversity of producers, and it does not deal adequately with the issues of quality and process innovation.

The production function is static, but the temporal dimension is crucial in order to make sense of production in a practical way. Decisions about production are often related to time saving, for example, being first to market or meeting production deadlines. Saving time and saving money may be related, but may also constitute separate goals. Neoclassical economics is not suited to interpreting phenomena in which time is the deciding factor. Time also is crucial for understanding learning processes and for explaining change.

In neoclassical production theory, producer behaviour is explained by the notions of optimisation and equilibrium, which leaves little room for producer diversity: all producers are assumed to produce to their maximum ability (represented by the production function), which is determined by the availability of technology. Production possibilities are in fact dynamic, both generally and for each individual producer. Neoclassical production theory works with homogeneous, discrete variables. Price based models do not accommodate the notions of quality and process innovation; processes are hidden from the production function.

There is no alternative approach to neoclassical production theory that overcomes these limitations. The evolutionary approach has made advances in the study of production by focusing on the processes of innovation and technological change; however, no evolutionary theory of production has been developed. The producer capabilities approach (von Tunzelmann and Wang, 2007; von Tunzelmann, 2009) might provide an alternative foundation for an evolutionary theory of production. Producer capabilities constitute a bridge between production possibilities and production results and benefits. Producer capabilities are accumulated through learning processes, particularly those occurring through interaction in multiple networks simultaneously.

Von Tunzelmann and Wang (2007) mirrored Sen's (1985) approach to consumption capabilities, to model producer capabilities. Sen's (1985) work on capabilities refers to the role of the consumer and how it contributes to individual well being. Individuals and organisations are agents that can play different roles in the economic system; they can be consumers, suppliers and/or producers, separately or simultaneously. Sen (1985) defines consumer capabilities as the real choices made by individuals to achieve forms of being. 'Real choices' are determined by the individual's way of life, command over goods, and life circumstances. Sen (1999: 293) later defined capability as 'the ability – the substantive freedom - of people to lead the lives they have reason to value and to enhance the real choices they have'.

Analogous to Sen's consumer capabilities, and drawing on the dynamic technological capabilities literature (e.g., Teece et al., 1997), von Tunzelmann and Wang (2007) defined producer capabilities as the real choices made by the individual to transform resources into profits, choices that are constrained by the individual's values, life circumstances and command over resources. Acknowledgment of the diversity of producers is at the heart of the producer capabilities representation.

The formal analysis of producer capabilities proposed by Von Tunzelmann and Wang (2007) and von Tunzelmann (2009) can be summarised as follows. Producers – individuals or firms - have access to a vector of resources, y_j, with certain characteristics. Each producer has a choice of transformations to the vector of resources, which depends on the producer's attributes and circumstances. The production transformations for y_j are represented by the vector $t(y_j)$ and moderated by an efficiency function $g(t(y_j))$. The efficiency function acts as a moderator by providing a space for the various outputs achieved by each producer from the transformation of a set of resources. The vectors t_j correspond to the production possibilities of each producer from a set of resources $y_{j;}$ the vectors g_j correspond to the producer capabilities associated with each producer.

The set of vectors $y_{j,}$ t_j and g_j is particular to each producer. These vectors are associated with the producer's history, assets, preferences and dispositions, thus its current circumstances as well as its historical context. Production possibilities and producer capabilities are historical; therefore, the vectors $y_{j,}$ t_j and g_j represent the picture at a given moment in time along a continuum of values for these vectors throughout the life of the producer. The transformation of resources will result in a profit for the producer represented by $p(g(t(y_j)))$. The producer capabilities of a producer m can be represented as $R_m(Y_m)$ for some $g_j \in G_m$ and some $y_j \in Y_m$ where G_m is the set of the producer production possibilities and Y_m is the set of the producer's command over resources

Producer capabilities include all the real choices available to the producer for transforming resources into profits. They may consist of basic operational transformations, or encompass sophisticated processes of innovation. Conceptually, producer capabilities include all the basic technological capabilities identified by Viotti

(2001) (see Table 2.1). They also allow for drawing a distinction between the resources used in production and the resources needed for managing technological change (Bell and Pavitt, 1993). In an analysis of different producers, some may have all three capabilities presented in Table 2.1 available as real choices for transforming resources; others may have only the choice to make minor adaptations to local conditions and to perform simple routines, in a passive relation to technological change.

Table 2.1: Basic Technological Capabilities and Typical Technical Functions of Industrial Firms

	Typical Technical Functions
PRODUCTION CAPABILITY (Knowledge, skills and other conditions for the process of production)	**Assimilation of process/product technology** **Passive Incremental Innovations** • Minor adaptation to local conditions (of infrastructure, goods and services supply, human resources, and product demand) • Balancing the process/line of production • Simple debugging and routine maintenance • Inventory control • Management of inputs procurement and output sales • Quality control of final products • Sporadic training
IMPROVEMENT CAPABILITY (Knowledge, skills and other conditions required for the continuous and incremental upgrading of product design and performance features and process technology)	**Assimilation of process/product technology** **Passive incremental innovations** • Major adaptation to local conditions (of infrastructure, goods and services supply, human resources, and product demand) • Shop-floor experimentation • Preventive maintenance • Network with suppliers and consumers • Total quality type control systems • Permanent training • Product/process improvement • Equipment 'stretching' and adaptation • Regular search for outside knowledge and skills, including benchmarking, copying, imitation and reverse engineering • Science and technology skills • In-house R&D
INNOVATION CAPABILITY (Knowledge and skills and other conditions required for the creation of new technologies, i.e., major changes in the design and core features of products and production processes)	**Innovation of product/process technology** • Process/product innovation • In-house R&D • Basic research • Cooperative R&D • Licensing own technology to others

Note: Except for cases of innovation start-ups, the technical functions typical of the technological capability of *innovation* usually subsume those of *improvement,* as well as this last one comprises those of *production.*

Source: Viotti (2001: 9)

Producers transform resources into products by articulating demand and supply; therefore, they should be at the centre of economic theory. Von Tunzelmann (2009) proposes a three-fold model to understand the relationship between supplier, producer and consumer from a capabilities perspective: the capabilities schema (Figure 2.1). A capabilities perspective distinguishes Sen’s three levels of the characteristics of the goods and resources actors can access (1st row), their freedom to transform or consume them (2nd row) and the utilities or profits they obtain (3rd row).

Figure 2.1: The Capabilities Schema

Actors	*Supplier of Technology*	*Producer*	*Consumer*
Characteristics	**S&Tpossibilities**	**Production possibilities**	**Product possibilities**
Capabilities	S1 K **Technological capabilities** S1’	E1 D1 S2 K **Production capabilities** D1’ S2’	E2 D2 **Consumption capabilities** D2’
Rewards	**Profitability (IPRs)**	**Profitability**	**Utility**

Source: Adapted from Von Tunzelmann (2009)

In this three-fold model of production each producer – individual or organisation - acts as a supplier of goods and services to customers and as a consumer of resources (e.g. technologies, goods and services). ‘Actors’ refer to the particular roles played by individuals and organisations in the relations identified in the capability schema. Agents, individuals or organisations, assume different roles more or less simultaneously; for example, a doctoral graduate could act as producer of research and, at the same time, as consumer of software or laboratory equipment.

Producers supply a diversity of products to consumers (S2). The product possibilities depend on the capabilities of the producer and the capabilities of the consumer. Producer capabilities determine the possibilities of transformation of resources into products for each producer, and the profitability they can obtain, which is related to their particular efficiency (S2’). It is not enough to be able to develop a product if there is no consumer capable of obtaining marginal utility from that product. Consumers generate demand for products (D2), to which they give value depending on their efficiency to use those products (D2’).

The production possibilities of the producer are influenced by the capabilities of the producer and the capabilities of the supplier of technology. The capabilities of the supplier of technology determine which production possibilities they could offer (S1), and the efficiency of their capabilities affects the profitability they can obtain (S1’). Producer capabilities generate a demand for production possibilities (D1). Producer capabilities are not homogeneous, differences in efficiency imply differences in the producer’s profitability and, therefore, in the value they give to production possibilities (D1’). In this model, the technology supplier represents one of the actors in the supply chain; more columns representing other suppliers could be included.

The solid arrows in the capabilities schema are market interactions, but these are not the only interactions that occur. Actors in the capabilities schema can have interactions resulting, for example, of the exchange of knowledge (KE1 and KE2). Actors learn through social interactions, and their learning has an impact on their capabilities. For example, producers learn from suppliers and from using different suppliers’ technologies/products. Market and non-market relations promote learning and capabilities accumulation, which may change the structure of actors over time.

There is a large body of research in innovation studies supporting the propositions of the capabilities schema. For example, the innovation studies literature has for long argued about the need for convergence of technology (supply side) and demand for successful product innovations (e.g., Rothwell et al., 1974; Tidd et al., 1997). The seminal concept of ‘absorptive capacity’ (Cohen and Levinthal, 1990) encapsulates the findings on the importance of technological and producer capabilities as a condition for the expansion of production possibilities and for higher profits.

Producer capabilities are relational. They arise in the encounter between the circumstances and the actors performing within them. Therefore, producer capabilities can be understood only in their historical context. Producer capabilities arise from economic practice, which takes place in a particular field – the examples provided in von Tunzelmann (2009) are all related to particular industry fields. Building on Section 2.1, analysis of producer capabilities for industrialising countries should be located in a particular SLS, that is, it should consider the history of the SLS to locate producer’s practice in a historical and field context.

Producer capabilities as a framework for the analysis of production processes is a novel approach. The three-fold model could be used as a tool to understand and interpret new situations and different actor behaviours, in the context of policy making and government planning. However, its diffusion and development remains limited. It could be developed further if ‘put to work in practice’ in a process of reflective interaction between theory and empirical results. There have been a few attempts in this direction, for example, the study of the East German innovation system by von Tunzelmann et al. (2010), the study of two industrial regions in Brazil by Pamplona da Costa (2012) and the study of foreign R&D affiliates in emerging markets (Ujjual et al., 2012).

Although producer capabilities are rooted in Sen’s capability approach, research on the area of production has not expanded in the corresponding academic community. The annual conferences of the Human Development and Capability Association (HDCA) tend to focus on consumer capabilities. However, the 2011 conference[6] had a section on technology and innovation. I presented a paper (Ibarra and von Tunzelmann, 2011) that introduced the producer capabilities framework, its application and its connections with Sen’s capabilities approach. The papers in that section represented less than 10% of the papers presented at the conference. The majority were concentrated on the areas of education and health from a human rights perspective. The few papers in the science and technology group emphasized the ideas of freedom and wellbeing from a welfare economics perspective. Jobs and production have not been central to the capabilities approach. Emerging as a new theme at the 2011 HDCA conference was a reflection on the need for the United Nations Development Programme to pay more attention to jobs, in their Human Development Reports.[7] It is unusual in this context to make links between producer capabilities and consumer capabilities (referred generally by HDCA as ‘capabilities’).

[6] International Conference of the HDCA, Innovation, Development & Human Capabilities. The Hague, 5-8 September 2011.

[7] The *Human Development Report* has been commissioned and published annually by the UN since 1990. It features data and analysis for policy, and discusses people’s wellbeing and development. The aim is to advance human development and it is closely linked to the principles of the HDCA.

Despite the predominance of Sen's capabilities approach in other areas than production, Sen (1997, 1999, 2000) acknowledges the importance of the relation between consumer capabilities and labour. However, there is no conceptual framework linking the benefits –utilities and profits – obtained by individuals in their roles of producers and consumers. Consumer capabilities and producer capabilities can be understood as two sides of the same coin; the achievements of one person occupying two different roles.

Definitions of capabilities and related concepts abound. It seems pertinent to include some clarifications at the end of this section, particularly in relation to the difference between competences and capabilities identified in the literature. The revision of concepts concludes with a definition of the terms as used in this thesis.

Competences, capabilities and capacity

The concepts of competences and capabilities are related; however, a review of the literature shows different and contrasting understandings depending on the context. These concepts are of interest in the fields of innovation, management, development studies, education studies and labour studies. Von Tunzelmann's (2009) review – covering selected works in the fields of innovation, management and economics – identifies at least 20 different usages of the concepts of competences and capabilities. Also, the field of education includes several different usages, the most important traditions being the capability approach (Unterhalter, 2005; Robeyns, 2006; Walker, 2007) and the vocational educational education and training (VET) approach (Vargas et al., Gallart, 2002, 2001; CINDA, 2009, Young 2008a,b; Allais, 2010, 2011, 2012; Malloch et al., 2011; Eraut, 1994, 2004) .

This thesis adopts von Tunzelmann's (2009) proposition to consider a distinctive feature of competences, that is, that they are exogenous to the particular part of the system under study, while capabilities are observed and accumulated by developing a practice within the system. Competences and capabilities are at play simultaneously in the dynamic transformation of one into the other. The distinctions can be applied to the case of individuals as well as to collectives.

This thesis assumes a complementary relationship between the attributes of individuals for professional performance, which I will call competences, and the professional practice through which these new attributes are developed, through the process of doing, which gives place to the accumulation of what I will call capabilities. Capabilities can be observed in both work practice and outside of work, for example, in consumer behaviour or in involvement in community or family activities.

Capacity includes both competences and capabilities. It designates the potential and the realisation of an individual or a field for production performance.

2.3 An Economic Anthropological Perspective: Doctoral Graduates

Doctoral graduates represent a small fraction of a country's population - and particularly small in the case of Chile; however, their importance is strategic. They have the highest level of formal education and have the competences to conduct R&D. For these reasons they are considered to be the group most likely to contribute to the advancement of knowledge and technological change, and to perform key roles for economic development (OECD, 1995, 2002, 2005, 2007).

Policy and research in relation to doctoral graduates' strategic roles in production processes and technological change often have been based on theories of human capital and market failure. Human capital theory (Schultz, 1960, 1963; Becker, 1994) assumes that individuals can be considered to be a form of capital, and education an investment in human capital, which results in positive economic returns. Enhanced human capital through education produces both private returns (better salaries and working conditions) and social returns (social benefits such as better health, better informed consumers and citizens, lower crime rates). These returns are supposed to reflect the increased productivity of more highly skilled and more knowledgeable individuals (Schultz, 1963). Market failure (Bator, 1958; Stiglitz, 1989) refers to the functioning of the markets under conditions that distort the equilibrium, for example, in the case of public goods. Most actors benefit from public goods, but would not choose to produce them due to the difficulty involved in appropriating their benefits.

Human capital and market failure theories are aligned to neoclassical economics; they share assumptions about the rationality of decision making, economic convergence to market equilibrium, etc. These underlying assumptions are incompatible with the producer capabilities approach. Human capital theory focuses on potential, on preparing an input for 'production' in the linear understanding of production from inputs to outputs. In focusing on producer capabilities we move from the individual to a collective and a contextual view. While acquiring a competence can be seen as an individual effort, producing and developing producer capabilities is a collective process that occurs in a particular historical context. The ability to develop producer capabilities depends (at least) on technological/supplier capabilities and consumer capabilities, as proposed in the three-fold model.

Here the thesis turns to Pierre Bourdieu’s (2005: 193) propositions on the principles of an economic anthropology:

> To break with the dominant paradigm, we must – taking note, within an expanded rationalist vision, of the historicity constitutive of agents and of their space of action – attempt to construct a realist definition of economic reason as an encounter between dispositions which are socially constituted (in relation to a field) and the structures, themselves socially constituted, of that field.

Application of the producer capabilities approach needs to be related to a particular field, and to consider history. Section 2.2 discussed the use of SLS as characterising economic fields – more accurate than a general idea of fields, and including the historical perspective (see Ch. 3, Section 3.3). The producer capability approach aims at explaining the economic practice of the actors in the field, and this thesis is concerned with one particular agent acting in the SLS field, doctoral graduates. The logic of practice (Bourdieu, 1990) in the fields of economic production is represented by the producer capabilities approach.

To understand the encounter between agents (doctoral graduates) and the field (SLS), both socially constituted and explained in relation to each other, I draw on academic work on education and professional performance (Eraut, 1994, 2004) that illuminates understanding of doctoral graduates as an actor in the SLS. The focus of interest is doctoral graduates’ professional participation in SLS, that is, an aspect of their work related not to what they could do (i.e., potential), but to what they actually do (i.e., realisation).

Using the distinction between competences and capabilities, work performance is the realisation of an individual’s capabilities. People bring to their particular work situations knowledge, skills, attitudes and beliefs that contribute to their performance. Capabilities are dynamic: once doctoral graduates undertake work they continue to learn and develop:

> Therefore it is inappropriate to think of knowledge as first being learned then later being used. Learning takes place during use, and transformation of knowledge into a situationally appropriate form means that it is no longer the same knowledge as it was prior to it first being used. It also follows that learning to use an idea in one context does not guarantee being able to use the same idea in another context: transferring from one context to another requires further learning and the idea itself will be further transformed in the process. (Eraut, 1994: 20)

Eraut (2004) argues that professional performance is complex and involves the simultaneous use of different kinds of knowledge and skills, which individuals learn holistically taking from formal education, but also and to a great extent, from informal learning at work. His research on professional learning shows that most learning is not taught, but arises from work practices and interactions in the workplace. This kind of learning goes largely unnoticed by the learners (Eraut, 2004).

The literature on innovation and management considers capabilities mainly as organisational assets (Figueiredo, 2001). Explaining how innovation occurs has oriented research on capabilities and technological paths, in which the firm is the unit of analysis (Fagerberg, 2005). Organisational capabilities are at the root of the process of firm innovation. Organisational capabilities are more complex than just the combination of the individual capabilities of organisational members: they include other organisational dimensions - from physical resources to managerial systems, and the values and beliefs of the organisational culture (Leonard-Barton, 1995).

To contribute to innovation, doctoral graduates need to become part of the organisation’s capacity building effort. They can contribute indirectly from outside the firm - and long before innovation is observed. They may contribute to organisational capacity building which does not lead to observable innovations - for internal firm reasons, broader industry learning system reasons, or other reasons.

2.4 Synthesis without Consensus: Systems and Networks Alignment

The previous sections laid out the theoretical basis for defining SLS as the object of study (Section 2,1) and for understanding the logic of practice within them (Section 2.2.). Section 2.3 presented the theoretical background for analysing fields through the perspective of agents, in this thesis that of doctoral graduates. This section presents the basis for understanding how fields change.

According to Bourdieu (2005) the economic field is a field of struggles in which different agents confront one another to gain access to exchanges and to maintain or transform relations of force amongst them. Agent's actions depend on their position in the field in relation to other agents. Dominant players orient their efforts to strategies aiming and maintaining or reinforcing their domination. When new players appear the structure of the field is modified. The relations among forces also can change - with the adoption of new technologies or the acquisition of greater market share by some players. Bourdieu (2005) offers general reflections on how real field transformations may occur, he points to the role of technology, the crossing and redefinition of boundaries between fields, the relation of agents with the state, and changes in sources of supply and demand.

The dynamic of transformation of industrial fields has been explained by von Tunzelmann (2003, 2010a) as the result of coevolution of technology systems and governance. Using historical evidence, von Tunzelmann proposes that, alongside the history of industrial sectors, technology creation and application align with governance in some way. Governance refers to the organisation of collective action and includes issues of structure – how decisions are made, control – the power to make decisions within structures, and process – the implementation of structure and control (von Tunzelmann, 2003: 366).

Von Tunzelmann's (1995, 2003, 2010a) work is based on interpreting patterns of industrialisation. It synthesises many previous studies of specific technologies, and specific countries and industries, which are reinterpreted in the context of wider industrial development. He considers the role of key agents, particularly firms (the micro-foundations of growth and development). Von Tunzelmann does not assume that industrialisation, technological change and innovation are always desirable, positive or lead to progress.

The issue of alignment (von Tunzelmann, 2003, 2010a) may contribute to explaining the direction of change. Agents may hold different views, interests and aims in their participation in the field, which may conflict. Understanding the alignment or misalignment (contradiction) between different agents' aims in the industrial field - considering their position and the systems of technology and governance in place - could shed light on the history of the field and its likely development. Von Tunzelmann proposes the understanding of these differences and contradictions as a possibility for governance and policy making: 'The alignment issue aims to direct their multiple objectives towards a commonly accepted outcome that is here taken to be economic advance, without necessarily forcing them to abandon their differences of viewpoint'(von Tunzelmann, 2003:379).

In analogous manner alignment could help understanding the dynamic of changes internal to the firm. Drawing on Bourdieu's (2005) proposition that the firm can be understood as a field in itself, the actions of the firm are the result of the alignment of the forces, positions and aims of its many internal agents. Firms involve an internal structure of agents with different amounts and types of capital, which come into play to coordinate firm's actions. This can explain firm's internal conflicts, for example, getting coincidence between the interests of owners and managers (von Tunzelmann, 2003; Lazonick and Mazzucato, 2012).

2.5 Conclusion

This thesis is located within the general area of technological change and economic growth in relation to industrialising economies. It takes SLS as the field of analysis and applies the producer capability approach - an alternative to conventional production theory - to understand the practice of doctoral graduates in relation to production and technological change in SLS. The issue of alignment is presented as contributing to explain field dynamics.

Bourdieu's relational philosophy constitutes an underlying epistemological base for the thesis. Bourdieu proposes to study practice in a particular field from the perspectives of the agents in that field. His is a general proposition that can be complemented by compatible theories specific to the fields and practices of interest, in this thesis, SLS, producer capabilities and alignment analysis. The novelty of the approach in this thesis is the combination of different, but complementary theories with coherent epistemological stances.

Chapter 3. Methodology

This chapter presents the methodology and research strategy of the thesis. The thesis is located within the general area of enquiry related to understanding how producer capabilities accumulate and develop. The strategy chosen to study producer capabilities compares the history of three SLS from the perspective of the roles and positions assumed by doctoral graduates.

Section 3.1 introduces the thesis research questions. Section 3.2 describes the general methodological approach used to answer the research questions, which consists on adopting a Bourdieusian perspective. It implies understanding the participation of doctoral graduates in the process of accumulation of producer capabilities as constituting part of the history of SLS. This relational, historical perspective is organised as a set of coherent methodological tools by applying Bourdieu's concepts of field, capital and habitus.

Section 3.3 presents the research strategy, which consists of a comparative analysis of capability accumulation in three SLS in Chile: copper mining, fruit growing and salmon farming. It describes the process followed to select the three industries and the methodology applied to study them. Doctoral graduates' historical participation is inferred from analysis of the SLS's history, and is illustrated by individual case studies of doctoral graduates work histories. Section 3.4 describes the method used to construct the individual case studies which are used primarily as examples to illustrate the analysis. Section 3.5 concludes with some general methodological reflections.

3.1 Research Questions

The general research questions underlying the thesis are: How do doctoral graduates participate in the accumulation of producer capabilities in SLS? What factors are important? And what are the implications for public policy? These questions are extended by considering the possibilities and constraints offered by the methodological approach:

How do doctoral graduates participate in the accumulation of producer capabilities in SLS?

- How do doctoral graduates emerge to take up positions in the history of different SLS?
- What roles and positions do doctoral graduates assume in SLS?
- What are the practices of doctoral graduates in relation to SLS?
- What are the differences and similarities in doctoral graduate participation, across the three SLS?
- What producer capabilities are they likely to accumulate?
- What are the implications of doctoral graduates’ practices and capabilities accumulation for the SLS?
- What can be inferred about how capabilities accumulate?

What factors are important for doctoral graduates’ capability accumulation in SLS?

- What types of capital are important for the participation of doctoral graduates in SLS?
- What characteristics of the SLS are important?
- What are the differences and similarities in the factors related to the three SLS?
- What doctoral practices are important?

What are the implications for public policy?

- What are the lessons for public policy from the three cases and their comparison?

3.2 A Relational Perspective using Bourdieu’s Concepts

The thesis is designed to study economic fields – particularly SLS - from an anthropological perspective, the perspective of doctoral graduates as agents in the SLS. I start from the assumption, based on the theoretical analysis in Chapter 2, that building producer capabilities, which can lead to an active SLS, is desirable for developmental purposes.

My perspective gives primacy to relations and historicity, which means that the guiding principle to understanding practice is in relation to historical circumstances.

Understanding historical circumstances implies relating them to the practices that shaped them over time. This epistemological stance – apprehending the social by looking at relations and historicity – is deeply rooted in my sense making of the world. I can identify the influence of many years of study and professional practice in the area of science, technology and innovation. This discipline considers the importance of history and uses systemic models that focus on relations, although its assumptions are often tacit (e.g., the concept of NIS discussed in Ch. 2). I also acknowledge the influence of years of study on the biological roots of learning (Maturana and Varela, 1980, 1987, [1973] 2006) and cognitive science and human experience (Varela et al., 1993; Varela and Shear, 1999). Nevertheless, my understanding remained intuitive and hard to make explicit or applicable to a research endeavour.

It was only during the years of development of this thesis, from reading philosophy of science and, particularly, by reading Bourdieu, that this ontological and epistemological stance took on a shape and a coherent meaning. For example:

> I could twist Hegel's famous formula and say *that the real is the relational*: what exist in the social world are relations - not interactions between agents or intersubjective ties between individuals, but objective relations which exist "independently of individual consciousness and will", as Marx said. (Bourdieu in Bourdieu and Wacquant, 1992: 97 – original emphasis)

And that 'all sociology should be historical and all history sociological' (Bourdieu and Wacquant, 1992: 90).

Explanations are not to be found, therefore, in the components of social phenomena; explanations and meaning can arise from relations. Relations, as distinct from interactions, are historical and anchored in the positions of the agents in the field. The research questions interrogate the practice of accumulating capabilities for production. Bourdieu (1990) understands practice as constructed in time, as bringing together the history of institutions and the history of bodies (individuals):

> An institution, even an economy, is complete and fully viable only if it is durably objectified not only in things, that is, in the logic, transcending individual agents, of a particular field, but also in bodies, in durable dispositions

> to recognize and comply with the demands immanent in the field. (Bourdieu, 1990: 58)

The methodological framework of this thesis consists of the three main concepts of field, habitus and capital- as defined by Pierre Bourdieu. I use Bourdieu's concepts because they 'are designed to be *put to work empirically in systematic fashion*' (Bourdieu and Wacquant, 1992: 96 – original emphasis) and because they offer consistency; thus, 'to think in terms of field is to think *relationally*' (Bourdieu and Wacquant, 1992: 96 – original emphasis). I took up the challenge of putting 'the concepts to work' as set of coherent methodological tools to understand doctoral graduates' practice within SLS.

'Field' refers to the relevant practice context, the social historical circumstances within which the practice took place. In this thesis the relevant field is the SLS. Bourdieu used the analogy of a games field to explain this concept: players believe the game is worth playing, they know the rules of the game, and each has a particular position in the field (Bourdieu and Wacquant, 1992). SLS have structures that make it possible to identify agents and their positions; there are rules that govern the structures and practices; and it is possible to identify boundaries to the effects of the field. An analytical perspective of fields reads as:

> ...a field may be defined as a network, or a configuration, of the objective relations between positions. These positions are objectively defined, in their existence and in the determinations they impose upon their occupants, agents or institutions, by their present and potential situation (situs) in the structure of the distribution of species of power (or capital) whose possession commands access to specific profits that are at stake in the field, as well as by their objective relation to other positions (domination, subordination, homology, etc.). (Bourdieu and Wacquant, 1992: 97)

'Habitus' refers to the person's dispositions, preferences and beliefs. All these characteristics are expressed in the way we – individuals - act, the decisions we make, and the feelings and thoughts we experience. Habitus is a durable structured system that organises our practice and our representations of practice. It is generated by particular circumstances, and expresses a certain historical context. Habitus - like field and capital

- is a dynamic concept, for example, some of our decisions and actions may change our dispositions or beliefs in a durable, but not immutable way. At any moment, one's life is embedded in circumstances that define a horizon of possible choices for acting, thinking, feeling, etc. Moreover, the choices visible to us are only those choices that the habitus allows us to envisage as possible. Habitus is the result of history; it is based on our embodied experience of the particular circumstances encountered on our journey through life. Habitus shapes our future since we can only do, choose, feel, etc., within the range of what is possible within our habitus. Although our circumstances are not necessarily of our own making and do not depend on us completely, our journey has an impact on them. Our contexts and we as individuals evolve in an interconnected dynamic (Bourdieu, 1990: 52-62).

'Capital' is the result of the accumulation of different assets over time (Bourdieu, [1986]2004). Bourdieu distinguishes between different kinds of capital; in this thesis I use his distinctions of three main forms of capital: economic, cultural and social (Bourdieu, [1986]2004). Economic capital is the most evident; it is comprised of money and property or other goods with market value. Cultural capital can take at least three forms. It can be embodied (long lasting dispositions that define the way people act), objectified (goods that have cultural value and are valuable to those who can make use of them, e.g., books, instruments, etc.), or institutionalised (the recognition given by the field, e.g., educational credentials, in this thesis doctoral degrees). Social capital derives from belonging to networks, forging strong relations that are maintained over time through a series of interchanges (e.g., in this case, through membership in scientific collaborative networks).

All forms of capital are constructed historically and are relational (they are recognized by agents in the field). Capitals can be interpreted as people's endowments or attributes in relation to the game. Sen (1985) uses the concept of 'entitlements', which is related to capitals. Entitlements, translated to producer capabilities, correspond to the individual's command over resources. Individuals have access to a particular set of resources, for which they have a set of possibilities for transforming with certain efficiency (see Ch. 2, Section 2.2). This relation between individuals and resources is determined by the individual's capitals.

Field and habitus are articulated through the concept of capital. Capital defines the initial positions of the different agents in the field, and changes in capital often are explained through the dynamics of the game. Capital refers to historical accumulation of different assets over time (Bourdieu, [1986]2004). The concepts of field, habitus and capital can be defined only as a system (Bourdieu and Wacquant, 1992): in isolation, they lose sense. At any given moment, the structure of a field is defined by the distribution of capitals held by agents. Capital exists only in relation to a field. Habitus is shaped by the field and is at play in the struggle to maintain or to change the distribution of capital.

Practice in a field responds to the logic that is not the result of a set of conscious and constant rules, but the result of 'practical schemes, opaque to their possessors, varying according to the logic of the situation...Thus the procedures of practical logic are rarely entirely coherent and rarely entirely incoherent' (Bourdieu, 1990: 12). Bourdieu criticised the neoliberal economics understanding of the logic of practice for its failure to recognise that rational action and mechanical reaction are not the only reasonable economic actions:

> Thus the so-called 'rational actor' theory oscillates between the ultra-finalist subjectivism of a consciousness 'without inertia' which creates the meaning of the world *de novo*, at every moment.... and an intellectual determinism which... reduces action to a mechanical reaction to mechanical determinations and reduces economic agents to indiscernible particles subjected to the laws of a mechanical equilibrium. (Bourdieu, 1990: 46)

Choice is crucial to Bourdieu's (and to Sen's, 1985,1999, 2002) understanding of economic practice:

> But, at a deeper level, how can one fail to see that decision, if decision there is, and the 'system of preferences' which underlies it, depend not only on all the previous choices of the decider but also on the conditions in which his 'choices' have been made, which include all the choices of those who have chosen for him, in his place, pre-judging his judgement and so shaping his judgement. (Bourdieu, 1990: 49)

In order to put Bourdieu's concepts to work, I relate them first to theory. They are general organising concepts that gain depth and specificity from the theory in relation to their application in this thesis. Chapter 2 described the theoretical underpinnings to this thesis. I proposed SLS as a framework for the analysis of economic fields in the context of industrialising countries, and of producer capability as a central concept to understand the logic of economic practice in SLS.

3.3 Comparative Research Strategy

This section presents the research strategy and discusses the selection of case studies (Section 3.3.1), and the approach to studying the selected cases (Section 3.3.2).

The research strategy consists of comparing producer capability accumulation in three SLS – copper mining, fruit growing and salmon farming in Chile. Comparative analysis of case studies takes account of complexity, diversity and uniqueness (Ragin, 1987). A small number of cases can be interpreted historically, combining evidence from multiple observations, in a holistic analysis. Similarities and differences can be examined to discuss which findings might be general and under which conditions.

3.3.1 Choosing similar SLS

I decided to study the most similar industry sectors – to be constructed as SLS and based on purposeful selection. The logic of the comparative enquiry is whether similar industry sectors in Chile demonstrate similar patterns of producer capabilities accumulation. If so, the similarities may explain accumulation, and the differences may be irrelevant factors. If not, the explanation of how producer capabilities accumulate may lie in the differences between industry sectors (Peters, 1998).

The industry sectors were selected for their similarity in several characteristics of economic output and input. On economic output measures (international market share, export growth) they are important players and all are export-oriented. The three sectors are similar in their inputs: they are natural resources-based industries, and their work forces have similar educational level composition. Most workers in these industry sectors have not achieved higher education (for a summary of the main characteristics of SLS see Ch. 1).

The universe of possible industry sectors in Chile from the set of eight strategic industry sectors included in Chile's innovation policy (CNIC, 2007, 2008) identified copper mining, fruit growing and salmon farming as the most suitable for this study. The eight strategic industry sectors were scrutinised to identify similarities in economic performance and economic potential, using four criteria: position in the local economy (share of national production and export); economic growth potential; international economic position (international market share); and evaluation of the sector by CNIC.

The three sectors have a common geographic logic. Comparing sub-national units has the advantage that several factors are held constant (Peters, 1998), for example, employment law and regulation. It should also reduce the effects of other factors, such as cultural and social differences, which can show subtle variation across sectors or may be difficult to capture in cross-country comparisons. Comparing different sectors in the same country is a novel approach in technology and innovation studies. Comparative strategies have been applied to the study of NIS (e.g., Nelson, 1993), NLS (e.g., Viotti, 2001) and SSI (e.g, Malerba, 2004). NIS and NLS studies compare countries, and SSI studies compare the same sectors in different countries.

The three industry sectors selected are the most similar amongst the eight sectors considered, but their patterns of capabilities accumulation were unknown a-priori. Comparison is the strategy used to explain observed behaviour and to formulate some general conclusions. A great diversity of patterns of capability accumulation (the dependent variable I am attempting to explain), is ideal for a robust research design (Peters, 1998). My choice to include three cases – rather than comparing only two - ensures such diversity.

3.3.2 Constructing SLS as fields using a co-evolutionary approach

Bourdieu’s recommendations for studying fields consider that the field emerges through empirical work, by identifying boundaries, dominant forms of capital and so on, because they are interconnected. It is relations that define the structure of the field:

> There is thus a sort of hermeneutic circle: in order to construct the field, one must identify the forms of specific capital that operate within it, and to construct the forms of specific capital one must know the specific logic of the field. There is an endless to and fro movement in the research process that is quite lengthy and arduous ....when my knowledge of forms of capital is sound I can

> differentiate everything that there is to differentiate. (Bourdieu and Wacquant, 1992: 108)

Also,

> The notion of field does not provide ready-made answers to all possible queries....Rather its major virtue, at least in my eyes, is that it promotes a mode of construction that has to be rethought anew every time. It forces us to raise questions: about the limits of the universe under investigation, how it is "articulated", to what and to what degree, etc. It offers a coherent system of recurrent questions that saves us from the theoretical vacuum of positivist empiricism and from the empirical void of theoreticist discourse. (Bourdieu and Wacquant, 1992: 110)

Bourdieu (2005) applies the concept of field to the economic sphere, in his study of the house market in France, which exemplifies how his concepts are put to work. Bourdieu’s general recommendations to studying fields were a starting point for the study of SLS, but they had to be matched to theories of historical industrial development. This allowed me to build on previous knowledge from a new perspective – a lesson learned after futile efforts to delve into history books, which made it clear that my search needed more specific guiding principles. I returned to work in economic history and innovation studies.

The methodology used to construct the SLS fields consists of applying the ideas of historical co-evolution and alignment of systems proposed by von Tunzelmann (2003, 2010a) (see Ch.2, Section 2.4). My goal was to conduct descriptive and explanatory inferences on the evolution of SLS. Grounding my search in industrial development theory had several implications. As described by King et al. (1994), it was clear which facts were relevant, and I did not need to have a complete theoretical background to start collecting data because theory and data became interactive. The question that often guided my search was ‘if these theories are correct, what else might I expect to observe?’

Von Tunzelmann’s method has not been described formally, but, as I do, can be deduced from his applications of it. Von Tunzelmann (2003) interprets economic history as consisting of three industrial revolutions and analyses technological breakthroughs and revolutions in modes of governance. He relates governance changes and technological changes by arguing that they overlapped and coevolved.

The heuristic used by von Tunzelmann is based on evolutionary theories of technology and governance. Discontinuities in technology are associated with changes in technological paradigm, and continuous technological improvements are associated with the unfolding of a new paradigm along a technological trajectory defined by the new paradigm (Dosi, 1982). The selection of a new paradigm and its rise are related and co-evolve with the dominant modes of governance.

In principle, other technological revolutions (not just the big industrial revolutions) can be analysed similarly. The heuristic can be summarized as follows. The study of the history of economic fields starts by identifying changes in the technological paradigms that characterise different industrial development epochs. Starting with technological change does not imply that it happens 'first' or 'causes' governance change, rather both are codetermined; however, in practice it was easier to identify technological change as a starting point for the investigation.

The industrial development epochs need to be characterised and compared. For each epoch, its origins, dominant technologies, type of processes and levels of automation must be identified. The study of different epochs should be complemented by identification of the dominant modes of governance, industry structure, nature of competitive advantage, and type of capitalism. These dimensions of technology and governance can be analysed relationally to interpret the processes of change across epochs.

Constructing the history of the industry sectors, the SLS, for this thesis was a long, iterative process of identifying and characterising epochs in terms of technology and governance. The main sources consulted were historical accounts by academic researchers, legislation and, for the recent period, papers on the development of the industry written from economics and technology and innovation perspectives. The sources were searched to identify commonality among events regarded as relevant to the development of the sectors. These events included the promulgation of laws and breaks in production or export trends, events that I ordered along a timeline. The distinctions proposed by von Tunzelmann oriented the search as questions to be answered, for example: What process type was in place? What type of capitalism was dominant? The process was informed by empirical research into the construction of the examples described in Section 3.4.

The selection of documents included in the initial review tried to cover all authors recognized as serious and rigorous academics by the local academic and non-academic community. By drawing successive pictures of the fields in systematic iterative fashion (from a general draft to a richer picture), it became clear that the organising principle of the search was to identify momentous landmarks recognised as such from different historical perspectives. Therefore, the review needed to include the accounts of historians with different political stances. Characterisation of the field included general descriptive statistics, available, for example, in the demographics of labour forces and firms, and an analysis of sector regulation (laws and norms).

The first stage in the search for events in the sector's history resulted in a timeline of landmarks. The timeline was the basis for filling in and adding to von Tunzelmann's dimensions, which were registered on a matrix of dimensions by epochs. The aim was to summarize the coevolution of systems of governance and technology over long periods of time. The process was iterative, involving going back to sources to fill in gaps in the matrix, and searching for debates on developments related to the main events. When organising the results and thinking about how to identify epochs it appeared important to understand – or at least to have an interpretation - of how the event emerged. It seemed that discrete events lacked process: how do we understand the nationalisation of copper without digging into its origins, for instance? The second stage in the search for the sector's history was to extend each of the most significant events to include its origins and its consequences. This changed the timeline from a series of discrete points to a continuum on which events (understood now as processes) became blurred (overlapped). The last stage was to organise the timeline into epochs and review its dimensions accordingly.

Once the historical description of each SLS was completed, it was possible to draw a comparison. The comparison was facilitated by having used the same structured heuristic to construct each case in an explicit, systematic manner, as recommended by George and Bennett (2004). The comparative stage included analysis of the forces of change in SLS, the struggles within the field as Bourdieu (2005) calls them, which were analysed using the concept of alignment (von Tunzelmann, 2010a).

3.4 Locating Doctoral Graduates as Agents in the *SLS*

My research involved selecting SLS as the fields of study, mapping the history of each SLS, and locating the experiences of doctoral graduates within the SLS. This last stage involved deductive analysis based on the historical review, and an empirical study. This section discusses the latter, the empirical part, which consisted of the construction of 24 individual case studies of doctoral graduates' work life histories.

Producer capabilities emerge within a social context, as the result of learning processes. Learners are individual people in their particular circumstances. Doctoral graduates' participation in the accumulation of producer capabilities depends, on the one hand, on the (socially constituted) dispositions of the agents –particularly their capitals, and on the other hand, on the employment situation (demand for labour). The two parts of the traditional model of supply and demand, commonly considered as unconditional givens, depend on the economic and social conditions produced by the technology and governance systems and the characteristics of the industry sector. The participation of doctoral graduates - high skilled workers - in the accumulation of sectoral producer capabilities is the product of a *three-fold social construction*: production of doctoral graduates, supply of work based on the agents' abilities and dispositions, and the demand for labour.

The thesis takes the perspective of one particular group of agents in the process of capability accumulation in SLS: doctoral graduates. It is an anthropological perspective anchored in the particularity of experience, but allowing the possibility of generalisation:

> My entire scientific enterprise is indeed based on the belief that the deepest logic of the social world can be grasped only if one plunges into the particularity of an empirical reality, historically located and dated, but with the objective of constructing it as a 'special case of what is possible,' as Bachelard puts it, that is, as an exemplary case in a finite world of possible configurations...The aim of the researcher is to apprehend structures and mechanisms such as the principles of constructions of social space and the mechanisms of reproduction of that space,

> and 'that the researcher seeks to represent in a model aspiring to universal validity'. The researcher looks at the particularities of different histories 'to register the real differences that separate both structures and dispositions (habitus)'. (Bourdieu, 1998: 2)

The method for the empirical part of the thesis consists of constructing examples of the work experiences of doctoral graduates in the SLS. The purpose is to complement the study of each field and provide examples to illustrate the history of the field in relation to doctoral graduates.

3.4.1 Selection of individual case studies

I constructed eight individual cases per sector, 24 cases in total, to illustrate the relationship between SLS and doctoral graduates, and its diversity. The cases were purposefully selected to achieve maximum diversity in doctoral graduates' work experience. They were developed based on the logic of presenting in depth examples of individual experience in the process of accumulation of producer capabilities.

The cases includes different work positions of doctoral graduates in SLS, for example, as an employee in a producer or supplier firm, as an external consultant, as a participant in R&D projects for the SLS, or as a contributor to regulation. To select the cases I collected sets of basic information from publicly available documents, such as individual profiles indicating place of doctoral study, work position, previous work placements, media interviews, participation in seminars and conferences, publications and presentations. Selection of cases implied familiarity at this basic level with multiple potential cases.

To achieve the greatest diversity, I assumed that different generations of doctoral graduates would have contrasting experience since circumstances change over time. To capture historical changes in their work fields, I constructed three groups according to year of award of doctoral degree: a senior group of pre-1990 graduates; a mid career group whose members graduated between 1990 and 2000; and an early career group whose members graduated after 2000. The cut off years were selected based on the history of higher education in Chile (discussed in Ch. 4, Section 4.1). I identified changes in the field of higher education which I assumed would be relevant to the experience of doctoral graduates in Chile. The first group, pre-1990 graduates, includes those whose doctoral education had begun or was completed before the expansion of local doctoral programmes, before the effects of the 1980s' Reform became widespread, and under dictatorship. The second group graduated in the 1990s during the period of expansion of private universities in Chile, growth of doctoral education, competitive public funding (established by then), and the new democratic period. The last group graduated in the 2000s, in the period of funding for doctoral programmes and expansion of postgraduate studies (See Ch. 4, Section 4.2).

For each industry sector and each generational group I selected examples that varied by gender, work placement (universities, private and public organisations) and location (capital and regions). Although I searched extensively to find examples of different disciplines, all but one are in the areas of natural sciences, agriculture and engineering. The exception is a social science (economics) graduate. Tables 3.1-3.3 present the characteristics of the cases selected for the fieldwork. The categories in these tables were used to guide my search for and selection of cases, and reflect the dimensions of diversity I considered. A list of candidates for the fieldwork interviews was included under each column. The selection process involved my contacting the candidates in order, to request an in depth working history interview (a free account of their working life during and after their doctoral research, Goodson and Sikes, 2001); this process continued until I obtained one case for each column of characteristics.

Table 3.1: Characteristics of Copper Mining Individual Cases. Search Period: March – May 2010, Fieldwork: June 2010

Criteria	1	2	3	4	5	6	7	8
Generation	Senior	Senior	Senior	Mid	Mid	Mid	Early	Early
Gender	Male	Male	Female	Female	Female	Male	Male	Male
Main Work	Private	Public	HE	HE	HE	HE	HE	Private
Discipline	Eng	Sciences	Eng	Eng	Soc Sc	Eng	Eng	Eng
Location	Capital	Capital	North	North	Capital	Capital	Capital	Capital

Table 3.2: Characteristics of Fruit Growing Individual Cases. Search Period: June – August 2010, Fieldwork: September 2010

Criteria	1	2	3	4	5	6	7	8
Generation	Senior	Mid	Mid	Mid	Mid	Early	Early	Early
Gender	Male	Male	Female	Male	Male	Male	Female	Female
Main Work	HE	Public	HE	HE	Private	Public	Public	HE
Discipline	Agric.	Agric.	Agric.	Sc.	Agric	Agric	Agric	Agric
Location	Region	Region	Capital	Capital	Capital	Capital	Region	Region

Table 3.3: Characteristics of Salmon Farming Individual Cases. Search Period: December 2010– February 2011, Fieldwork: March 2011

Criteria	1	2	3	4	5	6	7	8	9
Generation	Senior	Senior	Mid	Mid	Mid	Mid	Mid	Early	Early
Gender	Male	Male	Female	Female	Male	Female	Male	Male	Male
Main Work	HE	Private	Private	HE/Private	Public	HE	Private	HE	Private
Location	Capital	South	Capital	Capital	South	South	South	South	South
Discipline	Sc.	Eng.	Sc.	Sc.	Sc.	Sc.	Sc.	Sc.	Sc.

3.4.2 Construction of individual case studies

The main methods used to construct the individual cases were: extensive internet searches on working activities; work history interviews; review of work documents (publications authored by the individuals and/or their institutions, policy documents related to their immediate work context); and work place observations of site and practice. The methods were taken from anthropological methods and practice (Hammersley and Atkinson, 1995; DeWalt &DeWalt, 2002; Jordan, 2003)

Working on the individual cases influenced the process of searching for the SLS's history. For example, interviewees recalled events in their work history that they saw as particularly significant and I later searched for these events in history books, to evaluate their importance to the SLS history. At a later stage, I used these references systematically. I coded interview transcripts and case notes for their direct relation to historical events, and organised them along a time-line. I compared the time-line to my findings from multiple documentary sources on the sectors' histories. Analysing the differences resulted in more search and reading to fill gaps on each side (individual cases and sector cases).

Analysis of the direct interactions between doctoral graduates and other agents in the industry sector (e.g., contracts), were possible only after in-depth analysis of the structures, positions and historical dynamic of the agents in the field. The recollections of interviewees were subjected to the same process. The data collected to construct the individual cases were not taken at face value:

> There could be no better time to recall that the truth of the interaction is not to be found in the interaction itself (a two-way relation that is always in fact a three-way relation, between the two agents in the social space within which they are located). (Bourdieu, 2005:148)

The core of the data gathering was the individual work story interviews with the 24 doctoral graduates constituting the sample population. The interviews were conducted respecting the ethical guidelines of the then Sussex Institute (my research was ruled by the prevailing Sussex Institute norms, and research proposal approval included an ethical review). Interviewees were contacted in advance and informed about the purposes of the research and the conditions for their participation (offer of anonymity, use of the information only for the thesis purposes, and the right to withdraw). All interviewees signed the consent form presented in Appendix 1. The interviews lasted for a minimum of one hour; they took place face to face, at the interviewee's work place, and were conducted in Spanish language, recorded and later transcribed. Interviewees consented to the use of the interview data for the purposes of the thesis. There were not questions on the research purposes, following the email with a short description, and most interviewees declined both anonymity and receiving copies of recording and transcripts. Since all interviewees are doctoral graduates, they are familiar with research activities and were well disposed to collaborate with a doctoral student research.

The interviews were aimed at collecting a piece of a 'life story', a data collection method popular in social science (Plummer, 2001). The concept of life story is based on the position that humans make meaning of the world through narratives (Bruner, 1990), and their collection provides understanding and meaning through the subjects' own perspectives of their lives and everyday world (Kvale, 1996, 2009). Adopting this approach allowed the possibility to focus on relationships not facilitated by other data collection methods. The interviews were open, free accounts of individuals' work experience. In most cases, interviewees talked for around half an hour, after that a few prompts where introduced, for example: 'could you expand on the period you worked in that institute?' 'Could you give me more details about your move from the research institute to the consultancy firm?' 'Could you tell me about your present working routine?'

According to Miller (2000), collecting life stories using a 'narrative approach' implies acceptance of subjectivity and a focus on the organisation of the narrative, which contains the most important information: 'The content of a life story that a respondent will give in an interview will be dependent upon how they see their life at that particular moment and how they choose to depict that life to the person carrying out the interview' (Miller, 2000: 139). In choosing a particular narrative, respondents are taking into account of what they think are the interviewer's areas of interest and, also of the effect that they (the interviewees) want to make.

The interviews were an opportunity for site observation in addition, whenever possible, to observation of work practices through visits to laboratories, participation in classes, seminars and fieldwork trips. After every site activity, there was more documentary material to include in the case: institutional leaflets, references to websites to review, references to written work, institutional rules, etc. All this material was included in the fieldwork notes.

3.4.3 Analysis of individual case studies

The analysis of the individual case studies in its final version focused on identifying changes in the accumulation of different kinds of capital. Often it involved revisiting the construction of individual case studies on more than one occasion.

Above, I described how the case studies were constructed, and the centrality of the interviews to the process. In the course of the analysis, my understanding of the cases and their construction began to change. It took more than a year of experimental approaches and writing to develop the contribution of the individual case studies in coherence with the theoretical and methodological approaches.

The first layer of analysis of individual's data was based on the interviews transcriptions. As mentioned earlier, I extracted a time line of events in the individual's work trajectory. I related each time line to historical circumstances and contrasted them to my progress on the history of the SLS. The parallel brought out new questions that enriched the SLS descriptions.

I began a new layer of analysis, still based on the interview transcripts. I identified common topics across the interviews and coded them (e.g., repeated references to research funding for which I could find no match in the history of SLS in relation to its importance). I attempted a discourse analysis of the transcripts and identified a common plot, as described in the literature (e.g., Miller, 2000, and Gergen, 2001). All were coherent accounts with a sense of direction towards an identifiable goal; the interviewees selected events relevant to the goal and presented them in chronological order. The interviewees presented a stable self identity along their stories, and provided explanations for the unfolding of events using causal linkages. I then tried a new coding system, this time working with the transcripts to identify references to different kinds of capital. The coding processes were all supported by the Nvivo software package. My files were growing in complexity and my understanding felt as developing between the obvious and the meaningless (e.g., comparing individual cases).

I could not be satisfied with the centrality of the interviews; my understanding of the cases aroused from the many sources consulted and my fieldwork observations as an individual familiar with the relevant local culture. Later on I discover I was not alone in refusing the simplistic conflation of 'voice as evidence' (Jackson, 2009) and questioning 'the obsession [of qualitative enquiry] with the voices of the participants as the primary most authentic data (evidence)... and the disappearance of other data' (St Pierre, 2009: 232). I knew I could not generalise from these in depth case studies. I wanted to construct them as examples, but initially I did not know examples of what they were going to be.

My theoretical and methodological frameworks had not matured; I was experimenting and did not have the elements to understand why I knew that I needed an anthropological perspective, which was not satisfied by my advances with the individual cases. As my reading and writing developed, I concluded that the interviews and transcripts should have the place of one more source, and should consider the effect of the ‘biographical illusion’ (Bourdieu, [1986]2000); in other words, accepting that the biographies were artificial creations. I respected them for holding the meaning each of their creators wanted to present their lives with. I realised that the work histories of these people could be understood only in context. For me – and coherent with the basis of my research – they had meaning only in the circumstances as they arise, that is, the SLS fields. Also, they were examples of what was possible in those circumstances.

My renewed approach to the analysis and re-construction of the individual case studies provoked several moral reflections. I concluded that the cases should not be pulled apart because they would lose their contextual meaning; coding of the transcripts did not make sense. Although most interviewees had not requested anonymity, my construction of the cases involved many sources they were not aware of (all were public sources, I intentionally did not use social networks or restricted access sources), which implied constructing a richer depiction than the sole interview (where interviewees had decided what they wanted to tell me). Most importantly, I felt uncomfortable with the possible re-use of the case studies for taking the stories out of context. I considered that the meaning interviewees wanted to give to their working lives was or primary relevance.

Ultimately, I used a multi-layer approach, which resembles Mauthner and Doucet’s (2008) proposition. It consisted first of scrutinising all the data on each case (not just the interview transcripts) to build a time line of objective events (dates and places of work) and then a second reading to connect events with historical circumstances, in an iterative process alternating with my understanding of the historical circumstances. Finally, I constructed each case as a story that synthesised most of the information I had collected on the case.

After much thought about how easy it would be to identify the interviewee (who had not requested anonymity, but who I felt should be granted it), I decided to include one of these stories as Appendix 2 as an example of how the cases included different sources and how their construction and analysis involved the researcher’s history too. The story is a writing device that condenses the fieldwork on the case of Dra Apple. In line with ethnographic fieldwork notes (Emerson et al., 2001), it contains descriptions, but also analytical writing, and my own reactions and emotions. The story of Dra Apple shows how the cases were constructed using multiple sources and how these sources where interpreted by me. For example, I had been in the city where Dra Apple lived and could appreciate the effects of the recent earthquake; I could compare the university campus with other university campus in Chile; and I agreed with her description of the centre as having an excellent reputation in the region, because I could see how outstanding it was. In every story, observations like these jump out of the text. I also did not need funding schemes, acronyms, or types of contracts to be explained because I was familiar with them all. I could be invited spontaneously to fieldwork in mining activities because I had my security shoes on and my helmet with me in anticipation of this possibility.

Written stories were the best device for synthesising each case material. I worked with them in two more layers. First, to identify capitals at play based on all the information on the case and my knowledge of the fields. Second, another reading to identify what the case exemplified. The written story of Dra Apple (Appendix 3.2) is the final outcome of the process. All the written stories and selected quotes from the transcripts (translated by me) were used to introduce the examples in the discussion in the empirical chapters (5, 6 and 7), and to provide examples of the effect of scientific field on doctoral graduates' practice (Ch. 4).

3.5 A Reflexive Relational Approach

The underlying methodological approach to the description in the previous section was constant attention to maintaining a reflexive approach to the research; this was particularly important and also motivated by the interdisciplinary character of this thesis. The relational focus of the approach acted as an axis for evaluating the coherence of using different methods.

A reflexive approach - in Hunt and Sampson's (2006) understanding of reflexivity - is a process that allows development of a sense of standing outside oneself to observe one's doing and thinking, and moving fluidly between one's outside perspective and inside perspectives. This process implies an awareness of one's assumptions, suspension of quick judgements, allowing time for emotions and prejudices to sink, and enabling a fresh view.

3.5.1 Developing a reflexive approach

The method I had used systematically to develop a reflexive approach was writing with different devices. First, I used a research diary as a tool for registering insights and for systematic revision and rewriting of previous entries. I also used a free-writing book, where I wrote, edited and constructed different mind maps, drawings and representations of my thinking, which I later analysed and developed further. I undertook numerous analytical exercises trying out different representations of the data and their relation to theory, matrixes, double entry tables, graphs, and systematic experimental exercises, all of which were intermediate steps in the analytical process.

I have a close familiarity with the research setting. The advantages of close involvement were easy access to sources of data, including interviews, and context background for the research; the disadvantages are having preconceptions. Rather than embarking on a discussion of insider and outsider perspectives (Davies, 1999), it would be more appropriate perhaps to consider the view that the divide between outsider and insider is not clear-cut since ‘in a sense, all social research is a form of participant observation, because we cannot study the social world without being part of it’ (Hammersley and Atkinson, 1995: 249). The challenge for me has been developing a reflexive approach to a familiar setting. I worked continuously on this as part of the learning process involved in ‘becoming a researcher’ (Dunne, Pryor and Yates[8], 2005).

3.5.2 Use of daily experience

The research topic has the particularity of being strongly related to the experience of being a doctoral student and a research assistant. I daily had opportunities to observe doctoral graduates at work, at a time of change in the English university funding and management systems. Although not one of the case studies, this experience provided insights into and familiarity with practices that could be transferred to the research process. It provided an opportunity for training as an ‘observant participant’ (Holy, 1984) in academic work. I felt strongly that my daily practices were close to the individual cases I was studying. The writing devices involved in a reflexive approach contain many entries and, later, comments on the experience of working in a doctoral graduate setting.

[8] The authors request that all three names are cited when referring to their book.

3.5.3 Multi-disciplinary research

My research drew on several disciplines – mainly innovation studies and higher education studies. Multi-disciplinarity was a challenge from an early stage in the research and provided both stimulus and pain. Each of the two main disciplines I drew on has its own sphere of communication, inseparably linked to what Bakhtin (1986a) calls its own ‘speech genre’ defined by the thematic content, style and compositional structure of the utterance. There are terms used in each discipline that give a taste of the particular profession, and context of the writings within it.

I took up the challenge of producing text that addresses a multidisciplinary academic audience by not adhering to one genre because: ‘The transfer of style from one genre to another not only alters the way a style sounds, under conditions of a genre unnatural to it, but also violates or renews the given genre’ (Bakhtin, 1986a: 64), but rather by following Bakhtin’s (1986b) advice to consciously develop multiple styles, connected by dialogic relationships.

3.5.4 Applying a relational perspective

A relational approach, as implemented for this research, implied progress on each part in parallel. All the chapters in this thesis began as open files to which I made regular additions, following a time-plan. My time-plan gave me an order to work more in-depth on one subject each week, but everything remained on my working table as work in progress. I also realised that this approach resembles the work conducted in laboratories or engineering workshops: it is experimental and incremental.

Chapter 4. The Scientific Field as Empirical Background

This chapter gives an account of the scientific field as empirical background for the study of doctoral graduates within SLS (Ch. 5, 6 and 7). The scientific field in this thesis is the context for the practice of producing science, which involves agents, structures, relations and rules of the game. Most research activity in Chile is concentrated in a few universities (OECD and IBRD/WB, 2009), universities are the main agents of the Chilean scientific field.

The relevant fields for an individual are those which exercise an effect in his or her practice, such that practice cannot be explained only by the characteristics of the individual (Bourdieu and Wacquant, 1992). This chapter discusses how the scientific field has effects on doctoral graduates' work practice, making the point that doctoral graduates work practice in SLS cannot be understood without considering the scientific field.

As pointed out by Crossouard (2006), besides the policy focus on skills and training as outcomes of doctoral education, academics had observed in doctoral education processes of socialisation and enculturation. These processes involve developing a sense of belonging to a research culture. The effects of the practice of science imply the embodiment of a system of generative dispositions that is largely unconscious and transposable (Bourdieu, 2004). The system is specific to different scientific disciplines and personal trajectories and, through practice, becomes habitus. Scientific practice, in general, produces agents who act with conscious intentions and according to methods and programmes. The scientific craft implies learning and embodying complex theoretical structures and formalised knowledge, which pass into practice. Mastering the scientific craft is the result of prolonged practising of the routines and rules of the scientific field (Bourdieu, 2004).

As part of their education, doctoral graduates practice science and learn to work within scientific routines which they embody as dispositions. One can expect these dispositions to be long lasting if the doctoral graduate continues his or her practice of scientific routines, even in a field different from the university setting. The vast majority of doctoral graduates in Chile is employed in universities and research institutions; they consider research to be an important part of their work (see Ch.1, Section 1.4). Universities and research institutes are both work places for doctoral graduates and the places of origin of new doctoral graduates.

This chapter presents three perspectives on the history of the scientific field in Chile, those of universities, doctoral education and research institutes (Sections 4.1, 4.2 and 4.3). The historical overview is followed by a discussion of the encounter of doctoral graduates with historical circumstances. It includes the emergence of doctoral graduates within the field, their expansion and their current positions (Section 4.4). The chapter concludes with a discussion of the participation of doctoral graduates in multiple networks and multiple fields, often simultaneously, and its implications for the thesis research (Section 4.5).

4.1 Universities

The idea of focusing university activity on research rather than on the education of professionals emerged in Chile only in the 1960s and did not prosper under the university funding reductions of the 1980s. However, the idea of research being a function of the university prevailed. It has influenced the notion of scientific academic faculties, university excellence and the distribution of funding.

In the 1960s universities transited from employing only 'teaching staff' to employing 'research faculty' (Bernasconi, 2007). The notion of a 'research university' appeared in Chile in the 1990s as a means of differentiation in a competitive environment. Bernasconi (2007) argues that, on the basis of faculty composition, allocation of financial resources and postgraduate students, there are no research universities in Chile. His diagnosis is similar to an OECD and IBRD/WB (2009) report concluding that the Chilean research system, which consists mainly of universities, lacks focus and funding.

The field of higher education in Chile during the first decade of the 21st century was ruled by the logic of competition for scarce resources. Universities are heterogeneous players, in contrasting positions. For all universities students' fees are the main source of funding. Additional resources come, for example, from competitive funds for research activities. They need to present themselves as research institutions to get access to funding. Being a research institution is considered valuable and related to academic excellence; it is an asset for attracting students and faculty. Policy discourse regarding universities funding have been clear in moving away from funding students fees, undergraduate degrees are an individual investment and the role of the state is to provide a system of loans for wide access. Research – which includes doctoral education -, development and innovation are the only areas where public funding could be justified (see Chapter 1, Section 1.5). The current circumstances can be better understood as part of the following historical context.

4.1.1 Foundation to establishment of the university field: 1810-1960

The history of universities in Chile goes back to the republic, following independence from Spain in 1810. The Royal University of San Felipe, opened by the colony in 1758, was abolished by government in 1839 (Collier and Sater, 2004). New universities, public and private, were established under the republic, all financed by public resources and focused mainly on the education of professionals (Serrano, 1993).

The first republican university was Universidad de Chile, a public university founded in 1842, linked from the beginning to national development, and inspired by republican values (Bello, 1842; Serrano, 1993). Universidad de Chile was one of many Latin American universities created by the new independent governments. Republican universities followed the French university model; they were structured in faculties, and focused on professional training –typically law, medicine and engineering. An important proportion of the lecturers were prestigious professionals, teaching part-time alongside their professional activities (Bernasconi, 2007). The mission of the university was to construct the nation and the state; students did not have to pay fees.

From an early stage, private universities were part of the higher education system, as state collaborators (Serrano, 1993). The first private university was Pontificia Universidad Católica de Chile, founded by the Catholic Church in 1888, as a response to the ideas of the secular government. Public and private universities alike were funded by government, an unusual characteristic of the Chilean system compared to the rest of Latin America.

State control over public universities in Latin America declined with the 1918 reform movement (The Reform of Córdova, Argentina). Chilean public universities were part of the reform and after 1918 they gained autonomy from the state; they installed internal democratic systems of co-governance between academics, students and non-academic staff, with elections for Chancellors and Deans (Bernasconi, 2007). Public universities were totally funded with public money and it was a shared belief they have a crucial political role in transforming society. Córdova reinforced the commitment to gratuity of fees, which became an extended practice in the region by 1960s. The main activity of universities during this period continued to be education and training of professionals (Bernasconi, 2007).

The professional associations were established during this period. They aimed at representing and advancing the different professions and contributing to the country's development. They had no influence, either then or later, on the award of professional degrees.

4.1.2 Emergence of the idea of research as a university mission: 1960-1973

By the early 1960s, universities were mainly for undergraduate teaching. The public universities concentrated 60% of the enrolment and had national presence. The private universities belonged to the Catholic Church or to regional non-for-profit organisations. The university system was small and homogenous, ruled and funded by the state (Bernasconi and Rojas, 2004). The 1960s were years of change in Chilean history. The Agrarian Reform, for example, disrupted the stability of the agriculture sector which had not changed from colonial times (see Ch. 6, Section 6.1). Also, the nationalisation of copper had no precedent in the relationship between the state and the private sector (see Ch.5, Section 5.1).

Universities were seen as important agents for the transformation of society. They were interrogated in their roles and responded with a process of reform, known as the University Reform (1967-1973). The University Reform was a time of intense debate on the nature of the university mission (Bernasconi and Rojas, 2004). It gave place to renewed commitment to the ideals of the Reform of Cordova and to transformations in the universities (Bernasconi, 2007). Enrolment grew almost threefold (from 55,104 to 146,451 students, Brunner, 1986:49) and universities changed to accommodate the new ideas of focusing on research rather than education of professionals (Bernasconi and Rojas, 2004).

The traditional focus of Chilean universities on professional training implied universities were – and still are - organised around professional titles rather than undergraduate degrees. A university qualification grants the student lifetime professional status[9]. There is no independent system regulating the professions. For example, the faculty of engineering confers the professional qualification of engineer following six years of study and submission of a dissertation.

A BSc degree is awarded after four years of stud`y in professions of five or more years of studies. The BSc degree is not regarded as significant by either students or employers (academia, government or private sector), what is important is the professional title. Students do not enrol for the bachelor's degree; they enrol in a professional programme. There is no graduation ceremony for the award of a BSc degree. For example, social sciences students can enrol on professional programmes in journalism, sociology or psychology (all five years programmes involving a dissertation) and will be awarded their bachelor's degrees in social sciences after the fourth year. The dissertations required by professional degrees are research projects or professional projects involving an innovative element.

Pre-1965, the BSc in life sciences was awarded as part of the professional study programme in medicine. After that time, as part of the reform ideas and ideals, a research oriented bachelor's degree programme in life science began to be offered by a few universities. However, in other academic areas, the number of pure BSc programmes, and number of students enrolling on them, remained very small.

The National Academy of Sciences, and the National Academies of Fine Arts, Medicine, Social Sciences, Political Sciences and Ethics were created in 1964 by the Ministry of Education (Law 15,718, 1964). Their aim was to promote a national science culture.

4.1.3 Dictatorship: 1973-1990

The military coup in 1973 brought the University Reform to an abrupt end. Universities were intervened by imposing military rectors in all public universities and most of the

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[9] The exception is the professional title of lawyer which is granted by the Court of Justice to the successful candidates of a national examination.

private ones. Some social sciences and humanities faculties were closed down and total university enrolment had fallen to 118,978 students by 1980 (Brunner, 1986:49). The traumatic changes to university life were followed by the imposition of a new order, stated by law between 1981 and 1982. As part of the dictatorship's economic reforms (1973-1990), higher education funding became increasingly competitive and dependent on private sources. A diversified system of financing of the existing universities was introduced, which transferred an important part of the costs of a university education to the students and their families (DFL N1, 1981, and DFL N4, 1981). Between 1980 and 1990 public funding fell by 41% (OECD and IBRD/WB, 2009). The reform allowed the creation of self-funded private education institutions (DFL N5,1981 and DFL N24, 1981) which, in 2009, accounted for half of total student enrolment (CSE,2010).

The 1980s reform imposed different conditions for universities created before and after 1982. Universities created before 1982, both public and private, continued to receive direct public funding. They had a representing institution, CRUCH (The Council of University Chancellors) since 1954 (Law 11.575, article 36). They continued under the same conditions marking a difference with the private universities created after 1982. Even when the conditions for CRUCH universities may seem homogenous, only public ones have to comply with the rules to public services, for example, norms for management and use of resources and limitations to use financial services (such as loans).The new funding system included the creation of a competitive fund for research projects, FONDECYT, Fund for Development of Science and Technology (DFLN33, 1981).

4.1.4 New democratic period: 1990 onwards

In March 1990, before leaving the House of Government to the new democratically elected President, the dictatorship published a law for the education system. LOCE (Law 18,962) established the regulatory mechanisms for a hybrid system of private and public institutions. The changes to the regulatory body after 1990 had been along the lines of improving the system in place, and maintaining its structure. In 2005, a provision was introduced to allow student loans that would be guaranteed by the state, in order to widen access to higher education (Law 20,027) and in 2006 the information and accreditation system was introduced (Law 20,029).

In 2009, higher education in Chile was funded mainly by the private sector. The OECD and IBRD/WB (2009) estimate that 84.5% of spending on higher education was private, approximately 83.7% from household incomes and 0.9% from other private sources. Enrolment in the Chilean higher education system has grown rapidly, from 7% of the population aged between 18 and 24 years old in 1980, to 41 % in 2009, and a total of 809,417 students distributed across a diverse group of 176 institutions (CSE, 2010). A majority of 80% of the students were enrolled in private institutions with universities accounting for 66% of total enrolment (CSE, 2010). Although access to higher education has expanded, there are important differences when breaking the figure by socio-economic groups. Among the richest 10% access rates area at around 80% ; amongst the poorest 10% they have 12% access (Espinoza, 2007; OECD and IBRD/WB, 2009).

Chilean higher education is segmented and stratified. There are differences in ownership: public universities and private universities. The later are owned by religious groups, leaders of political parties, the Masons, independent boards or international organisations such as Laureate International Universities. Regulation is different for universities created before and after the reform of 1982. There are also differences between universities located in the capital and in the regions and important differences in size – whether measured by number of students, economic resources or square meters.

4.1.5 Chilean universities in the international context

The Chilean higher education system shows transformations that have been observed worldwide, with some characteristics, such as privatisation, particularly widespread compared to international trends and dating from much earlier. In the Latin American context, there are different degrees of transformation to a market oriented system which have been heavily influenced by the agenda of the World Bank (Torres, 2002), and probably are more evident and rather more premature than in the US or Europe. Rhodes and Slaughter (1997) were among the first to call attention to a process of change in the higher education system to an increasing focus on economic competitiveness, which they called 'academic capitalism'. The changes they foresaw, based on university case studies in the United States and Australia, were already present in the Chilean system after the 1982 reform.

Contemporary higher education globally is evidence of the realities of increased enrolment and diffusion of the idea that higher education is a private rather than a public good, both of which are having a deep impact on how academic systems and universities operate (Altbach, 2007). The private education sector has grown, and depends almost exclusively on student fees; most state financial support has been withdrawn. For Altbach (2007), the consequences of these worldwide trends are clear: higher student fees; less basic research; and more academic entrepreneurialism. Altbach observes increasing stratification, with the elite institutions attracting ever higher proportions of students from affluent backgrounds.

It is not surprising, then, that in the Chilean system these consequences and changes to the academic profession are similar to the global trends described by Stromquist (2007). In a six country comparative case study[10], she concludes that the higher enrolment achieved by selling higher education through commercial ventures, has been followed by a deterioration in the working conditions of academics, changes in employment relationships, and an increasing segmentation of academics across institutions. The situation is worse in the private universities, where contracts are less secure, and there is a high disconnect between research and teaching (Stromquist, 2007). The author points also to the high proportions of part-time employment amongst lecturers, and its implications for university governance. Finally, she draws attention to the replacement of self-regulation by external mechanisms of control, especially accreditation systems.

Other case studies show how, in a market model – such as the case of Chile, at least for the private universities - there is intense competition for professional talent since the reputation and income of the university depends on the quality of its academics (Frank and Opitz, 2006)[11]. The system tends to concentrate the most successful academics in the most prestigious research universities and, also, within those universities there is internal differentiation as a result of the relative success of academics in competing for external funding. In contrast, academics working in bureaucratically organised universities – which to an extent applies to the public universities in Chile – can

[10] The countries considered are: Brazil, Denmark, Mexico, Peru, Russia and South Africa.

[11] Frank and Opitz (2006) compare the cases of Germany and the US..

increase their salaries either by seeking positions in other universities or supplement them by accepting part-time opportunities elsewhere (Frank and Opitz, 2006).

4.2 Doctoral Education

The doctoral population is small in Chile, even in universities –their main place of employment – it reaches no more than 20% (See Ch.1, Section 1.6).Chilean doctoral education has developed as part of the higher education system, organised and run by universities. Doctoral education only started expanding in the 1990s. Before then doctoral degrees were seen as part of the progression of an academic career. In most cases doctoral studies were undertaken abroad. International doctoral degrees are valid in Chile. The requirement for proof is a certificate issued by the awarding university. There is no need for national accreditation of postgraduate degrees as opposed to undergraduate degrees and professional qualifications.

The main characteristic of the system for doctoral studies in Chile in 2006 was concentration. Programmes, enrolment and graduation show high concentration by region, discipline and university. Doctoral activity is concentrated in the capital and in two other regional capitals, mainly in the disciplines of science and technology, and more than 70% of students are enrolled in three universities. The programmes state that they prepare researchers to lead research projects and to contribute to the production of knowledge. Programmes are mainly associated with single disciplines and there is little reference to job opportunities for future graduates (Revision of doctorate programmes webpages, CRUCH, 2008a). Scholarships for doctoral studies have increased, initially focused on funding doctoral studies abroad and later including also funding for local study.

Doctoral education in Chile developed in the context of competition for scarce public funding and for students –who pay fees. It was born as a ‘borrowed’ concept, in the sense that the programmes were intended to satisfy international standards, taking as reference European and United States systems.

The definition of the doctoral degree is part of the law that regulates higher education in Chile:

> The degree of doctor is the maximum level a university can award. It is conferred on a student with a Bachelors or Masters degree in the corresponding discipline, who has fulfilled the requirements of a superior programme of study and research, which certifies that the student has the capacity and knowledge needed to carry out original research. In addition to approved courses and other activities, a doctoral programme must include preparation for and defence of an approved thesis, consisting of original research, developed autonomously, which constitutes a contribution to the discipline of study. (LOCE, Article 31, my translation)

The doctoral degree requires an original piece of research in the form of a thesis, which is a feature common to most countries' systems (Nerad and Heggelund, 2008:313) and demonstrates the contribution to the development of a discipline or professional area (Powell and Green, 2007: 234). According to Boud and Lee (2009), in their review of changing practice in doctoral education, although there are many differences across countries and disciplines, there is a common emphasis on the role of doctoral graduates in the reproduction, maintenance and transformation of disciplines. Boud and Lee (2009) recognise also that common to contemporary doctoral degrees is that they should be research based; this is a characteristic of the modern doctorate established in the 19th century in Europe, and adopted later in the US, and in the 20th century by Britain and Australia and eventually by other countries (Boud and Lee, 2009).

The history of the development of national doctoral education is directly related with research focus of the 1960s. Later on, in the 1990s, the expansion of doctoral education was supported by policies based on market failure and human capital theories. The next paragraphs present a brief historical account of the development of national doctoral education in Chile.

4.2.1 Foundation of doctoral education:1960s - 980s

The first doctoral programme offered in Chile was in Theology, in 1933, by Pontificia Universidad Católica. In 1947, Universidad de Chile launched a doctoral programme in Philosophy. Both programmes were isolated initiatives; it was several decades before doctoral education took off in Chile. According to Devés and Marshall (2008), the foundations of a national system of postgraduate studies were laid in 1968 with the launch of doctoral programmes in exact sciences and engineering, offered by the four universities that were strongest in those areas. Postgraduate studies have developed gradually since then. By the early 1970s, there were a dozen programmes with enrolment of little more than a hundred students. Doctoral education was neither a matter for public policy, nor of great concern to university policy. Devés and Marshall (2008) see the foundation stage as explained by individual efforts and the aim of preparing new academics by selecting the best students from the undergraduate programmes and training them further.

In 1982, there were 16 active doctoral programmes in Chile, with a total of 124 students, located in four universities. At the end of the dictatorship, 1989, the programmes had growth to 35, mainly in the areas of science and technology (CRUCH, 2008). Devés and Marshall (2008) attribute this expansion to the national competitive fund for research, FONDECYT. They argue that FONDECYT enabled the consolidation of critical masses of researchers and the development of new doctorate programmes; it provided researchers with opportunities and incentives to specialise at postgraduate level.

4.2.2 Expansion of doctoral education: 1990s onwards

The expansion of doctoral programmes followed the expansion of undergraduate education in the 1990s. Devés and Marshall (2008) observe that the increase in the number and diversity of doctoral programmes took off in 1999 fostered by the creation of the Fund for Improvement of Quality in Higher Education (MECESUP) and the increased number of scholarships and loans available for doctoral studies in Chile and abroad (MECESUP, 2006). Between 1999 and 2004, MECESUP supported projects aimed at improving facilities, equipment, academic specialisation and academic exchanges. After 2004, MECESUP focused mainly on projects for curricular development and academic specialization and interchange in relation to curricula strengthen.

The system for accreditation and quality assurance in higher education started developing in the 1990s. Doctoral education was the first area to have an accreditation system based on a common agreement among universities offering doctoral programmes. In 2006 the system was regularised with the publication of the law on quality assurance and accreditation in higher education (Law 20.129). The law establishes mechanisms, conditions and obligations for accrediting institutions and programmes. Accreditation is a requirement for access to public funding for institutions and for students to scholarships and loans.

4. 3 Research Institutes

Research institutes have a marginal position in the scientific field compared to the centrality of universities. They are small measured by research activity and involvement of doctoral graduates; however they are specialised and some of them are particularly important to the research system associated directly with copper mining, fruit growing and salmon farming.

The prevailing developmental ideas of the 1960s have translated into policy oriented to enlarging the country's science base. Government created several public research institutes devoted to the main areas of economic development. The three related directly to the case studies in this thesis are: INIA (National Institute for Agricultural Research), IFOP (Institute for Enhancement of Fisheries) and CIMM (Research Centre for Mining and Metallurgy). These public research institutes initially were totally funded by government. Following the university reform towards self funding, in the 1980s public research institutes were required to obtain increasing percentages of funding from competitive sources (mostly government). A different model to that of the public research institute gave its origins to Fundación Chile, which is included in this section because of its importance to salmon farming and fruit growing.

INIA, related to the Ministry of Agriculture, was created in 1964 by CORFO, University of Chile, Pontificia Universidad Católica and University of Concepcion. INIA has 11 research centres across Chile. Its mission is development and transfer of knowledge and technology for innovation and productivity in the agriculture and forestry sectors. INIA engaged in R&D in fruit growing only during industry expansion at the end of the 1980s.

IFOP, also created in 1964, was the result of an international collaborative project involving the Chilean government, and UN agencies. It was funded by CORFO and the National Association of Fisheries. At that time, the fisheries were developing and expanding. Once they became established, they were subject to a process of regulation and IFOP became the main provider of data and technical support for the regulatory body. One of IFOP's main tasks became collecting data to calculate fish stock, which is the key input to allocate fishing quotas. The southern branches of IFOP (in areas away from the main fisheries activity) focused on R&D related to opportunities for the economic development for these southern regions of Chile, including early stages of salmon farming.

CIMM was created in 1970 by CORFO and CODELCO and was supported by international collaborations. It was created in response to the need for reliable measures of mineral properties and for R&D and technology developments for the nationalised copper industry, and the mining sector more generally. In 1998 CIMM created a spin off firm to supply commercial technological services to the mining industry.

Fundación Chile was founded in 1976 with matching funding from the US ITT Corporation and the Chilean government. Fundación Chile is a not-for profit organisation dedicated to identification of international technological developments with potential application in Chile, their adaptation and transfer.

New research institutes were founded during the 1990s and 2000s as private initiatives, not-for-profit organisations that were independent or connected to a university. They compete for public R&D funding. Some are related to the SLS studied in this thesis, for example, the Salmon Institute, created by the association of salmon producers, and the Life Sciences Foundation, a private project, partner of a private university, specialised in biotechnology and with projects in salmon vaccines and fruit varieties development.

4.4 Doctoral Graduates and the Scientific Field

This section complements the historical reviews in Sections 4.1, 4.2 and 4.3 by providing the perspective of doctoral graduates on the changes in the scientific field in Chile. I focus on how doctoral graduates began to populate Chilean universities, research centres and other organisations; how this process had been affected by historical changes, and how doctoral graduates have contributed to shaping the scientific field.

In what follows, I present some inferences and illustrate them with examples of individual case studies, which were constructed as part of my empirical research (see Ch. 3). The individual case studies were constructed in relation to the SLS; however, the scientific field played an important part in the working life histories of all my interviewees. It is intertwined with accounts of their work in the SLS and demonstrates the implications of the historical circumstances of universities and research institutes on their working lives.

4.4.1 The 1960s and the idea of a research career

Doctoral graduates working in universities up to the 1960s were a small proportion of university faculty, only 5% in 1965. The change of vision on the role of the university around 1968 and the expansion in number of students (see Section 4.1) implied new directions for universities. The orientation towards research resulted in the creation of faculties which were not directly associated to the professions but to scientific disciplines – always in the logic of serving the development of the country; and the renewed interest in the professions resulted in the opening and expansion of study programmes – for example, in mining engineering to support the process of nationalisation.

The new study programmes attracted students in the 1960s. The case of Dr Bio illustrates the exciting opportunity opened for a young undergraduate interested in science who was studying in a professional programme close to his scientific interests.

When Dr Bio was an undergraduate doing pharmacology, the department opened a BSc programme in biochemistry, students could choose to finish their careers as pharmacists or as biochemists. Dr Bio opted for biochemistry and took a research oriented track. He published, applied for postgraduate education in the US and was successful in obtaining funding from the host institution.

A research career like Dr Bio's would have been unlikely before the 1960s. Publishing was not a priority for faculty members, who were concentrated on teaching. Scientific capital was valued in the university context, and institutionalised cultural capital (the doctoral credential) was desirable for faculty members, but was not a requirement and its value was only beginning to be acknowledged.

In the 1960s universities made efforts for funding doctoral studies for their faculty members (see Section 4.2). For example, Dr Science was hired as an academic and went to the US funded by his Chilean university with the obligation of going back to his academic post.

4.4.2 The 1970s and changes in the valorisation of capitals in the universities

At the beginning of the 1970s there was an increased valorisation of science and research activities, which were seen as important contributors to social and economic development. These were also the early years of the public research institutes created to develop science and technology relevant to strategic industry sectors (see Section 4.3). As described in Section 4.1, the military coup represented an abrupt end to funding for research and expansion of research institutions.

Two individual examples, Dr Bio and Dr Science (both used as examples of the 1960s), illustrate how the greater valorisation of scientific capital represented opportunities for doctoral graduates to access and maintain job positions. Some doctoral graduates were inspired by the social role of science in the political project of the 1960s and early 1970s. The examples also illustrate how after the military coup, valorisation of scientific capital was secondary to alignment to the new political regime.

In 1970 Dr Bio was working at a prestigious research centre in the US –several novel laureates worked there at the time - but decided to go back to Chile because: 'I had political motivations for getting close to the development needs of Chile, to make a contribution to improving living conditions in the country'. In 1970 he started travelling to Chile regularly to work in research collaborations and in early 1973 took a full time position in a public research institute. Dr Bio found a job easily in Chile, a stable public sector contract with research possibilities. The situation changed for Dr Bio in September 1973 with the military coup. His political views were not agreeable to the dictatorship and he went back to work in the US, returning to Chile at the end of the 1980s.

Dr Science completed his studies in an area close to that of Dr Bio and also in the US. In the early 1970s he returned to Chile and resumed his academic job. Over the years he built a strong scientific and academic position and was promoted within the university hierarchy.

The field of higher education and the public research centres did value cultural capital (particularly doctoral degrees) and it was possible to transfer it to access economic capital in the form of a job contract, as it was the case of Dr Bio. The scientific field was not independent from the political struggles of the time. Higher education and public research centres were intervened (the dictatorship nominated chancellors and directors) which implied some people, for example, Dr Bio, was excluded - or excluded themselves - from the field even though they possessed cultural capital that was valued by universities (as shown by the position of Dr Science with similar cultural capital).

4.4.3 The 1980s and learning to compete for jobs and research funding

The main issues were adapting to the big changes resulting from the 1981-1982 reform and the expansion of undergraduate programmes. The pressure for self-funding was a main concern and the idea of competitive research funding was new to the system.

Holding a doctoral degree was unusual in the field of higher education in Chile. Funding opportunities for doctoral studies were limited and based on competition by academic merits. Funding was offered to the best undergraduate students, conferring symbolic value on the offer. The doctoral degree was valued as cultural capital in the form of embodied knowledge and institutionalised in the form of the doctoral credential. The effectiveness of the doctoral degree as capital in the field of higher education can be observed in the case of Dr Chancellor and how he had job offers in times of economic recession.

Dr Chancellor went to Europe and in his last year of study there- 1982- applied for a position in a Chilean university: ‘I was pleased when I was offered the job; Chile was in a deep economic recession [unemployment rose 25%]. The university had just been created as one of the branches of Universidad de Chile after the 1982 Reform’.

Before the 1990s the doctoral credential (institutional cultural capital) was probably recognized by higher education agents as a signal of knowledge and abilities (embodied cultural capital) to perform in the field of that particular time. The doctoral credential may have been considered a certification of research competencies and of specialised knowledge in a scientific discipline. Valorisation of doctoral credentials in higher education implied they could be translated into economic capital (a job contract in a university, for example).

Since the change of vision of academic work in the late 1960s, research rose in importance. Even though, the possibilities of doing research were limited because equipment and laboratories had to be built and funding for universities decreased with the dictatorship (see Section 4.1). The new system, established with the reform of 1982, presented competitive funding – FONDECYT – as the way to conduct research activities. It also considered the number of research publications by university as part of a composite index to allocate university grants. Doctoral graduates were in a comparative better position to access grants (economic capital) and funding for equipment (objectified cultural capital) because their credentials gave them advantage in the evaluation processes.

4.4.4 The 1990s, competition as the rule and real options for local doctoral studies

The field of doctoral education in Chile started to take shape in 1990 (see Section 4.2) and, therefore, it was becoming a 'visible' subfield of higher education. Doctoral graduates became the founders of the new doctoral programmes, most of them having obtained their degrees abroad.

Holding a doctoral degree became a tacit requirement for academic and research positions, especially for institutions offering doctoral programmes or intending to launch one. The market driven system of higher education in Chile was well established in the 1990s and there was strong competition for students and public funding. Graduates interested in an academic or research career understood they could have better chances of employment if they were awarded a doctoral degree. In the 1990s they have the choice of studying for a doctoral degree abroad and, for several disciplines, in Chile.

The case of Dr Rice illustrates how a doctoral credential was considered important capital for securing a job position. Research institutes had lost direct public funding and contracts became less secure. Dr Rice had been working in a public research institute for 10 years and had realized that his career opportunities in the institute would be better if he did a doctoral degree. He went off to the US founded by the institute and came back to work, but, on his return, he found out that he had been allocated a new research area. The institute was working under a new system; researchers had to compete for funding from national and regional agencies. Dr Rice managed to reinsert himself under the new conditions and successfully bid for funding for research projects.

Studying in Chile was now a possibility. The cases of Dra Crystal and Dra Bio-diagnostic also illustrate the motivation of securing an academic position. They choose to study in Chile. They both went to study in Santiago, the capital city, from far away regions where they had done their undergraduate degrees.

Dra Crystal had been a part time lecturer in her regional university for 10 years and had completed a self funded master degree in Santiago. She realised that her chances for getting a permanent, full time contract would be higher with a doctoral degree: ‘I could see all the funding agencies giving more points if the researchers had doctoral degrees. I realized sooner or later it was going to be a requirement for an academic position’. She studied in Santiago funded by her university. Dra Crystal went back to her regional university and her career flourished there, amongst other achievements, in the 2000s she became the first woman professor of her university.

Dra Bio-diagnostic was a good student and wanted to build a research career. She studied for her doctoral degree with a Chilean scholarship and aimed for an academic contract. She was employed in permanent, full time academic position after completing her doctoral degree and had done a successful academic career since then.

Both Dra Crystal and Dra Bio-diagnostic kept active relations with their colleagues from the doctoral studies - names of people they met at the time keep repeating in their interviews. They both remember their doctoral degree as a time where a whole international academic world around their discipline opened up to them. For example, they attended international seminars and presented their work while doing their doctoral degrees and they met international colleagues doing short stays in their laboratories.

In the 2000s Dra Crystal and Dra Bio-diagnostic were involved in the foundation of new doctoral degrees and had established academic careers. They both became director of postgraduate studies for their universities. At the time of the construction of the case studies, they were active researchers and worked in laboratories alongside colleagues and postgraduate students, carrying out a portfolio of externally funded research projects. Previous tutors or colleagues had become external examiners, co-supervisors and collaborators in research projects. Their international network had been important for projects, publications and to obtain placements for short stays for their doctoral students - often related to the development of joint projects. Dra Crystal and Dra Bio-diagnostic had taken part in evaluation and selection processes for funding agencies.

In 1990s, with the opening of higher education to the creation of new private institutions, the processes of licensing of private institutions required presentation of the faculty degrees to external commissions. The official information on university offers and performance –published annually - included number of faculty by degree level. The competitive funding system was well established in the 1990s, as well as the competition for students –fees had become the main source of universities incomes. The doctoral degree credential acquired a different value, universities counted the number of doctoral graduates within their faculty members and the funding agencies asked for copies of the certificates. As discussed in the examples, people aspiring for a career in academia felt a doctoral degree would help them to have a better chance to apply for a job or to advance in their careers.

4.4.5 The 2000s, the doctoral degree as the 'price of entry', and competitive funding as one of the rules of the game

The requirement of a doctoral degree for an academic position or a researcher contract in a public institute became explicit. The funding system, which promotes industry oriented research, was well established. It was not only having a doctoral degree but also developing a research topic with funding potential. The examples of Dr Academic-miner, who studied abroad, and Dr Micro-ecology, who studied in Chile, illustrate how in the 2000s the doctoral degree became a sort of 'price of entry' (Bourdieu, 2004, 2005) for an academic position.

Dr Academic-miner was hired as an academic in 2000, after finishing his undergraduate degree. His contract explicitly established he should complete a doctoral degree in a particular discipline within a time frame:

> In this particular university you need the doctoral degree for everything; otherwise you do not value much for this system. It is a questionable thing, but those are the rules, you cannot have an academic position without holding a doctorate. You cannot teach without a postgraduate degree, those are the rules of the game, but they are the same for everyone.

Dr Academic-miner went to Canada to study in one of the leading universities in mining engineering. On his return, he says, he had to learn to work in the competitive funding system: ‘The first two years I presented two projects and I failed, failed. The following year I swap them over and I won them both...you come back to have only your salary and you have to raise research projects. You need to be resilient because at the beginning nothing happens’. Dr Academic-miner reached a ‘regular rhythm with projects’ after a couple of years.

Dr Micro-ecology did his doctoral degree straight after his undergraduate studies in the same regional university. In 2005 he applied for an academic position ‘one of the requirements was to hold a doctoral degree’ and was offered a post in a different region – not the university where he had studied. He joined a research team specialised in an area of research of regional economic interest, aquaculture. He started working for the current research projects and undertook teaching activities. In 2009 he won a project which allowed him to equip a laboratory and develop his particular research niche within the team.

For these last two cases, the doctoral degree has become a sort of ‘price of entry’ to higher education employment. There was no questioning of this requirement, rather it was accepted and referred to as a matter of fact. Access to economic capital was partly obtained by an academic contract, ‘a base’, and partly by research contracts from competitive funding agencies.

In the 2000s attracting external funding had become even more important and more competitive. Proposals had to include partnerships with industry; therefore social capital coming from relations with industry became valuable in the field. In the past industry relations may have brought personal benefits in the form of consultancy jobs – which may or may not be done under the institutional umbrella – with placements for students’ practices or final projects, but none of these activities counted in faculty evaluation nor was it used for university diffusion. Whereas in the 2000s attracting funding did count, funding for applied research (for example, FONDEF, FDI) was considerably higher than FONDECYT and could be used to fund equipment and installations.

4.4.6 The 2000s, competition in a fragmented scientific field

In the 2000s higher education in Chile was highly fragmented. Doctoral graduates counted for 20% of total university faculty in 2007, but there were contrasting situations by universities and departments. In some cases all faculty members hold a postgraduate certificate (master or doctorate) and in some others none did. Doctoral graduates interested in doing research competed for funding in order to access resources, which allowed them to publish, increase their salaries, had positive performance evaluations, obtain placements for students, etc. Competitive funding was the norm. However, research funding is only a minor part of universities budgets, students fees are their main source of income. Doctoral graduates interviewed for the individual case studies gave great attention to research funding, but they were all involved in regular teaching activities.

University departments successful at attracting research funding built up capital to do research. They accumulated cultural objectified capital in the form of equipment, laboratories, books, etc. (which is institutional property, but is often linked to individuals' projects). Possession of comparatively more capital, put those university departments in a better position and made it more likely they would be successful in attracting future funding. Over time, they built reputation (symbolic capital in the scientific field), which, in turn, contributed to successful performance: 'Scientific capital flows to symbolic capital. The scientific field gives credit to those who already have it' (Bourdieu, 2004:56). This effect – which has been termed the 'Matthew effect' - has been observed for a long time in relation to allocation of research grants (e.g., Dasgupta and David, 1994).

People interested in an academic career – particularly doctoral graduates - is likely to be attracted by strong departments, since they provide a better base to apply for funding, better facilities to conduct research (access to objectified cultural capital), colleagues and students in the research practice. This situation can be exemplified by the case of Dra Apple who decided to go back to Chile in 2009 after ten years of studying and working in the US. She approached a research centre in her scientific field to negotiate a possible contract: 'The centre is a very good base to work. I came for little money but knowing I had a structure to back me up'.

The translation of cultural capital (embodied knowledge and the doctoral credential) into economic capital has gradually changed. Public universities had not expanded their permanent positions and had extended the use of weaker forms of contracts. Private universities have a small number of full time contracts and high proportions of part timers and temporary contracts. Research projects funded by public agencies include funding for researchers but under fixed time, external contracts. The relation between a university contract and a private sector one in terms of salary varies by profession. In the case of engineering the private sector salaries are higher.

The cases discussed in the previous section exemplified the increasing perception of difficulties in getting a job contract – even though, doctoral graduates have the lowest rate of unemployment of the national work force when considering years of schooling. The cases also give an insight into the idea of a university salary as ‘a base’ that needs to be complemented with the incentives for researchers coming from research projects or other activities – at least for some academics.

In higher education and in the scientific fields, the valorisation of embodied cultural capital is related to recognition by peers. Peers confer the doctoral credential, are referees of journal articles and evaluators of research projects. The greater importance of the last two in the 2000s implied a change in how embodied cultural capital was recognised, particularly for those starting a career and building a position in the field.

In the 2000s involvement in a doctoral programme can be seen as expanding possibilities and capacity for research. Research students are part of the team that applies for funding and develops research projects. Objectified cultural capital emerges mainly from participation in research teams and doctoral programmes. Achieving critical mass for research implies bigger projects and more funding for equipment which remains with the team (e.g. developing a laboratory –which growths in space and equipment - is a main asset to apply for funding and it is enriched by each new project). Working in a doctoral programme also constitutes an opportunity to accumulate capital in the form of reputation.

4.5 Conclusion: Doctoral Graduates at the Intersections among Fields

Practice of doctoral graduates in SLS - particularly as ‘scientific supplier’ (see Ch. 5, 6 and 7) – are studied in this thesis considering the scientific field. First, because doctoral graduates embody a scientific habitus forged in the scientific field. And second, because a majority of them – in the case of Chile - combine their participation in SLS with participation in scientific fields (in Chile and in international scientific networks). They are enculturated into the scientific craft: 'A scientist is a scientific field made flesh, an agent whose cognitive structures are homologous to the structure of the field and, as a consequence, constantly adjusted to the expectations inscribed in the field.'(Bourdieu, 2004:41).

The predominant form of capital in the scientific field is 'scientific capital', which 'is the product of recognition by competitors' (Bourdieu, 2004: 55). Scientific capital is closely linked to but is not the same as cultural capital. Doctoral graduates hold cultural capital in: the embodied scientific practices they master and their knowledge of the field, the objects they use in their practice (personal ones or objects they have access to, e.g., books, instruments, equipment, laboratories, etc,), and the doctoral degree as an institutionalised credential. Scientific capital is based on knowledge, but also on recognition and, therefore, is a form of symbolic capital (Bourdieu, 2004).

Universities – the main agent in the Chilean scientific field - are a space of economic action for doctoral graduates. They have employment contracts with universities and, in most cases, full time contracts. A university salary may be the main or only income for full time faculty. The encounter between doctoral graduates and SLS has to consider the effect of the scientific field in the interactions. To consider it, it is necessary to understand the structure of the field, the position of the agents, the logic of practice and the struggles involved. The evolution of the scientific field has been shaped to a great extent by higher education policy.

The reforms of the 1980s were an abrupt discontinuity in the history of higher education in Chile. The new system gave place to new (adapted) forms of evaluation, contracts and promotions – amongst other changes. Universities were ranked annually by number of publications and research projects from FONDECYT and they translated those indicators to faculty evaluations. Individuals learnt to work under the new rules and soon got involved in producing and reproducing them.

The new system implied shifts in the valorisation of capitals. Scientific capital – signalled by the doctoral credential – had greater importance. Doctoral graduates were good candidates for taking positions in the direction of the system and for influencing policy. In practice, evaluation and advisory committees for FONDECYT and CONICYT had been outnumbered by doctoral graduates.

The new rules of 'self funding' and competition imposed in the 1980s gradually became the 'rules of the game'. In the 2000s those rules became taken for granted. Doctoral graduates connected to SLS (all national priorities) were in favourable positions to apply for funding - to access and accumulate cultural and economic capital. Their work careers can be interpreted as the practice of comfortable, well-adapted individuals. Doctoral graduates with full time university contracts are actively involved in producing and reproducing the field by engaging, for example, in project evaluations and peer review activities.

To study doctoral graduates' participation in SLS, in this thesis I consider that they take part more or less simultaneously in several fields, including at least the field of their discipline, the organisation they work for, the scientific field, and the SLS.

A discipline is a field formed by agents who share 'collective capital of specialized methods and concepts, mastery of which is the tacit or implicit price of entry to the fields. It produces a 'historical transcendental', the disciplinary habitus, a system of schemes of perception and appreciation ...' (Bourdieu, 2004: 65). Doctoral graduates in SLS are related to different disciplines, most of them in the areas of science and technology.

The organisation(s) doctoral graduates work for - a university, a private firm, a research institute or any other- constitutes a field in itself, with an internal structure of governance (Bourdieu, 2005:205, referring to the firm as a field, see Ch. 2, Section 2.4). The organisational field imposes a structure with effects on individual practice. Doctoral graduates working in universities, for example, will be involved in the internal dynamic of struggles and confrontation of powers between the different agents within the university field.

The scientific field, in Chile formed mainly by universities and to a lesser extent by research institutes, is a field shared by most doctoral graduates involved in SLS. The scientific field has specific characteristics, for example, a great quantity of accumulated history, expressed in economic form and in principles of organisation and practice routines (Bourdieu, 2004). The price of entry is scientific capital, embodied and developed into a ‘sense of the game’ and also a propensity to take part in scientific production (Bourdieu, 2004). The scientific field is also a field of struggle, a socially constructed arena where agents in different positions and armed with different resources, confront one another to maintain or transform their power positions (Bourdieu, 2004).

This chapter aimed at bringing to light the structure of the scientific field, by describing the structure of the institutions and the position of doctoral graduates. The scientific field is common relevant background to doctoral graduates for the studies of SLS in the following chapters (Ch. 5, 6 and 7).

Chapter 5. Copper Mining

This chapter is the first of the three chapters dedicated to the three industrial sectors in this study. It relates the history of the copper mining industry in Chile to the experience of doctoral graduates in the field. The chapter provides a historical overview of copper mining, structured around the systems of technology and governance in place in three historical epochs. The historical analysis is followed by a discussion that locates doctoral graduates within the field. I infer possible positions for them and illustrate my analysis with case studies. Finally, I analyse doctoral graduates' practice in the field and its implications for capability accumulation at the individual level.

5.1. History of Copper Mining in Chile

Chile is the world's main producer of copper, accounting for a third of global production. Copper is central to Chile's economy: it represented nearly 20% of GDP and more than 50% of total exports in 2010 (COCHILCO, 2012). Chile produces and exports a diversity of minerals, but copper is by far the biggest mining industry and in 2010 accounted for 90% of Chile's mineral production (COCHILCO, 2012).

Copper production in Chile and worldwide has experienced impressive expansion since the 1970s and industry forecasts indicate that this growth will continue in the coming decades (Urzúa, 2011). Copper mining activity in Chile is concentrated in the north of the country, and is the main economic activity in most northern regions.

Although the majority of the population may not be familiar with the statistics, the Chilean people refer to copper as the country's 'bread', 'Chile's salary' and 'Chileans' patrimony'. All primary school children read '*Subterra: cuadros mineros'* (*Underground: mining portraits*, Lillo, 1904), and learn that Chile is a mining country and that copper belongs to all the Chilean peoples. Mining stories - old and new- are part of Chilean culture, including the story of the rescue of the 33 Chilean miners in 2010, which has become an international mining story.

Despite copper's economic and cultural significance, mine workers (almost all males) accounted for only 1% of the work force in the 2002 National Census (INE, 2003) – down from 2% in 1992 (INE, 1993). The average years of schooling of people working in the mining industry in 2002 was 11.6, roughly one year more than the national average in the active work force, and one year more than in 1992 when it equalled the national average. Most workers in the sector do not have tertiary education; their schooling consists of part or all of the 12 years of compulsory primary and secondary education. The changes between 1992 and 2002 can be explained in part by the retirement of less educated workers (Ibarra, 2006).

Copper has become the productive sector with the highest average education in the Chilean economy and is also the sector with highest level of unionisation and the highest salaries in the country. Official statistics only count workers employed in copper producer firms, ignoring workers in organisations indirectly involved with the production of minerals. Katz et al. (2000: 30) estimate that in 1996, more than 8,000 professionals were employed in engineering firms serving the copper industry in Chile, a number that is comparable to all workers employed in mining producer firms with two or more years of higher education.

This historical analysis distinguishes three epochs related to the dominant systems of governance and technology. Their characteristics are summarized in Table 5.1 and described in the succeeding paragraphs.

Table 5.1: Characteristics of Copper Mining in Chile by Epoch

Epoch	Early Period	Great Copper Mining (GMC) Development	Expansion and Catching up
Approximate dates	1820s-1880s	1920-1973	1975-1999
Location of leaders	UK	US, Canada	Chile, Australia, US, Canada, South Africa
Role of Chile Internationally	Important producer - unstable	Important producer - stable	Main Producer
Chilean Strategy 'Copper for the country'	Source of government funding individual basis- govt as host	Source of government funding – ownership basis - tax system + 'milking cash cow' attitude	Source of government funding – more complex tax/finance system –role of market failure etc.
Demand	Local demand from UK	World champions	Global
Technology leaders	SME, some imports	Big business	International
Technologies	Rudimentary	Standard and kept by investors	Complex, ICT, biotech, environmental solutions
Automation	of Transformation	of Extraction	of Control (at a distance)
Process Type	Labour	Capital	Capital/Information/knowledge
Size of firm	Small/medium	Big/Great Copper Mining (GCM)	GCM and network
Advantages	High ore grade	Internal integration	External integration
Organisation	Entrepreneurial	Multidivisional	Networked
Industry structure	Competitive	Oligopolistic	Mixed, later oligopolistic+
Type of Capitalism	Personal	Managerial	Collaborative
Property	Mostly Chileans	From Mostly foreign to 100% Public	Hybrid, oligopolistic
Mode of Governance	Markets	Hierarchies (corporate and later state)	Hybrid. Market rules Regulation development. Big companies
Power	Landowning	Capital	Knowledge/Capital
Skills	Physical	Professional	Specialised/Expert
Education	Development of primary education system Foundation of universities	Massification of primary and secondary education. Professionalisation	Massification of higher education. Foundation of the postgraduate system
Governance Actors	SME. Some Foreign investment	SONAMI Mining engineers Government agencies Unions	CODELCO Large international and national players SME less important SERNAGEOMIN
Associated Infrastructure	Ports, roads, railways, coal supply	Ports, roads , railway	Biotechnology, energy supply, telecommunications

Source: Author's elaboration based on vonTunzelmann (2003) and multiple sources.

5.1.1 Early period: Labour processes, growth and decay (1820- 1890)

Mining has been important in the Chilean economy since its beginnings. Salazar and Pinto (2002) argue that from the incorporation of the Chilean territory to the imperial Spanish system, economic growth was driven by exports and mining – initially gold mining. After independence in 1810, gold mining declined, and Chile became an important producer of silver and copper.

Copper mining represented more than 80% of Chile's exports between 1859-1875 when Chile had around 44% of the world market (Salazar and Pinto, 2002:116). During the 19th century, the Chilean industry presented slow technological change compared to international competitors. Processes were labour intensive, although relatively few people worked in copper mining (Collier and Sater, 2004). A major addition to the industry was the introduction of reverberatory furnaces, a processing– rather than an extraction technology – known as the 'English system' and developed for application in foundries and exploited for many years in Swansea, South Wales (Collier and Sater, 2004; Salazar and Pinto, 2002).

The Chilean industry consisted mainly of small and medium sized enterprises (SME) controlled by Chilean entrepreneurs and a few British owned copper concerns (Collier and Sater, 2004). Exports increased during the 1840s and 1850s, fostering the development of a national coal industry and the first telephone and railway systems (Collier and Sater, 2004; Salazar and Pinto, 2002).

By the 1880s, however, Chilean copper production had declined, at the time when demand for copper was growing as a result of industrialisation and the new copper-wire based electrical, telegraph and telephone systems development. Chile missed out on the opportunity represented by this new and growing international demand. History explains this as being due to the country's lack of participation in technological change at a time when international producers' production methods were changing dramatically. The copper mining industry in Chile collapsed and was unable to compete with European and US firms with superior capital and technology (Salazar and Pinto, 2002; Collier and Sater, 2004). By the end of the 19th century Chile's share of the world copper market had fallen from a third to just 10%. In 1911, Chile's share was only 4%of the world market (Collier and Sater, 2004:160).

The decline in copper production coincided with the severe economic crisis in 1873-78, which was aggravated by natural disasters (Collier and Sater, 2004). The world economic recession hit the open, export based Chilean economy which relied on a few main products (Salazar and Pinto, 2002).

In addition to the economic crisis, Chile was involved in a series of international conflicts that reached a peak in 1879 when Chile declared war on Peru and Bolivia (Collier and Sater, 2004). By the mid 1870s, Chile's mining businesses included exploitation of Peruvian and Bolivian deposits of sodium nitrate, for export to Europe to be used as fertilizer (Collier and Sater, 2004). This 'War of the Pacific' concluded with Chile's taking over Peruvian and Bolivian territories rich in nitrate deposits. There has been endless and passionate discussion among historians about whether the war was motivated by a desire to appropriate these nitrate deposits in order to escape the economic recession (Salazar and Pinto, 2002). Shortly after, in 1891, Chile experienced civil war.

Discussing the development of the industry, Urzúa (2011) argues that Chile lost the opportunity to launch of a new era in the history of copper by remaining locked into old mining techniques based on high grade ore deposits. He describes how the country lacked the technological, organisational and financial capabilities to develop and run a modern mining operation. Urzúa (2003) compares the Chilean situation with mining expansion in the US and Canada in the 19th and early 20th century. He discusses how the US and Canada changed their scale of production and management practices based on a series of technological advances, collective learning processes and major investment. I would add that Chile lacked the will to take on a long term commitment to copper. Governance of the sector was dominated by individual entrepreneurs, with a culture of short term results and rent seeking. There were more attractive endeavours to invest in, namely nitrate mining. Between the 1880s and 1920s the country lived on the nitrate boom; nitrate was a profitable business and the main source of state revenues (Meller, 1996).

The second part of the 19th century witnessed both the rise and decline of copper production, the development of initial infrastructure and the formation of the Chilean education system. Mining regions in this early period had higher rates of student enrolment than the agricultural regions in the central valley (Egana, 2000). The first national public university, Universidad de Chile, created in 1842 (see Ch.4), offered mining engineering amongst its first study programmes. Also, during the early 1880s, the state established two mining schools in the northern regions.

Private institutions collaborated to form the Confederation of Mining Enterprises (SONAMI, Sociedad Nacional de Minería), created in 1883, to take part in the system's governance. The norm that gave official status to SONAMI was signed by the President of Chile, and is still in place: it states that the confederation represents the private mining companies in the country. Its main objective is advance regulation, institutions related to mining issues and the training and professionalization of workers in the sector.

5.1.2 GCM: Capital processes, denationalisation and nationalisation (1920-1973)

The two forces shaping the 20th century copper mining industry in Chile were foreign investment and state intervention. A new form of mining emerged in this period: 'Great Copper Mining' (GCM), characterised by huge mines and capital intensive exploitation.

At the end of the 19th century international competitors replaced the exploitation of rich, small deposits using labour intensive techniques with exploitation of large deposits of lower grade ores (Collier and Sater, 2004). This represented a new technological system for mining based on large scale, capital intensive processes. The technologies associated with the new production system were open pit extraction and flotation for recovery of low grade ore material (Urzúa, 2011).

The Chilean copper industry required capital investment for its revival, but local capital was being directed to the shorter term profit nitrate industry (Collier and Sater, 2004). Nitrate production reached a peak between 1900 and 1920 (Meller, 1996: 42) to decline and collapse during the Great Depression in the mid 1930s. The decline of the Chilean nitrate industry is generally recalled as the end to a period of wealth when benefits were appropriated by the nitrate mine owners, mainly foreign, and the workers were left in misery.

As Collier and Sater (2004: 161) point out: 'The literature on the subject [nitrates] is often reproachful, the reproach itself usually directed at the foreign interests who controlled so large a part of the business'. Salazar and Pinto (2002) give a fuller picture describing the complexity of factors that intervened to put an end to the nitrate era: technological obsolescence, lack of investment in technological change until too late, appearance of synthetic substitutes, and political decline; in other words technology, markets and governance. The end of the nitrate era left a painful legacy of unemployment, famine and misery.

There may have been lack of interest in copper among local investors, but not among foreign investors. The copper industry decline began to reverse at the beginning of the 20th century with massive US capital investment (Salazar and Pinto, 2002; Meller, 1996). The explanation given for the process of foreign investment, known as 'copper denationalisation', is the capital intensive character of copper exploitation at this time and long periods for investment recovery (Meller, 1996).

After the nitrate experience, there was concern about how the mining revenues would be shared in the country, and the prominence of foreign investment was controversial. There are accounts of debates as early as 1916, where the President of SONAMI called for state intervention, which contrasts with the dominant liberal economic environment (Salazar and Pinto, 2002). The professional association of mining engineers – established in 1930 and still in place - gained influence in the 1940s and 1950s. They sounded alarms about what they saw as a mortgage of the national patrimony.

By the 1950s government had raised taxes on the copper industry and increased its regulation (Meller, 1996). Until 1955, little was documented about the industry's strategic development; the international investors formed an enclave and had few relations with local actors (Salazar and Pinto, 2002). There was tension between the state and the international investors, which was resolved by the processes of nationalisation in 1966 and Chileanisation in 1971. Nationalisation was the acquisition by the Chilean State of 51% of the GCM companies. Chileanisation was the next step a law was voted in unanimously by parliament, which gave to the state 100% ownership of the GCM, organised as the public company CODELCO (Law 17450, 1971).

Soon after, in September 1973, there was a military coup and huge transformations to the economy. Salazar and Pinto (2002) consider that the copper mining sector made comparatively slower progress towards privatisation under the new economic system due to the high symbolic value of nationalisation. To that should be added the political role of a law allocating a percentage of CODELCO revenues to the armed forces, which aligned its military interests to public ownership of CODELCO.

5.1.3 Expansion and catching up (1974 -l 1999)

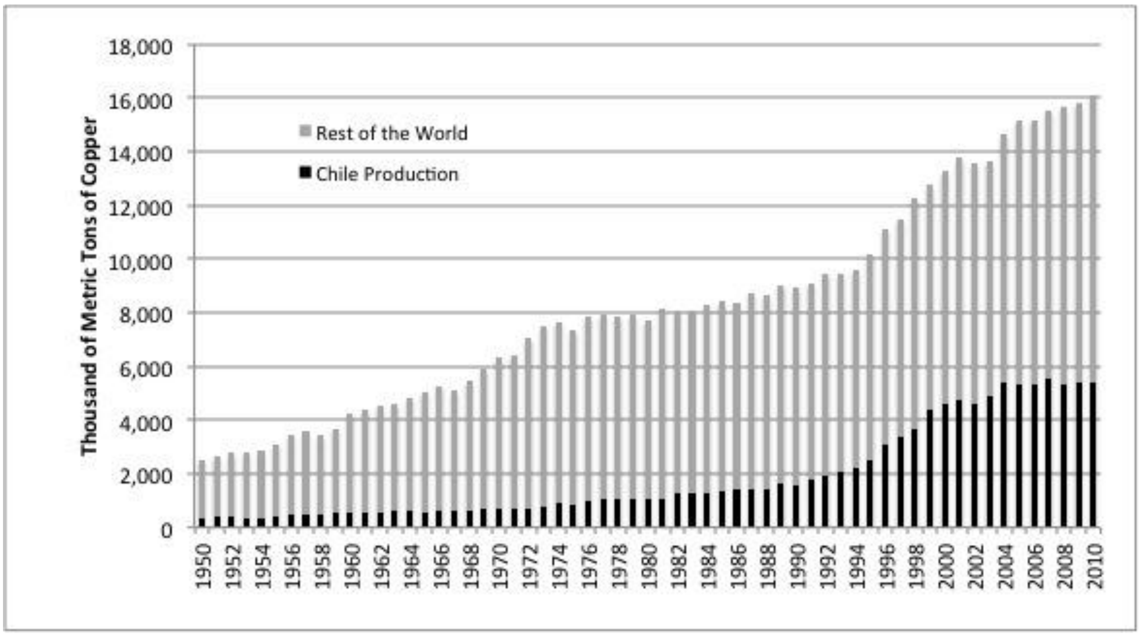
The world copper industry and Chile's industry grew steadily over the period 1974-2010 with the highest growth rates in the 20 years from 1990 (see Figure 5.1). Characterisation of this epoch in this thesis ends in 1999 based on the available information, although I provide some figures up to 2010 in order to give an idea of later trends.

Governance, industry structure and incentives for foreign investment

The period of industry expansion and catching up (1975-1999) gave place to hybrid governance (public and private participation), based on market rules and regulation. The big copper producer firms became the main governance actors.

After two decades of stagnation (1950s and 1960s), Chilean production started to grow in the 1970s when CODELCO concentrated a majority of production (see Figure 5.2), and expanded in the 1990s with exploitation of new mines by large national and international private firms.

Figure 5.1: World and Chilean Production of Copper (1950-2010)

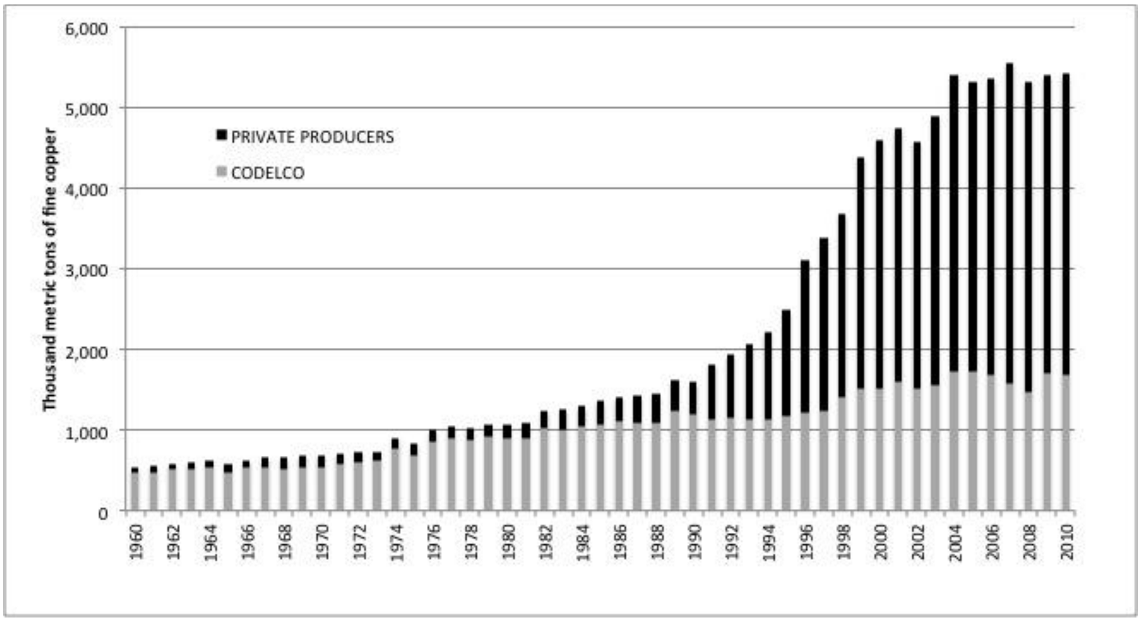


Source: Author’s elaboration of COCHILCO (2012) data

In the 1980s and 1990s, the state ‘rolled back’ from copper production when investment projects initiated by concessionary firms matured and entered production. Changes to the law in 1983 allowed the participation of private companies in the GCM as mining project concessionaries. These policies were introduced with the aim of expanding the sector. Some were critical of the new regulation. Guzmán and Lavados (1980), for example, alerted to the inconvenience of giving away resources to foreign firms that could be exploited by CODELCO - alone or in local partnerships. They argued that technically and financially, CODELCO – if allowed access to the international banking system – was capable of taking over the new mining projects that were being opened to foreign capital. Opening up to private participation attracted multinational firms keen to exploit a tax and regulatory system, which, compared to other copper rich countries, was favourable.

Figure 5.2 shows how CODELCO’s production share reduced from almost 100% after nationalisation to around 30% from 1999. The participation of private companies started to gain a foothold in CODELCO at the beginning of the 1990s, following the take up of concessions and projects approved in the 1980s and after the new democratic government settled.

Figure 5.2: Chilean Copper Production by Public and Private Firms (1950-2010)



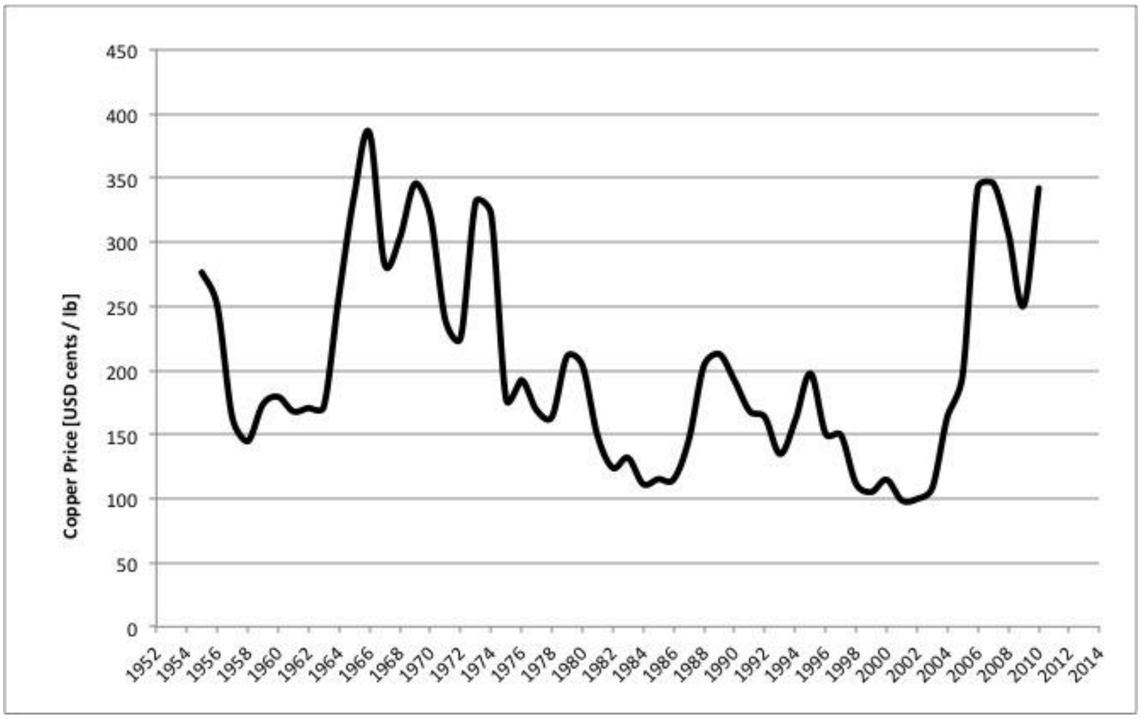
Source: Author’s elaboration of COCHILCO (2012) data

Copper production grew and is forecast to continue to do so. Since the 1990s the industry structure has seen several mergers and acquisitions amongst big producers, and amongst suppliers. The players have become stronger and interaction more complex, with the involvement of national and international actors. A majority of Chile’s copper comes from the GCM, but there are also small and medium producers. They accounted for 7% of total production in Chile in 2010 (COCHILCO, 2012).

Copper prices

The mining sector was determinant in Chile’s faster economic growth during the 1990s, accounting for 8% of GDP and 46% of total exports. Chilean mining grew at a rate of 11% during the decade (Katz et al, 2000). By the end of the 1990s, when Chilean production had grown in volume to reach a world market share of 30% (see Figure 5.1), the price dropped (see Figure 5.3).

Figure 5.3: Price of Copper (1950 - 2010)



Source: Author's elaboration of COCHILCO (2012) data

Historically, Chile was a copper price taker. However, in the early 2000s a few political actors began to question Chile's potential – as a major player – to influence copper prices. They interpreted the lower prices in the late 1990s as a consequence of oversupply and claimed that they were acting as subsidies for the copper consuming countries (Lavandero, 2010).

This suggestion proved politically controversial and inflamed debate over copper revenues. It was the motivation for the setting up of a Parliamentary Commission to study mining taxes (Lavandero, 2004)[12]. It revealed the low contribution to tax from the private Chilean firms compared to CODELCO, and compared to taxation in other copper mining countries. The whole process of investigation by the Parliamentary Commission – which was highly problematic – resulted in a law on mining royalties (Law 20026, 2005), which was slightly modified by Law 20469 (2010). In relation to

[12] The Commission was chaired by MP Jorge Lavandero. The reference is to an edited book that contains the interventions of the members of the Commission in full, and the expert studies that were part of the evidence presented.

copper prices, the Parliamentary Commission found evidence to support the hypothesis of oversupply (Lavandero, 2004). MP Jorge Lavandero (2010) affirmed that CODELCO and BHP Billington gave credit to the oversupply argument and stocked part of their 2002 production (see Figure 5.1) with the result that prices increased (see Figure 5.3). This increase was sustained by strategic management of production planning.

Technological change and perspectives on the catching up process

The global copper industry underwent a process of technological change beginning in the 1970s. Urzúa (2011), drawing on Pérez (2001), calls it the 'rejuvenation' of copper. The industry was considered mature in the 1970s with low rates of innovation; 40 years later it can be considered a sector of intensive research, development and innovation. Chile made successful progress to catch up with the new technological wave, according to growth indicators and position in the global industry.

Katz et al. (2000) consider the period between the mid 1970s and the 1990s from what they term a co-evolutionary perspective. They explore the economic, technological and institutional factors, as well as the innovative behaviour and the interconnections among these elements, to explain the history of the sector during that period. They looked at different kinds of producer firms, suppliers of equipment and engineering services.

Katz et al. (2000) explain the rapid growth in the 1990s as being the result of a process related to technological and institutional factors. They argue that the series of institutional changes relevant to the copper mining sector during the 1970s and 1980s transformed the working conditions for firms, which, in turn, explains the expansion of the sector in the 1990s. The factors they acknowledge as having had an impact on the increasing profitability of the industry include macroeconomic stability, economic changes to regulation on copper, mining concessions, and the tax system. The profitability of the sector attracted investment from international and local companies and increased the rate of expansion in the 1990s.

Another perspective is provided in the study by Urzúa (2011) who analyses the development of producer capabilities. Urzúa (2011) claims that during the late 1980s and early 1990s CODELCO based its innovation strategy on continuous improvement, by improving operations via adaptation of existing technology. CODELCO could afford to adopt this method because its ore deposits were richer than those of international competitors. In Urzúa’s (2011) view, Chilean producer firms and suppliers embarked rather late on technological change based on information technologies that were rejuvenating the global industry.

According to Urzúa (2011), it was only in 1996 that CODELCO launched an innovation strategy and started working purposefully on developing technological advantages. Since then CODELCO has established several international partnerships to undertake technological challenges. Between 1995 and 2005 CODELCO was granted more patents than all Chilean universities and research centres combined. Urzúa warns, however, that although CODELCO’s efforts may be outstanding in the Chilean context, they are modest compared to international competitors. Urzúa (2011) attributes the 1990s expansion to the arrival of multinational corporation investments from leading mining countries, for example, Canada, Australia, South Africa and the United States.

Urzúa’s (2011) analysis of producer capabilities focuses on the knowledge intensive supplier sector, which he considers emerged between the mid 1970s and early 1980s. During this decade the copper industry growth slowed down and producer firms embarked on vertical disintegration, spinning off functions, and diffusing to the emerging supplier sector capabilities that previously had been located almost exclusively within the mining firms. The new supplier firms continued to accumulate capabilities through participation in investment projects and the operations of parent companies and other industry players. Urzúa (2011) likens the situation of Chilean knowledge intensive mining suppliers to that of the Chilean GCM producers. Low accumulation of capabilities before the spinoffs compared to international competitors, resulting in an originally weaker base and start up, which explains why Chilean suppliers were developed as followers. The leadership grew around industries in other countries, such as Australia.

Katz et al. (2000) and Urzúa (2011) provide complementary perspectives to explain the expansion of Chilean copper mining in the 1990s and the preceding years of technological and governance changes. I would argue that Katz et al. (2000) are more optimistic about the position of the sector in relation to future development; they consider that in the 1990s Chile was closing the relative technological gap with the international competition. They suggest that changes in context had different effects on different types of companies (they provide a company classification). Each type of company developed quite contrasting strategies, for example, international companies invested mainly in exploiting new deposits and, therefore, had no need to invest heavily in technological development – the widely available technology was sufficient. From that perspective, Katz et al. (2000) argue that most of what could be done in the country in terms of developing indigenous technological capabilities, will be linked to CODELCO and to the actions of the public sector – through universities and technological institutes, because the private sector does not have the incentives to do it.

5.2 Coevolution of Technology and Governance in Copper Mining

Copper mining's history was described above as consisting of two technological revolutions or 'technological paradigms' (Dosi, 1982), that is, periods when the relevant technological problems and the spectrum of technological solutions changed. The first refers to the change in the late 19th century from rudimentary extraction of high ore mineral to exploitation of large lower ore deposits using open pit and flotation technologies. The second was rejuvenation of the industry in the 1970s with the diffusion of technologies for automation and control at a distance, Information and Communication Technologies (ICTs) and biotechnology (Urzúa, 2011).

The copper mining industry supplied the industries that developed during each of the industrial revolutions. Its dominant technological paradigm mirror the historical revolutions of technology identified in von Tunzelmann (2003). In this section I analyse the origins and unfolding of the three epochs through a discussion of the coevolution of the systems of technology and governance (von Tunzelmann, 2003; and see Ch. 3).

5.2.1 Technology and governance in the first epoch (1820-1880)

The copper industry developed in the UK following the first industrial revolution and, therefore, around demand generated by industrialisation. As a supplier to the industrial revolution, the copper industry followed not only the demand trends, but also the dominant ideas on production.

Technological change occurred within the paradigm of the technology used for transformation - which dominated the first industrial revolution – and the key resource continued to be labour. Copper technology changed following thousands of years of labour intensive processes. The main innovations in the late 18th and the 19th centuries were in copper processing (outside the mine).

The dominant mode of governance was markets. The industry leaders in the UK were Welsh entrepreneurs; during the second half of the 18^{th} century they made use of the port infrastructure, and improved smelting and refining technology. By the end of the 18^{th} century the industry structure was highly concentrated around businessmen in Swansea, the world centre for copper smelting during the first industrial revolution.

The Chilean industry followed a similar pattern in the first epoch (1820-1880). Initially, the industry structure was competitive and populated by entrepreneurs and individual capitalists. Extraction technologies were labour intensive and rudimentary. The main innovation adopted was the smelting technologies developed in Swansea. The industry made use of the developing ports and railways infrastructure. The industry declined at the end of the 19^{th} century due to capitals being diverted to the more profitable nitrate business.

5.2.2 Technology and governance for the development of the GCM (1920-1973)

The second industrial revolution generated important demand for copper, particularly for electrification and telephone lines in the US and the industrialised world. The copper industry supplied the second industrial revolution and its development mirrored the characteristics of the dominant industries in that epoch.

The US – which together with Germany was one of the main centres of the second industrial revolution - was a copper rich country with small mines exploiting high ore content deposits. The electrical copper wire mill industry started in the US in 1877 and by the turn of the century the first open pit mines had started production. Open pit technology and the later development of flotation techniques allowed exploitation of large low ore copper deposits. They represented a technological revolution in the production of copper and were capital intensive processes. The industry was able to reduce production times to meet increasing demand and, also, to overcome the constraints on high ore grade mineral by exploiting more abundant lower grade ore. The US quickly became the world largest producer of copper. Electricity (one of the dominant technologies at the time) was used to improve the mining process, electric locomotives replaced steam trains carrying ore to the mills, and electrolytic refining was developed in the 1950s.

The Chilean copper industry developed with capital and technology from the big copper producers in the US. They invested in Chile as an extension of their US activities. They introduced open pit and other mining technologies. The price of copper was fixed in the US through negotiation among the producer hierarchies and the US government. Underground mining continued, although the big firms transformed their processes using the new technologies.

The big copper firms were internally integrated and multidivisional. Managers and engineers came from the US to direct the Chilean branches. The structure of the local market was oligopolistic – dominated by big US firms. The nationalisation process implied a change to the structure – towards the almost monopolistic position of the public producer, CODELCO – but the logic of production and the characteristics of the epoch were maintained.

5.2.3 Technology and governance for expansion and catching up (1975-1999)

Demand for copper grew with industrialisation in China and India. China has become the most important export market for Chilean copper. The international industry has experienced a process of 'rejuvenation', which constitutes a technological revolution. The new technological paradigm is mirroring the third industrial revolution. The intensive period of process innovation – renovation of most processes and the application of new control technologies – was followed by the development of a networked structure of suppliers, and internationalisation of the big producer companies in the 1990s.

New players emerged in Australia and South Africa, and the Chilean industry became more prominent, but at the end of the period the structure was less diverse with international firms establishing branches in all those countries. New technologies allowed increased speed to market and annual production volumes bigger than in previous epochs. Overcoming the constraints of existing mineral deposits implied sophisticated development of exploration technologies (e.g. use of satellite technologies), resulting in discovery of new deposits.

In the case of Chile this epoch was one of intensive technology innovation and catching up. An emergent network of technology suppliers developed in the 1990s. In the first decade of the 2000s the industry developed into an oligopoly dominated by the GCM firms. There has been also a concentration of suppliers and increased dominance of big international supplier firms.

The dominance of technologically rejuvenated GCM firms does not imply there are no other technological approaches. Lone 'pirquineros' can still be found excavating mountains alongside small and medium sized rudimentary extractive firms and capital intensive medium sized firms that have not updated their production processes with the new technological possibilities provided by ICTs and biotechnologies.

5.3. Doctoral Graduates in the History of the Copper Mining Field

In this section I locate doctoral graduates within the history of the copper mining field in Chile. I identify when they joined the field and analyse the historical changes from their perspectives. I analyse the situation of doctoral graduates over time, referring to the historical review in Sections 5.1.and 5.2 and illustrating my inferences with case studies of individual experience in the sector. The cases are examples of the finite possibilities of doctoral graduates' roles within the historical circumstances, analysed using Bourdieu's concepts of field and capital (see Ch. 3).

5.3.1 Absence of doctoral graduates in the field during the first two epochs

The first epoch of copper mining - 1820 to 1880 – workers developed physical skills to extract the mineral by hand, while mine owners focused on managing their investment portfolios to obtain maximum rents. Mining engineering existed as a professional university programme from 1842, but there were no doctoral graduates in the industry.

During the second epoch – capital processes, 1920 -1973 – the big foreign companies conducted R&D in their home country, foreign engineers were responsible for technological design and other complex tasks; local workers operated the plants and maintained the machinery. Workers learned to follow procedures and standards, and to respect hierarchy and discipline. The work in foreign-owned companies complied with international quality and safety standards. Up to the 1960s the presence of doctoral graduates was small and confined to work in the universities.

5.3.2 Emergence of doctoral graduates in the field: 1970 -1973

The third epoch started with a nationalised industry, which concentrated production in CODELCO. Nationalisation of copper – and other mining resources – was widely approved of by society (see Section 5.1.3). Amongst other reasons, it represented recovery of a source of wealth, some sort of justice in light of the enormous profits made by large foreign companies, freedom from foreign power and availability of economic resources to satisfy the multiple needs of the Chilean people.

The earliest experiences covered in the case studies are of two doctoral graduates who were undergraduate and graduate students in the 1960s and 1970s. The cases of Dr Cape and Dr Bio are illustrative of two contrasting emergent doctoral careers in the field of copper mining. The process of copper nationalisation implied the valorisation of embodied knowledge (cultural capital) to be applied to the industry technological development – one of the visions of the nationalisation process was doing research and developing innovative technologies locally.

Dr Cape lived through the process of copper nationalisation as a young engineering undergraduate student. He recalled the abundance of new career opportunities that opened up for him and his classmates:

> When I started university the industry - the mining industry- was in foreign hands. Foreign companies exclusively. Later on came the processes of Chileanisation and nationalisation. Those processes implied that Chilean engineers had to be in charge of all the mining industry. I went to study chemical engineering at the University of Concepcion [regional university with national leadership] which later introduced the programme of metallurgic engineering, orientated to mining, particularly copper mining. This was very attractive, precisely because it was an enormous occupational field for graduates. Foreign engineers had to be replaced by Chilean engineers. In fact, graduates from my university were for a while the majority in Chuquicamata [a CODELCO mine].

Dr Cape completed both study programmes, chemistry and metallurgic engineering, and later did a doctorate in metallurgy in the US. The field had opened to specialists by giving value to cultural capital (embodied knowledge and credentials). Dr Cape had been related to the copper industry almost all his working life.

Dr Bio was doing research in molecular biology in the 1960s, he was part of the first generation of research oriented careers in Chile (see Ch. 4, Section 4.4). He worked in a research laboratory in the US and travelled regularly to Chile to work collaboratively with Chilean colleagues. His relations with the copper industry started in 1972, when he embarked on research in bioleaching, which he saw as an opportunity for career development and for personal satisfaction:

> I started to feel frustration...In my opinion and after my experience if one wants to be successful in science; one has to look for new problems, ideally local problems. That is how something interesting may arise. Otherwise, competing with the big research structures in the US and Europe is too difficult...
>
> There was also a political reason, it was the time of the Popular Unity government and there was great interest in doing things for social benefit. I got interested in doing applied research. I think it came from there, it was for political reasons that I moved to the productive sector. It was not the neoliberal approach of today, it was to be closer to peoples' needs.
>
> One of the interesting things to do was to use microorganisms to extract copper. I applied for a position in INTEC, which then was a CORFO institute, and I was successful. It was during the Popular Unity government but they did not know I was from the left, they found out later. I worked there but unfortunately only for short time; I started in 1973 and finished in September 1973 [with the military coup]. However, though short experience, I think it shows clearly that I was moving closer to application, but without leaving science. I was not going into empirical applications, but into applications grounded in deep knowledge of the phenomenon.

Dr Bio made it clear that he was hired because of his scientific capital (embodied knowledge recognised by the scientific community) and not his affinity to the socialist government. After the military coup, Dr Bio left INTEC and left Chile, but his relation with the copper industry through research in bioleaching continued, and is a long story that is explored further in the next period. He maintained his resolution to do applied research, the approach he took to the many areas of research he has been involved since he began his work on bioleaching.

Dr Cape and Dr Bio are examples of the different motivations, dispositions and interests among the professionals attracted to the copper industry at the time. During this early period the copper industry was an attractive work place, offering good job opportunities and professional challenges. It also enabled participation in the historical changes occurring in the country. Dr Cape and Dr Bio belong to the first generation of specialised, high skilled professionals in the copper industry. There were no other 'big players' before them. Research in bioleaching was unknown, which made Dr Bio a unique expert. Chilean specialist engineers only began to appear when they took over the positions formerly occupied by foreign engineers and to manage rather than just operating the technology.

5.3.3 Learning times for doctoral graduates in the field but few new entrants: 1974-1981

Production of copper in Chile was concentrated in the public company CODELCO. There were some outstanding technological innovations during this period, for example, the Teniente converter, developed and patented in Chile in 1977. Chilean engineers had taken over from foreigners and were managing the industry successfully.

The case of Dr Cape illustrates how – having established relations with the industry in the early stage of valorisation of scientific capital – he had opportunities to participate in technology and innovation development. Dr Cape was a university academic and worked on projects for the mining industry. In 1981 he received a job offer from CIMM, the public institute for R&D for the mining industry (see Ch. 4, section 4.3). CIMM was 'absolutely the right place for a person with my education' and Dr Cape moved to a full time position there:

> It was a great opportunity for me, appropriate for my education and with good challenges... I could do research and also had other challenges. At the time the trend was for research institutes to be self-funded... In all the years I was there we did many projects for the copper companies.

Dr Cape achieved a place in the industry based on recognition of his cultural capital, which he developed further over this period. CIMM research equipment was outstanding in the country; working there gave him access to objectified capital that he exploited for his research. He developed social capital by getting to know others in the industry involved in R&D. he related to them regularly as clients, partners or colleagues in industry activities.

The period 1974-1981 corresponds to the first years of the dictatorship. University budgets were cut; there were no national scholarships for postgraduate studies (see Ch. 4) and international collaboration was limited given the political circumstances. Doctoral graduates already in the field, such as Dr Cape, continued to strengthen their positions, but there was no major growth in the number of doctoral graduates in the field.

My focus on doctoral graduates implies that the experience of people who were unable to undertake doctoral studies at the time is overlooked. I think it is important to complement my cases with one provided by Urzúa (2011). He interviewed a professional who joined CIMM expecting to study for a doctoral degree abroad and, who around the mid 1970s, was about to start his study commission when:

> The government changed drastically the mining development policy, including CIMM’s focus. Postgraduate studies were considered unnecessary. The focus of the new government can be summarised by the following statement of a high executive at the Chilean government: ‘Engineers should just work at the operations and if a new challenge emerges that requires a ‘new technology or knowledge’ it would be acquired at the international market’. Thus, sponsoring postgraduate studies was cancelled. (Urzúa, 2011: 182; quoting his interview transcript)

Dr Cape had been awarded his doctoral degree – funded by the host country - and also had experience in the field. He had accumulated capital and was in a strong position as an early expert in the field. This was not a time of investment at CIMM or the universities.

5.3.4 A challenging technological learning environment: the 1980s in the industry

In 1981 and 1982 Chile suffered one of the deepest economic recessions in its history (see Ch. 1). These were also the years of university reforms, which were followed by the introduction of policy for self-funding for research institutes (see Ch. 4). Copper prices were low and world copper production did not grow at the beginning of the 1980s (see Figures 5.1 and 5.2). However, during the 1980s CODELCO was involved in several technological innovations, some of which are reflected by CODELCO patents.

CODELCO did not develop all of its technological projects alone; it had contracts and collaborations with CIMM –where Dr Cape was working – and with private companies – such as the firm employing Dr Bio, whose case is discussed below.

Dr Bio was keen to return to Chile in the 1980s after more than 10 years abroad. His work on bioleaching brought him a few research contracts in Chile from the private sector and one for a university. After re-establishing himself as a researcher in bioleaching, he was hired by a small mining company as the micro-biologist in a team of 14 bioleaching researchers, many of whom were doctoral graduates. The team developed a successful industrial process, which later was transferred to CODELCO and is known as a CODELCO project. Dr Bio feels 'very proud of having been part of that, because I believe it may be the most important technological development done in Chile'.

After exploiting the innovation the company decided to move away from technology development and the research team was fired. Most former team members are still working in the mining sector; they were engineers and went to work in the newly opened bioleaching plants or at CIMM. Dr Bio found a job in a research institute dedicated to a different subject. He had to restart his research career, and his reputation in the copper industry gradually faded away.

Dr Cape and Dr Bio were involved in the industry from the 1970s, when technology and innovation activity began to expand. They both held cultural capital which was valued in the industry field. They both accumulated capital to match the changes in the field. Dr Cape participated in numerous projects, kept updated and continued to learn. Dr Bio participated in an important innovation, which had a place in the field. When R&D in bioleaching lost relevance, Dr Bio's capital in the subject lost value. Bioleaching is still important in the field and there was renewal of R&D in the area in the 2000s, but Dr Bio had already left the field. Once he left to begin building a position in a different subject, his capital (knowledge, experience, reputation and social network) in copper was lost, and other players took on the position of bioleaching experts.

5.3.5 Mining as a possibility for research funding: the 1980s in the universities

In the 1980s, numbers of doctoral graduates in the country were small, there were a few doctoral programmes in Chile, but no funding programmes for doctoral studies – the first scholarships were granted in 1988 (see Ch. 4). The universities had been reformed and were obliged to seek for funding, with the result that academics had to focus on research with funding potential.

The case-studies of Dra Salt and Dra Crystal are examples of academics who embarked on careers in the mining industry in this period. They were not doctoral graduates in the 1980s; their experience illustrates the implications of the university reform in the relations of academics with the industry.

Dra Salt was finishing her undergraduate studies when she was appointed as a lecturer at the polytechnic in the copper mining region following the mass dismissal of lecturers that occurred in 1973. Dra Salt experienced the deep changes in the higher education system in the 1970s and 1980s, for example, the merger of the polytechnic with the local public university, military intervention in university management and the university funding reform. She did some consultancy for the mining industry and worked on projects and practical work with her students in the copper firms. It was a time of university restructuring and she was involved in administrative, teaching and research activities.

Dra Salt had a passion for research, but was not able to start her doctoral studies until 1989. By then, it was clear that mining production was a strategic area for the university. In the late 1980s the university began to support faculty members to do doctoral research in the US on copper mining. Dr Salt had become interested in salt deposits, a natural resource with mining value and also a fragile eco-system. Her topic was not part of mainstream mining research and she had to overcome several difficulties in order to complete it.

Dra Crystal also was working in a northern regional university during this period. The 1980s were years of learning and accumulation for her; she maintained a fairly low academic profile. The learning she accumulated in this period was important for her more prominent roles in the 2000s. Dra Crystal worked part time for her university in the 1980s. She taught, and participated in research and consultancy projects for the copper mining industry.

The 1980s were not conductive to entry of new players to the field of copper mining except for those involved in the production sector. Universities were suffering from the severe reforms and there was no funding to build research capacity. It is probable that the universities and research centres that were already established names in the mining sector participated in some of the biggest projects – for example, CIMM and some universities - but such opportunities were unlikely for the newly formed engineering faculty in the northern region where Dras Salt and Crystal were working. The chances of accumulating capital were probably reserved to those already in the game.

Well established players probably preferred to hire people with doctoral degrees rather than would-be graduates since this was not a period of long term investment. University and research centre funding was disappearing and these organisations were under pressure to obtain funds from competitive sources. By the end of the decade the economy had begun to grow. Copper mining was opened to foreign investors and the structure of the copper industry was changing.

5.3.6 Funding pressure for R&D institutions: the 1990s

This was a period of economic growth for both the copper industry and the Chilean economy generally. During the 1990s, national and international mining companies joined the industry, sharing the space with CODELCO. By the end of the decade private firms accounted for two thirds of production and the industry was dominated by big firms (see Section 5.1.3).

The 1990s saw the creation of public competitive funds for research, development and innovation, for example, FONDEF and FONTEC. To receive funding, projects had to be proposed by producer firms or partnership involving a research centre and a producer. The involvement of a producer was considered proof of the project's industry applicability. Competitive funding was the dominant form of research funding of universities and research institutes. The case-studies of Dr Cape, Dra Crystal and Dra Salt are examples of effects of the new system on doctoral careers.

Dr Cape was working at CIMM at the beginning of the 1990s. He recalled that CIMM changed then and moved focus towards becoming a service provider rather than a research centre; however, there were some attempts to revitalise the research centre model funded by public companies. This resulted in CIMM undertaking a few contracts for CODELCO, some of which Dr Cape participated in: ‘one could work in a relaxed way there, because it was funded by CODELCO’

Dr Cape felt the pressure for self-funding grow to the point that it became counterproductive, resulting in the transformation of CIMM in the 1990s into a service provider rather than a research centre. Dr Cape left CIMM and moved to the private sector, to provide engineering services to the industry. He has been an employee and a partner in one of the most important engineering consultancy firms in the sector since then. When Dr Cape moved to the private sector, he was already a well positioned ‘player’. After 20 years working in copper mining technological development at CIMM – which had been considered the best research centre in the field – and having been involved in challenging projects, he was recognized as an expert of long trajectory. Dr Cape had accumulated cultural capital (embodied knowledge and social capital) during all his years of working for the industry; he had worked in different projects with many other engineers from CODELCO and other mining firms and mining suppliers.

Government launched several competitive schemes during the 1990s, including MECESUP to improve teaching and research capacity in the traditional universities. Dra Crystal managed to obtain funding for her doctoral studies as part of a MECESUP project. The project provided funding for developing research capacity in mining in her northern university. She had a full time academic position in 1989 and in 1997 enrolled in a doctoral studies programme. All of her previous experience in research and projects for the mining industry informed her doctoral research topic.

Dra Salt had problems obtaining funding for her area of interest since it did not fit with mainstream research funding policies. While she was finishing her doctoral studies in the early 1990s, she had a research project on salt deposits funded by FONDECYT. Throughout the 1990s, she became increasingly interested in the environmental impacts of the mining industry. She continued her studies on salt deposits forging partnerships with academics in other university departments. Compared to the way that other areas developed, her area of research was rather limited. Dra Salt’s relations with copper mining in the 1990s were mainly based on teaching activities related to chemistry and mining engineering.

During the 1990s technological change was led and developed mainly by producer firms and science and technology suppliers (mostly private engineering firms). The relevance of CIMM decreased and– at least in some areas – it became just another service provider competing for funding.

The policy for funding universities was very influential in decisions about which areas of research would be developed – even when there was no explicit strategy in place (see Ch. 4). Areas that were able to attract the interest and support of industry firms were likely to obtain funding and to develop, implying the accumulation of capital and a virtuous circle of growth. On the other hand, areas on the margins of firms' interests were unlikely to develop.

The argument of research merit – were the researcher and her research outstanding they would be recognized and would develop against all odds – seems an idealisation, because the criterion may hold for FONDECYT (a minor but prestigious source of funding), but not for other funding programmes. A research area that does not accumulate capital in its different forms (equipment, a knowledgeable team, links to the relevant scientific community, etc.) is unlikely to develop or to have any influence or effect on the field of copper production.

5.3.7 Maintaining and improving positions in the field: 2000-2011

The first decade of 2000 is too recent to be covered by the history books or by sector studies. The most recent period has shown continuity of technological and governance systems. Sector governance has been dominated by big national and international companies. It has shown sustained economic growth, with high prices for copper and growing demand from China and India.

The sector has provided job opportunities and, therefore, it is likely that doctoral graduates already in the field – with established positions and accumulated capital – will continue to work and to develop careers in copper production. The case studies of Dr Cape, Dra Crystal and Dra Salt are examples of continuity and deepening of the pattern of capital accumulation within the field.

Dr Cape was working in a big engineering consultancy company during this period. He was offered a partnership in the firm and became a stakeholder while maintaining his directing and engineering roles. He cultivated a relationship with academia, giving occasional presentations at conferences and participating in various postgraduate programmes. Dr Cape was well known in the copper industry as an expert with long experience. His firm provided services to the mining industry and was involved in many technologically challenging projects: it was a leading firm in its area of expertise. In 2010, it was acquired by a transnational provider of engineering services and Dr Cape became an employee of a big international engineering firm.

Dra Salt continued her academic career and maintained her research interest in salt deposits, new mining resources and environmental issues. Her relationship with the copper industry was sustained through teaching on engineering programmes.

Dra Crystal was part of an academic team that accumulated capital (knowledge, equipment, reputation and social networks) during the 1990s. She finished her doctoral degree in 2000 and this sparked a big change in her work life. Several of her colleagues were awarded doctoral degrees at the same time. The team had done some research projects and consultancy for the mining industry before Dra Crystal began her studies for her doctoral degree. After she was awarded the degree, many possibilities were opened to her and her colleagues:

> Having the doctoral degree implied we could offered postgraduate programmes...all that helped us to gain space in research, we increased the number of publications because it was not only us, but also our students' publications. Alongside the postgraduate programmes, we created a research centre for the mining industry...It was a good time because only doctoral graduates could apply for that funding [there are 20 doctoral graduates in the centre]. That meant resources, new equipment, laboratory expansion and resources for research. It implied also a new vision.
>
> The funds came from the regional government and they asked for closer contact with the region and the industry. Until then we had mainly FONDECYT projects, which are scientific projects, and we had to start doing CORFO projects, like INNOVA, straight industry research projects. It was not only technical assistance and consultancy - which we had done always - but research for the industry. All these things have happened in the last five to ten years, it has been like an explosion. We had to change from working in small groups to

> produce scientific publications, to working in big teams with other universities and people from the industry.

Although Dra Crystal had worked for the mining industry as an academic in a mining region since the 1980s, only in the 2000s did her career expand. She and her team had enough accumulated capital to attract even more, in the form of bigger projects.

5.3.8 Arrival of doctoral graduates from other fields: 2000 -2011

In the 2000s the copper industry was clearly an attractive and wealthy field where scientific knowledge was valued. It was clearly possible to get partnerships for research projects and direct contracts from firms in the industry. This attracted doctoral graduates from other areas to the field of copper production. The case-studies of Dr Trans-tech and Dra Academic illustrate the potential attraction of the industry for university academics. Both did their doctoral degrees and began their academic careers in the 1990s, but moved to work closer to the copper industry only in 2009.

Dr Trans-tech held an academic post in a university in Santiago between 1999 and 2009, during which time he developed his area of expertise and gained recognition. His teaching, research and diffusion activities increasingly were focused on a technology relevant to the capital intensive industry sectors, including copper mining. His job did not require much equipment, ‘a good computer is enough’. He gradually built a relation with firms in the mining industry by doing projects and training, but he felt limited support from his university for relations with industry. In 2009 he moved to a research centre dedicated to the copper industry, which was part of a university in Santiago. He saw potential in the industry: ‘mining is where the money is in this country...where we could be leaders, where we are leaders’. He considered that the new university provided a more supportive structure for developing strong relations with industry.

Dra Academic built a strong reputation as a researcher in an economic discipline through publishing, during and after completion of her doctoral studies. In 2009, she moved to a university research centre dedicated to the copper industry. It was a career opportunity for her and she could see potential connections between her early work and the copper industry. However, she felt she needed to ‘reinvent’ herself and to study to make ‘new connections’, which implied ‘an important cost’. Her first presentation in a seminar dedicated to copper was in 2010; her previous research had application to other sectors or was contributing to advancing knowledge in her niche discipline.

5.3.9 Expansion of doctoral graduates in the field: 2000-2011

In addition to doctoral graduates moving to the wealthy copper industry, in the 2000s there were graduates who did their doctoral degrees on aspects of the mining industry in the expectation of building a position within the sector through employment in academia or directly in an industry firm. The case studies of Dr Academic-miner and Dr Company are illustrative of these later doctoral careers, of people with involvement in the copper industry during or before their doctoral research. Dr Academic-miner and Dr Company obtained their doctoral degrees in the 2000s. Their doctoral research on the copper industry in Chile was conducted abroad, and both returned to Chile to do work related to the copper industry.

The first case, Dr Academic-miner, studied mining engineering and went straight into an academic career and doctoral studies in Canada. He pursued and academic career because 'even though I am a miner, my personal life is more important to me than money... Santiago was my option rather than getting lost in a mountain'. Dr Academic-miner had been working with a colleague since 2003. By 2010 they had a team of around 12 engineers, final-year students and postgraduate students, working with them in a dedicated laboratory, which was basically a computer cluster for developing specialised software. They were working on various research projects with application to the industry. These projects were funded by public competitive funds, most of them in partnerships with the private sector.

Dr Academic-miner had built a reputation as an expert in a specific niche mining area. He was known in the industry and also in the international scientific community of researchers in his discipline. He cultivated relations with the specialist scientific community through regular attendance at international conferences, and publications.

The projects for the Chilean industry were facilitated by knowing people in the firms. For example, one of their biggest projects was with CODELCO and a Canadian software company. Dr Academic-miner had a colleague in CODELCO, working on the same area, with whom he discussed the original idea for the project. The Canadian firm was 'an obvious' partner because it was well known in the area:

> Discovering how to make relations is something one learns in the field,... not from colleagues in the department, but colleagues from my very specific area, professionals one gets to know while working outside university. There the network takes shape with people one relates to again and again.

Dr Academic-miner and his team had specialised in a niche technological research area: ‘What we do is almost unique in Chile’. The most important national conference on copper, MININ, was taking place at the time of the interview. MININ is a biennial conference attended by academics, consultants and professionals from the producer industry and industry providers. Several members of the team were presenting in MININ 2010. Dr Academic-miner identified a few people in Chile working in his area; all are working in copper mining firms and are potential counterparts for research projects.

The second case in this group is Dr Company, who obtained sponsorship from a big copper firm for his doctoral studies. He returned to Chile, after finishing his doctoral studies, and started to work for his sponsor, applying his doctoral research. Dr Company was deeply interested in Chile’s development and industrialisation processes. He recalled his decision to continue doctoral studies as a way of finding answers to questions that had unsatisfactory answers, for example: ‘If things work as researchers and policy makers say [in Chile], how is it that we have not made any advances in technological and production development in comparative terms?’After a few years, he embarked on his postgraduate studies with a clear idea of his topic: ‘if Chile has a chance to industrialise it has to be around or linked to natural resources’.

He focused on the copper industry and used it as a case study for his master’s dissertation. From there he went on to do doctoral research sponsored by a mining firm. He knocked on many doors before obtaining sponsorship. He believed several factors came together to help him succeed: the project proposal - which was interesting for the companies and in tune with policy discourse, the discussion on the mining royalties, and the relatively small size of his project by mining standards (at a time of high copper prices).

Dr Company had studied the sector as part of his masters dissertation and was clear about the role of the big copper companies: ‘their decisions –because they are so big –

are political, their decisions affect the whole economy even unintentionally'. He realized that were his doctorate successful in becoming an interesting proposition to develop the industry – it could be his chance 'to go straight into the mining industry'. Therefore, throughout his research, he balanced academic and production interests.

5.3.10 A conquered field for doctoral graduates: the 2000s

The examples of the 2000s illustrate different relations between doctoral graduates and the field. Dr Cape maintained a strong position, based on active and continuous involvement in industry activities. Those who moved to other areas of work lost their position, for example, Dr Bio. Some perhaps decided not to cultivate a place in the copper industry, such as is probably the case of Dra Salt. Old players may have changed their positions, for example, Dra Crystal. She and her team could access more resources and challenging research projects. When new funding opportunities were open they could use the capitals they had accumulated.

There is also a diversity of new entrants, for example, Dr Trans-tech, Dra Academic and Drs Academic-miner and Company. Dr Trans-tech and Dra Academic moved to the field from other areas. Their previously accumulated capitals were translated to the copper industry, achieving them a place in a specialised research centre and in the industry.

Dr Academic-miner had been 'a miner' – said with pride - since he was an undergraduate. He had built a place for himself in the industry by specialising in a niche area; his work location was Santiago and with potential for a rewarding impact in the industry. Dr Company has found in the copper industry, and in a position within a big company, a place to work towards Chile's development, a passion he is fulfilling by combining personal interest and company interests. This group of new entrants shows a variety of reasons for involvement in and dispositions towards the copper industry. They are examples of how the industry may attract high skilled professionals.

There are several institutions that have become taken for granted in this last period, for example, the regular sector publications (visible in all the offices visited during my fieldwork) and the regular international conferences which provide opportunities for interactions in the community of copper professionals and researchers from producer firms, consultancies and research institutions.

5.4. Doctoral Graduates' Practice in the Field of Copper Mining

This section analyses the roles of doctoral graduates in the field of copper mining, focusing on the effects of practice on capabilities accumulation. It draws on the historical context (Sections 5.1 and 5.2) and the types of doctoral graduate's capital active in the field over time (Section 5.3).

The main role of doctoral graduates in the copper industry is taken as that of scientific supplier, that is, supplier of science and technology possibilities for the producer firms or firms serving the industry. The analysis is based on the dynamic capability schema (see Ch. 2, Section 2.2), applied to the individual case of doctoral graduates acting as scientific suppliers.

The theoretical model represented by the dynamic capability schema can be used as a tool to analyse the three-fold relation, supplier-producer- consumer, at a particular point in time. The analysis can be reproduced for different moments to give an account of the time dynamics (see Ch. 2). I apply it here to explain the dynamic interchange between the individual labour of scientific suppliers (doctoral graduates) and the demand for their labour (Section 5.4.1), and between scientific suppliers and suppliers of resources for their labour (Section 5.4.2). I reprise and expand on the examples in Section 5.3 to illustrate my analysis. Finally, Section 5.4.3 extends the analysis to the organisational level, connecting the practice of individual scientific suppliers with the organisations employing them.

5.4.1 Scientific supplier and the demand side

Doctoral graduates 'appeared' in the field of copper mining in the last of the three epochs in the historical review (Section 5.2). In the 1960s there were very few doctoral graduates in disciplines related to mining and they worked in universities. During the period of industry expansion and catching up – 1975 to 1999 – doctoral graduates had opportunities to take positions as high skilled workers in the industry or as specialised service providers. I refer to their role in the industry as 'scientific suppliers'.

The scientific possibilities of scientific suppliers – at the individual level of workers offering their labour - are the product of a *three-fold dynamic social construction*: the constructions of a producer of work, a demand for labour, and a supply of services and resources to produce work. In this section I analyse the demand side (see Figure 5.4):

first demand from producer firms, and second demand from research organisations, which I refer to as science and technology suppliers.

Figure 5.4: Capabilities schema for Scientific Supplier and Copper Producer (Demand Side)

Actors	*Scientific Supplier*	*Copper Producer*
Characteristics	**Scientific possibilities**	**Production possibilities**
Capabilities	S2 **Scientific capabilities** S2’	KE2 D2 D2’ **Production capabilities**
Rewards	**Earnings/Scientific Rewards**	**Profitability**

Source: Adapted from Von Tunzelmann (2009) and see Ch. 2 in this thesis.

Scientific suppliers contribute to enhancing the production possibilities of the copper firms. This is exemplified by the case of Dr Bio and the development of a commercial bioleaching process in the late 1980s and early 1990s, introduced in Section 5.3. Dr Bio was the micro-biologist on the team – scientific labour is often a collective effort. As the subject specialist in the team, he embodied certain scientific capabilities which had an impact on the firm’s production possibilities (S2). The production capabilities of the mining firm employing the team matched the offer of Dr Bio and colleagues; the company was able to obtain profitability from their labour and, therefore, this constituted a demand for the production possibilities (D2).The mining company paid Dr Bio a salary – a measure of the value of his work (D2’). The salary was three times higher than a university salary and he remembered the period as a time when he worked less and earned more – a measure of his efficiency (S2’). The relation between Dr Bio and the mining firm was dynamic; he was at the firm for more than five years during the development and exploitation of the commercial bioleaching process. When that was completed, the team offered the company new production possibilities, but the company decided to close down the department. There was no demand (D2) and no salary (D2’); Dr Bio was unemployed for the first and only time in his life. However, the balance for him was positive:

> It is easy to make accounts. I did when I moved to the mining firm: they could fire me any time; it was not like University of Chile where they cannot, but they paid three to four times more. Therefore, if I stayed five years in the mining firm, it would be like 20 years at the university, it would be like getting retired. If I could bear it for more than five years I could not lose. [Laughs] I was there for more than five years.

This comment on 'economic rationality' needs to be put in context. Dr Bio knew and liked both the project and the research team of a group of 14 professional most with doctoral degrees. In parallel with his job in the mining firm, he had developed a FONDECYT funded research project. He reached agreement with the firm to continue this project, which was on bioleaching bacteria, but was focused on basic questions with no immediate application: 'I could continue with my research and at the same time had to do the applied stuff, even though it was boring, I had to do it...'. He was proud of the team's achievements and reflected on the irony of working for a private company having been attracted to copper for a socio-political motivation. Dr Bio's disposition as a scientist, his specialised knowledge of biological phenomena and personal motivation towards applications with social impact, were an integral part of him as a 'labour producer' with effective capital in the field.

Dr Bio was a scientific supplier internal to a copper producer firm. Once the technological development proved successful, the firm entered into commercial agreements with bigger copper producers to transfer the technology. At the time, Dr Bio was part of the organisation – his employer, the copper producer firm –that acted as technological supplier to other producers.

Scientific suppliers can be internal to the producer firm, in the role of employee, or external, in the role of independent consultant or employee in a science and technology supplier organisation – as in the second stage of Dr Bio's work in the copper producer firm. Other examples of science and technology suppliers to producer firms are universities and research institutes and, also, engineering firms. The examples in Section 5.3 include scientific suppliers, for example, Dr Academic-miner and Dr Trans-tech working for universities, and for other organisations, for example Dr Cape, working for an engineering consultancy firm.

The structure of copper production was clearly different in the 1990s. CODELCO was no longer the only big player in the field; there were also locally owned private producer firms and branches of large international diversified mining companies. The circumstances arising from the dominant mode of governance defined a horizon of possibilities for the scientific supplier. The hybrid character of the field - with public, private, national and international actors – offers a variety of possible positions for the scientific supplier and also a set of boundaries. They might be employees of private or public producers, or of a public or private science and technology supplier. They might provide independent scientific services to producers or suppliers.

Demand for the labour of scientific suppliers from other actors than those mentioned above would seem unlikely. Other aspects adding to the complexity in the field include: regulation, taxation, mining law and monitoring of resources (outside private explorations). There were no projects or institutions with funding to do research in these areas, for reasons that are not obvious. Government actions are focused on regulation related to finance and property issues; therefore, eventually it might demand (depending on government's policy capabilities) a scientific supplier related to the disciplines of taxation and mining law. My search for doctoral graduates taking on those roles yielded no results. There were expert suppliers in mining law: well established law bureaux had specialisation in the field but did not employ doctoral graduates. Law schools dictate mining law, but do not conduct research in the area.

5.4.2 Scientific suppliers and the supply side

Scientific suppliers rely on suppliers of resources that make their work possible. They may need access to information, analytical laboratories, specialist equipment, samples, plots, data and software to perform their scientific activities. The scientific possibilities for doctoral graduates emerge from their technological capabilities and the technological capabilities of their suppliers. The relation between scientific suppliers and technology suppliers – a particular type of their multiple suppliers - is represented in the first two columns in the capabilities schema (Figure 5.5).

Figure 5.5: Capabilities schema for Scientific Supplier and Technology Supplier

Actors	*Technology Supplier*	*Scientific Supplier*
Characteristics	**S&T possibilities**	**Scientific possibilities**
Capabilities	S1 KE1 **Technological capabilities** S1’	D1 **Scientific capabilities** D1’
Rewards	**Profitability**	**Earnings/Scientific Rewards**

Source: Adapted from Von Tunzelmann (2009); and see Ch. 2 in this thesis.

A scientific supplier may have several different technology suppliers. Figure 5.5 represents the relations with one of them, but this could be replicated for any number of others. Technology suppliers can vary, for example, from external or internal to the scientific supplier’s organisation, and based on science or applied technology.

Analytical laboratories are an example of a common external technology supplier. Doctoral graduates interpreted laboratory results and made decisions based on them. Scientific suppliers’ technological/consumer capability implies they demanded laboratory services (D1) and they allocated resources - from the project budgets they controlled – to pay for services if they considered that they would benefit their work performance (D1’). The laboratory’s technological capabilities to deliver the service have an impact on the scientific possibilities of the doctoral graduate (S1’) and the profitability of laboratory firm (S1’). As in the previous examples, the process involves ongoing exchange between the actors (KE1).

The dynamics of the process can be observed in different time pictures of the laboratories (technological suppliers) in relation to scientific suppliers, in 1960, 1980 and 1999. In the 1960s there were no local independent laboratories specialised in mining samples, there were no consumers demanding the services, there were no local technological capabilities to provide them, and the mining companies were vertically integrated. In 1980 the research institute CIMM - created in 1970 with contributions from CODELCO and international aid – was a well established supplier of laboratory services for accurate measuring of mineral ore and other specialised tests. CIMM started by supplying CODELCO and CIMM internal scientific suppliers, but in the 1980s had several clients. In 1998 CIMM created a spin off to provide commercial technological services (laboratory and other) when it was clear that CIMM's laboratory was only one amongst several technological suppliers. Scientific suppliers sent samples to national and international laboratories.

Relations between scientific suppliers and internal technology suppliers are not reflected in market transactions, although they define scientific possibilities. Internal technology suppliers - for example, colleagues - may provide scientific suppliers with inputs and also demand services from them. This was the case of Dr Bio in his role as 'the team's microbiologist'. It applies also to Dr Cape's work. Given his speciality he was often the 'assembler', he participated in interpreting the client's request at the beginning of the project and had responsibility for putting together the contributions of the different engineers (electrical, mechanical, etc.) to finalise the project.

Technology suppliers can have different origins, for example, they may be based on applied technology or science. In the cases discussed in Section 5.2, doctoral graduates mentioned a variety of technology suppliers: laboratory services and specialised software amongst applied technology based suppliers, and journals and scientific conferences amongst science based suppliers. There were also specialised suppliers of industry news and fairs. In every office I visited during fieldwork there were copies of the journal *Mineria Chilena*, which was first published in the 1970s, and interviewees had all attended EXPOMIN, the biggest industry fair in Chile, held first in 1990.

5.4.3 Organisational level

The organisational level considered here is the firm level and includes copper producer firms and science and technology supplier firms but not copper consumer firms since copper goes primarily to the external market. Firm capabilities result from the joint efforts and capitals of different agents in the organisational field, as discussed in Chapter 2. The copper producer firm is at the centre of the capabilities schema in Figure 5.6, facing the copper consumer on one side and the science and technology supplier on the other. This particular supplier – amongst many serving the copper industry- is the one I assumed would be most likely to include doctoral graduates.

Figure 5.6: Capabilities Schema for the Copper Producer Firm

Actors	*Science and Technology Supplier*	*Copper Producer*	*Copper Consumer*
Characteristics	**Sc/Tech possibilities**	**Production possibilities**	**Product possibilities**
Capabilities	S2 KE2 **Sc/Tech capabilities** S2’	D2 **Production capabilities** D2’ S3 KE3 S3’	D3 **Consumer capabilities** D3’
Rewards	**Profitability/IPRs**	**Profitability**	**Utility**

Source: Adapted from Von Tunzelmann (2009). See Chapter 2.

Product possibilities for the copper consumer are the result of the producer’s capabilities, which shape its supply (S3) and the consumption capabilities of the copper consumer, which define a demand (D3). The efficiency of the copper producer firm defines its costs and its profitability (S3’). The price paid by the consumer to the producer (D3’) also defines the producer’s profitability.

The Chilean copper industry has grown steadily since the 1970s, high prices of copper (D3’) and expectations of market growth have had an effect on producers’ profitability and their relations with suppliers. In the 1970s and the early 1980s CODELCO dominated copper production in Chile. Therefore, demand for the production possibilities offered by science and technology suppliers came from CODELCO’s producer capabilities (D2).

According to Urzúa (2011) this was the period when the base of science and technology suppliers was established. Many of these new specialised supplier firms were founded by former CODELCO scientists and engineers. In the 1980s, CODELCO and other big companies then established in Chile, started outsourcing processes that gave origin to more entrepreneurial initiatives, most of them spin-offs from CODELCO. There was also an important movement of suppliers from other industries towards the copper industry (Urzúa, 2011).

The value placed on science and technology supplier’s services (D2’) and the anticipation of growing demand was comparatively attractive. The pace of growth of science and technology suppliers slowed in the 1990s, new entrants were mainly international suppliers which – often – crowded out local suppliers (Urzúa, 2011). Sustained high profitability and producer demand for production possibilities made the industry attractive to suppliers of cross-industry technologies, and to international suppliers.

According to Urzúa (2011), who surveyed ten Chilean science and technology suppliers, the informal interchange (KE2) amongst suppliers and producers, has changed over time. In the 1980s and 1990s it was intensive and provided significant learning opportunities, but has become increasingly standardised in the 2000s.

Producer capabilities provided scientific suppliers with opportunities for training, exposure to new technologies and innovation, and increasingly complex scientific and technological problems. The significant expansion of industry production in the 1990s provided opportunities for science and technology suppliers to engage in and learn from complex scientific and technological challenges, for example, new large investment projects designed and constructed from scratch. These challenges were taken up by science and technology suppliers already positioned in the national and international industry (Urzúa, 2011).

In the 2000s there was space for new entrants in niche areas, for example Dr Academic-miner and Dr Trans-tech. Dr Academic-miner is among a small number of specialists in his scientific domain including specialists in producer firms - employees who acted as counterparts for his services. He interacts with them regularly in seminars and activities related to his area of expertise (informal KE2 relations). Those specialists from the producer firm are part of a firm producer capability which defines demand for Dr Academic-miner’s expertise.

As in the case of individual scientific capabilities, organisational capabilities accumulated over time. They accumulated first in the producer firms, which resulted in the creation of supplier organisations. Capability accumulation during the 1970s and 1980s allowed local producers and suppliers to take part in the major investment projects of the 1990s. However, increased competition with international suppliers and producers starting in the 1990s tested the competitiveness of Chilean organisations, crowding out many national suppliers (Urzúa, 2011).

In the 1990s the world industry structure became more international. The big producer firms from leading countries widened their international investments as did the strongest science and technology suppliers. Australian suppliers, for example, became the leading international players in the 1990s. In the Australian case the dynamics of capability accumulation had started 20 years earlier than in Chile; the industry had provided learning challenges; and suppliers had invested effort in responding to those challenges (Urzúa, 2011). According to Urzúa the 1990s – when the industry was international, Australian suppliers were strong players who could compete comfortably in the international arena; Chilean suppliers were lagging behind and showed no signs of catch up even in 2005. The arrival in Chile in the 1990s of international science and technology suppliers crowded out local suppliers. However, it may have contributed to the industry maintaining an internationally competitive level of production possibilities.

5.5 Conclusion: Patterns of Capability Accumulation

Sections 5.1 and 5.2 provided a construction of the history of the field of copper production in Chile focusing on technology and governance. Section 5.3 identified the specific forms of capital active in the field from the perspective of doctoral graduates. Section 5.4 analysed the logic of the field, the dynamics by which capitals are formed, deployed and lost.

Applying the theoretical framework elucidated how scientific capabilities are part of a dynamic relation between the scientific supplier – the individual doctoral graduate, the producer firms and the technological suppliers. In response to the question about how scientific capabilities accumulate, it appears from the analysis that accumulation takes place when the three-fold dynamic is sustained over time. Accumulation can occur at different paces depending on the intensity of the process, but time is crucial since learning processes are involved.

The capabilities dynamic involving scientific suppliers – particularly doctoral graduates - was not observed until the 1970s. It can be inferred that scientific capabilities were rare and production capabilities were not sufficiently complex for there to be a demand for them, which resulted in limited production possibilities for Chilean based copper production. In the mid 1970s, CODELCO accumulated producer capabilities which translated into demand for production possibilities. The scientific and technological capability dynamic began and continued to grow, in terms of activity, over subsequent years.

Since the 1970s there have been more than 30 years of sustained scientific capabilities dynamics. During this time the copper producer firms have demonstrated producer capabilities to demand production possibilities (D2) and valued and paid for the services of scientific suppliers (D2'). The scientific possibilities of the scientific supplier have increased over the period (S1). The interchanges among the actors have also increased as a result of a history of working together and various 'routine meeting opportunities' (regular fairs and seminars, and industry news journals). Successful interaction – for example, innovations, patents, improved processes and high industry profitability – have reinforced relations.

Individual scientific suppliers accumulated capitals valued by the industry and built recognised position as 'expert' in a scientific domain through their sustained role as scientific suppliers. Dr Cape, for example, has been in the field since the 1970s and Dr Academic-Miner was highly conscious of the investment needed to accumulate the requisite experience and reputation.

These observations are in line with Urzúa's (2011) fieldwork findings. He concludes, from informal discussions with ten copper mining experts, that to become an expert takes around 20 years of practical experience of applying high technological/scientific skills. Experts 'in the making' need to maintain high levels of training, have exposure to new techniques and technologies and engage in innovation processes and increasingly complex problem solving (Urzúa, 2011). The length of time and intensity of the challenges may need closer examination – and doctoral studies might play a role in reducing learning times. The conditions for accumulation of scientific capabilities seem to involve the dynamics of the capabilities schema being in place for a sustained period of time - measured in years rather than months.

In terms of accumulation of producer capabilities at the SLS level - referring back to Viotti's (2001) basic technological capabilities (see Ch.2, Section 2.2) – the Chilean copper SLS accumulated improvement capability and innovation capability from the

1970s. The typical technical functions of improvement capability have been present, for example, major adaptation to local conditions, total quality type control systems and in-house R&D.

There was experience related to accumulation of innovation capability. Among the innovation functions, it is possible to find cooperative R&D not only with research institutions but also with international competitors, for example, partnerships between CODELCO and Nippon Mining for bioleaching development in 2002; and between CODELCO, Nippon Telegraph and Telephone Co. Ltd and NTT Leasing Co. Ltd. for developing mining technology supported by ICTs in 2006. There have been experiences of licensing own technology to others (e.g., Convertidor el Teniente licensed in 2007 to Thai Copper industries). In house R&D has expanded, at least in CODELCO, with IM2, the institute for innovation in mining and metallurgy launched in 1998. These examples show the presence of technical functions related to innovation capability in at least one dominant firm, CODELCO, which presents active learning strategies. Measuring will be needed to conclude whether active innovation strategies are dominant in the SLS and how SLS compare internationally.

Chapter 6. Fruit Farming

This chapter relates and analyses the history of fruit farming and the working experience of doctoral graduates in the field. It follows the presentation and organisation of Chapter 5. It is another application of the concepts of historical coevolution of a field, effective capital of doctoral graduates within the field, and the dynamics of capability accumulation.

6.1. History of Fruit Farming in Chile

Chile is an important producer and exporter of numerous varieties of fresh fruits, and is a main exporter of grapes and apples, which in 2009, accounted for 67% of Chile’s fruit exports (ASOEX, 2010). Fruit production and fruit exports have expanded enormously since the 1980s, when Chile was not active in the international market. In the first decade of the 21st century, Chile was ranked first for world exports of grapes, followed by the US and South Africa. Most of Chile’s grapes go to the US and to Europe (in counter seasons). The US is the biggest world exporter of apples, followed by Chile whose export volume is equal to a third of US exports, and New Zealand whose export volume is half that of Chile. Chilean apples are exported to Latin America, Europe, the US, Asia, the Middle East and Canada (ASOEX, 2010). There is competition among different fruits in different markets, and also several different varieties of each fruit are exported, and each is associated with a specific market.

Chile’s main fruit growing area is in the central valleys; most production goes to international markets. Chile has exceptionally favourable geographic and climatic conditions for fruit production, and benefits from northern hemisphere countries importing out of season fruits. The share of agriculture and forestry in GDP fluctuated between 3% and 4 % in the first decade of the 21st century; of which 16% was fruit (ODEPA, 2009). In the same period, the share of agriculture and forestry in total exports was around 19%, to which fresh fruits contributed 26%.

In 2002, employment in agriculture and forestry accounted for 9% of total employment (INE, 2003) – down from 15% in 1992 (INE, 1993). Agriculture is the main source of employment in the central regions and is the sector with the lowest average years of schooling among workers: 7.1 years in 2002 compared to a national average of 10.8

years, and 6.1 in 1992 compared to a national average of 9.5 years (Ibarra, 2006). Most but not all agricultural workers have completed primary education. However, the number of workers with tertiary vocational education is very small and only very few have studied at university. Much of the work is temporary and is outsourced.

I distinguished two epochs in the history of agriculture in Chile based on the prevailing systems of technology and governance. Traditional agriculture characterized the sector up to 1960, followed by agribusiness, which started around 1980 and has produced what has been described as an ‘agriculture boom’, with fresh fruits being the most successful products. A summary of the characteristics of these two epochs is presented in Table 6.1 and discussed in more detail below.

Table 6.1: History of Agriculture and Fruit Growing in Chile

	Traditional agriculture	Agribusiness (fruit)
Approximate dates	1810-1960	1980-1999
Location of leaders	US, Canada, Australia, Argentina, Europe (depending on product)	US, Europe, South Africa, Australia-Asia, Argentina, Brazil (depending on product)
Role of Chile internationally/ main products	Wheat and cereals, related to favourable international market conditions; from 1940 oriented to internal market	Ranked 1st exporter in the world for grapes, 2nd for apples; important player
Chilean strategy 'Land for the country'	Basis of the social system and stability; social prestige in landownership; problem sectors to be integrated with the market	Diversification of exports; a new way of organising society
Demand	Changing with opportunities: Peru, Australia, US during gold fever boom (both short), Great Britain; domestic from the 1940s	Increased demand for fresh fruits from northern hemisphere countries
Technology leaders	Traders	Multinationals (US, Europe)
Technologies	Rudimentary, manual	Standard, to be bought and transferred (machinery, chemicals, production systems); complex, ICTs, biotech, environmental solutions
Automation	Very limited for transformation	of transformation and of distribution
Process Type	Labour	Capital; information and knowledge
Size of firm	Big haciendas	Big distribution firms and integrated producers; medium sized producers
Advantages	Cheap labour, counter-season, availability of land	Cheap labour
Organisation	Big haciendas	Entrepreneurial; integrated
Industry structure	Oligopolistic	Oligopolistic (distribution) mixed
Type of Capitalism	Personal	Entrepreneurial; managerial
Property	Mostly Chileans	Hybrid
Mode of governance	National and international markets; subsidies	International market
Power	Landowning	Capital; knowledge
Skills	Physical	Professional; specialist/expert
Education	Development and massification of primary and secondary education; professionalisation	Massification of higher education; foundation of postgraduate system
Governance actors	Landowners; state and government agencies	Large international and national players; few small firms
Associated infrastructure	Railways and ports; irrigation systems	Information and bio-technology

Source: Author's elaboration based on von Tunzelmann (2003) and multiple sources.

6.1.1 Traditional agriculture - pre 1960

In contrast to other countries in Latin America, the Chilean agriculture sector was established before independence in 1810. Chile's agricultural development included production of fruit (Lacoste et al., 2011). During its colonial foundations it became clear that gold deposits were scarce and economic activity in the valleys of the central regions resorted to agriculture and ranching (Collier and Sater, 2004).

Chile exported predominantly grains, to different markets, exploiting opportunities to supply regions enjoying an economic bonanza, for example, Peru up to the 1850s, California following the mining boom, and later Australia. By the beginning of the 20th century the grain export market had been lost to the Midwest American producers, and production turned to the internal market to supply the nitrate boom (Collier and Sater, 2004; Salazar and Pinto, 2002)

The land was worked by tenant-farmers who rented subsistence plots in exchange for services to the big landowners. The tenant-worker arrangement was characteristic of rural society in the valleys in the central region in the 1800s, but there were also some small, independent landowners that were struggling to survive against the predominance of the large haciendas (Collier and Sater, 2004). In the 1860s, the majority (over 70%) of Chile's population was engaged in agriculture (Rojas, 1993). Throughout the first epoch the situation of tenant-workers and other rural workers was poor: they received the lowest salaries in the economy and their contracts were often informal (Meller, 1996). Hard statistics align with anecdotal evidence of the poor life conditions and poverty in the countryside, in Chilean literature, poetry, folk song, legend and storytelling depictions.

Technology was rudimentary and technological change virtually absent. The main technological improvement was irrigation, in the form of construction of reservoirs and canals. Apart from the state irrigation schemes, there was little investment in the sector. Improvements consisted of better seeds, and use of fertilisers and pesticides (Collier and Sater, 2004). The trade in agriculture products benefited from improvements to transport, shorter shipping times, and a functioning national rail system.

Governance was based on the operation of the market and was dominated by the powerful landowners. In the early 20th century the state took on a bigger role, explained by Rojas (1993) as a consequence of new policies introduced after the Great Depression. The original development strategy was externally oriented growth to establish a position in the international economy. The Great Depression in the 1930s had a huge effect on Chile and revealed the fragility of this strategy. The new policies favoured internal development – import substitution and internal production protected by tax regimes and price policies. The new development policy was aimed at fostering the industrial sector and with supporting roles for other economic sectors, in particular agriculture.

Export of fruits in Chile can be traced back to the 1930s.[13] The private sector commercialised fruit exports to Ecuador and Panama. In the 1950s it expanded to the US with the introduction of refrigerated transport, provided by the pioneering public company for agriculture commercialisation, ECA, created by CORFO (Gómez, 1994). Exports were dominated by a few local commercial fruit firms and producers-distributors. These companies had links to international networks for the distribution of fruit (Gómez, 1994).

Agricultural production decreased in the 1930s and 1940s and became a threat to industrial development. The situation of discomfort with the sector's performance prepared transition to a new system marked by Agrarian Reform, a transformation that changed the organisation of the agriculture sector (Collier and Sater, 2004; Rojas, 1993).

The mode of governance before the Agrarian Reform was based on national and international markets (depending on the product). There were subsidies and price fixing policies, but government intervention was subsidiary to market rule. Rojas (1993) argues that regulatory measures had divergent effects and there was some transfer of benefits from agriculture to the industry sector. Measures such as price fixing, for example, benefited consumers in the urban populations needed for industrial development. Although there was no government support for agriculture, the tax system

[13] FONDECYT project 1080210, 2008-2012, entitled Frutales y Sociedad en Chile (1550-1930) (Fruit Trees and Society in Chile, in Spanish) and lead by historian Pablo Lacoste, may challenge this and other assumptions about history of fruit growing in Chile. This project is the first of its kind.

favoured the landowners (Rojas, 1993). The balance of export in agriculture was negative, which exacerbated dissatisfaction with the performance of the sector.

6.1.2 Transition and Agrarian Reform: 1960 - 1980

The period between 1960 and 1980 –implementation of Agrarian Reform - was one of transition between the two epochs identified here (traditional agriculture and agribusiness). Agrarian Reform in Chile marked a change in the most stable and traditional economic sector, which had influenced the organisation of Chilean society (Collier and Sater, 2004; Salazar and Pinto, 2002). The Agrarian Reform Law was passed in 1962 (Law 15020) and modified in 1967 (Law 16625). It allowed the expropriation of under-cultivated big haciendas and established the institutions and mechanisms to implement it. Agrarian Reform was halted in 1974 by a law passed by the dictatorship. Around 30% of the expropriated land was returned to its former owners, and cooperatives were dissolved although the system did not return to the previous hyper-concentrated structure (Salazar, 2009). The growth in agriculture production between 1975 and 1983 was lower than in the 1950s and 1960s (Salazar, 2009).

It has long been a matter of debate amongst social scientists as to why agriculture in Chile did not change until 1960. Salazar (2009) provides an explanation for the lack of investment in farms: the powerful landowners were involved in farming, but also in commercialisation and, latterly, financing. Part of their business was to lend to smaller producers, avoiding the risk of taking on the enterprise and focusing on rent seeking and financial speculation. Production oriented entrepreneurs did not develop among the elite landowners; this seems to have been the task of lower social classes (Salazar and Pinto, 2002).

There were several institutional changes during the transition period related to expected challenges after Agrarian Reform. The government created institutions for the implementation of the reform and to foster agriculture development. In 1962 it created INIA, the national research institute for agriculture. In 1968 CORFO developed a strategic plan for fruit farming, which was a continuation of the state’s role in fruit production in the 1950s, and the creation of fruit cooperatives (Gómez, 1994)

6.1.3 Agribusiness (fruit farming): 1980 - 1999

Since the 1980s, fruit farming has become an important agricultural activity measured by agricultural land use, volume of production and participation in exports (see Table 6.2). Fruit exports include several types, the most important being apples and grapes. Since the 1980s, the sector has experienced a process of technological catching up to international production standards. Governance of the sector is based on global market dynamics in which the main actors are the big exporting firms, which have become increasingly concentrated.

Table 6.2: Fruit Exports

Year	Fruit Exports US$'000
1961	18,452
1964	35,225
1970	45,427
1980	266,832
1990	1,016,781
1998	1,616,953
2001	1,781,413
2003	2,070,468

Source: ODEPA, 2010.

The development of Chilean agribusiness for global markets –fruit being the most important product - is considered an economic success or an economic miracle. Historical accounts highlight different reasons for the success of agribusiness exports. The lack of consensus is related to the different economic policies of rival political regimes. On the one hand, success is considered evidence of the effectiveness of neoliberal policies during the dictatorship (1973-1990); on the other hand, it is seen as the result of Agrarian Reform and the effects of developmental policies pre- and during the 1960s (Meller, 1996; Rojas, 1993). Other explanations are related to the issues identified in Salazar (2009) such as availability of financial capital from the reformed pensions system, foreign investment and privatization of public companies, and a cheap and flexible labour force.

During the 1980s, policy focused on reducing the external disequilibrium (Meller, 1996) and a strategy of export-based economic growth and regular repayment of the external debt. This resulted in a relatively improved macroeconomic position in the 1990s compared to other Latin American countries. Exporting was encouraged starting in 1985, through the imposition of low export duties and a high exchange rate. Internal disequilibrium was left to market forces, which implied high rates of unemployment, increased individual and firm debt, and had negative redistribution effects.

Agribusiness development was favoured by increases in international demand for fresh fruit from the northern hemisphere (Gómez, 1994). In the 1980s, the sector grew at a rate of 20% per year. The 8,000 producers and 300 distributers were the main employers in the central valley regions (Gómez, 1994). Up to 1981, the main exporters were national distributor firms, a few producer cooperatives, and some distributor-producer firms. The concentration of distribution can be explained by the economies of scale deriving from refrigeration chains, shipping and contacts with distribution firms in end markets.

At the end of the 1980s, there was capital accumulation in orchards and infrastructure, entrepreneurial capacity and a skilled work force in the central valley (Gómez, 1994). There was diffusion of new technologies, such as drip irrigation, refrigeration and sulphurisation to prevent fruit decay. Expansion in fruit farming drove demand for labour, but it was mostly temporary employment based on production cycles. According to Rojas (1993), only 20% of work placements in fruit farming were stable in the 1980s - and this has probably continued to be the case. Rojas identifies the new group of temporary workers with the increasing inequalities resulting from the processes of modernisation in the agriculture sector.

During the 1980s, Chilean fruit exports were concentrated in the US market and one product: table grapes. In 1988, Chile absorbed 86% of the international trade in table grapes (Gómez, 1990). The high concentration in one market of a highly perishable product was risky. Dependence on external conditions and the fragility of fruit exports became evident when two grapes that were supposed poisoned, were found at the port of Philadelphia in 1989. Chilean exports were banned from the US market and we, Chileans, literally had to eat our own grapes that season (I remember standing with a crowd in the outskirts of San Fernando’s town, receiving wooden boxes of grapes, being given away for free, distributed from lorries coming straight from the fields, and the amazed faces at the sight of the beautiful, huge grapes wrapped in tissue paper we had never seen before). Chile endured a major economic crisis in the fruit sector, which was successfully overcome by the state assuming most of the economic costs (Rammsy, 1998). Shortly after, in 1990, a fruit producer region was affected by fruit fly, which caused severe damage to the crop.

According to Gómez (1990), the 1980s was a time of relatively easy economic growth in fruit production. Between 1985 and 1990 the volume of grapes exported (the main Chilean fruit product at the time) increased, and the price decreased. The lower prices affected the producers, but not the prices paid to suppliers for packing and transport. Producers started out with high levels of profit in the 1980s, and around the mean for the Chilean economy in the 1990s (Gómez, 1990).

In the 1990s, the fruit farming scenario in Chile was of an established and export oriented production sector. Chile was a global player in grapes and apples and was expanding production to other species including avocados and berries. The industry was dominated by big distributors and producers. There were also numerous small farms, many of which were not integrated into the export trade. The sector was highly dependent on external circumstances.

Multinational distributors took the leadership in the 1990s: the ten biggest distributing companies had 60% of the market in 1994, with the four main ones accounting for 40% of the market. Medium and small producers were highly dependent on the distribution companies (Gómez, 1994). Some multinational distributors were integrated with production, although some, for example Dole Co., concentrated almost exclusively on distribution (Gómez, 1994). Governance was dominated by the market system, with a concentration of distributors and a larger number of producers selling to them. Chile's competitors in the early 1990s (US and Australia) had governance systems based on boards which behaved as monopolist sellers (Gómez, 1994).

6.2 Coevolution of Technology and Governance in the Fruit Industry

The history of the fruit sector presented in section 6.1 is generic, and the epochs identified apply to different fruits. However, analysing coevolution of technology and governance at a general level for fruit proved unsatisfactory. After several attempts, I realized that the obvious differences in the technological development of fruit species and in issues of structure and control, made general analysis futile. In order to analyse the historical coevolution I focus on the case of apples for the discussion in this section.

6.2.1 Technology and governance for the international apple industry

In the first part of the 20th century apple growing became an intensive agriculture production in the leading countries (e.g., the US). Apple growing is characterised by trees that can be pruned and trained into different shapes and sizes to promote the greatest orchard efficiency. Production changed with the use of dwarfing rootstocks and training systems that resulted in important increases in productivity per tree and per unit of land (Ferree and Warrington, 2003). The new technology 'heuristic' (Dosi, 1982) in apple production from the beginning of the 20th century was 'density' of production.

In the second half of the 20th century technological innovation in orchard management intensified (Ferree and Warrington, 2003). It focused on the development of herbicides, insecticides and fungicides for use in orchards 'designed' to reduce fruit loss, to improve fruit quality and to make production viable in areas where previously it was difficult. By the end of the century, research and innovation was focused on reducing chemical inputs and moving to organic production. Innovations in storage and postharvest techniques improved the quality and durability of the fruit.

Apple breeding – through conventional breeding and genetic engineering - has allowed the development of high quality varieties to suit consumer markets and to favour production (e.g., pest resistant cultivars). The most popular commercialised apple varieties in the northern hemisphere are the result of breeding programmes. They include 'Red Delicious' released in the 1960s and 'Royal Gala', 'Pink Lady' and 'Fuji' released in the 1980s and 1990s (O'Rourke, 2003).

Apple breeding is a long term endeavour because of the constraints to rapid genetic improvement (Brown and Moleney, 2003). There are a large number of public and some private breeding programmes across the world. Most are located in research universities (e.g., Washington State University) and public departments or institutes for agricultural development (e.g., Queensland Horticulture Institute in the Department of Primary Industries in Australia). Pioneer breeding programmes started around 1928 in Germany, Japan and Canada, but most programmes started in the 1970s and 1980s – which was a period of important growth in demand for apples.

In terms of governance, apple producers from Canada, the US and New Zealand had been influential in how decisions are made and implemented in the industry. They had been part of marketing boards which negotiate apple prices and conduct research for local producers. In the case of New Zealand, for example, apple growers and the government bounded together to form a marketing board for apples in 1948, with important benefits for New Zealand's producers (Welsh et al., 1999).

6.2.2 Technology and governance for apple production in Chile

Chile entered the international market for apples in the 1980s – although there had been attempts in the 1950s and 1960s, export volumes were modest - and had to catch up with an industry that has been renewing technologies since the beginning of the century. Apple production had been moving towards the technological paradigm of intensive agriculture at least 60 years before Chile started catching up after years of technological stagnation.

Chile entered the international apple market with production of existing apples varieties, developed by chance based on seedlings or in breeding programmes in leading apple producing countries. Chile adopted the technology of the leading countries, particularly the US. It was a 'free rider' on international fruit market developments. The main varieties exported by Chile between 1998 and 2009 were 'Granny Smith' and 'Royal Gala' (ASOEX, 2010).

The Chilean fruit sector had potential for growth after the emergent technological development in the 1950s-1960s - orchard development and distribution using refrigeration technology -, together with important changes in the structure of the sector after the Agrarian Reform. Between 1974 and 1981 external and internal factors favoured industry growth. There was important growth of demand in the northern hemisphere for fresh fruit and Chile had the advantage of counter season supply. Internal economic policy favoured exports and attracted foreign investment. The economic crisis of 1981-1982 in Chile made export orientation attractive for agriculture producers, especially when the exchange rate became highly convenient for exporters (see Ch.1). The industry developed under market rules, with some government support for the process of technological catching up (for example, training and technological missions organised by Fundación Chile). In the 1990s the industry benefited from incentives for technological development and associative R&D.

In the 2000s apple production in Chile had caught up technologically, but industry fitness for new technological challenges is not clear. In 2009, the fruit exporter's association (ASOEX, 2010) conducted a productivity evaluation of the main exported fruits. It concluded that Chilean apple production and productivity was comparable to those of its main competitors (US and New Zealand). The composition of apple exports has changed, with competing countries moving away from 'Granny Smith', for example. Access to new varieties is becoming increasingly problematic due to intellectual property rights (IPRs) issues. Chile introduced some technological innovations related to cultivation in the particular conditions of Chile, for example, exposure to sunlight resulting in fruit damage. Breeding programmes began in Chile in 2005; there are several initiatives competing for resources, but no long term commitment to any particular breeding programme.

6.3. Doctoral Graduates in the History of the Fruit Growing Field

This section examines possible careers for doctoral graduates in fruit farming in Chile; over time and within the historical context. The discussion relates individual experience to historical circumstances illustrating the analysis with examples, and analysing processes of capital accumulation within this field.

6.3.1 Few doctoral graduates, confined to work in universities: 1960s-1970s

The first generation of doctoral graduates specialised in agricultural subjects were working as academics in the 1960s. In the 1950s and 1960s Chilean universities had policies in place to send lecturers for doctoral studies abroad; before that time very few academics were doctoral graduates (see Ch. 4, Section 4.1). University lecturers were involved in revising study programmes and introducing specialist undergraduate areas (e.g., agrarian economics, livestock, orchards and soil, and plant technology). In the early 1960s, the universities reviewed their agricultural study programmes and there was general agreement about the courses that should be offered. In the context of ongoing Agrarian Reform, agrarian economics and the role of the state were at the centre of academic debate on the area of agriculture.

My search for doctoral graduates from the pre-1960s – extended to the 1960s to find active researchers – produced ten academics with traditional university careers, that is, they occupied an academic post, in the same university, throughout most of their careers. Their work focused on various proportions of teaching and research, and included managerial and/or administrative responsibilities in their universities. I did not construct case studies because none of these doctoral graduates had strong relations with the agricultural sector, although between 1990 and 2010 they were involved in teaching and/or research on fruit topics.

It is perhaps not surprising that so few doctoral graduates were involved in agriculture. The years of the Agrarian Reform and transition to the next epoch – 1960 to 1980 - were highly uncertain and not conducive to long term investment in technological developments. Most doctoral graduates were working in academia. The field of fruit faming was relatively marginal to the agriculture sector, and doctoral graduate involvement was too small for them to be considered a distinctive actor.

6.3.2 Positions in universities and research centres: 1980-1999

In this epoch export firms were the main governance agents, and technological change was based on transfer of standard technology. There is no evidence of research activity in the private sector during this period. Universities and public research institutes dominated the research scene and the employment of doctoral graduates.

Dr Chancellor and Dr Rice are examples of doctoral graduates in this epoch, who had university and public research institute careers respectively, and whose work was connected to the fruit sector. Dr Chancellor's worked on the structure and governance of the agriculture sector, particularly fruit farming. Dr Chancellor developed a strong interest in agrarian economics during his undergraduate study. His first job was for an NGO that supported small farmers following the Agrarian Reform. He worked for this organisation for a few years and: 'I got to know the farming structures very well and realized that, to make a contribution, I needed to study....I needed solid postgraduate study'. Although obtaining funding was difficult at that time (1976-1978), Dr Chancellor was awarded a scholarship funded by German aid, to do a doctorate in agrarian politics abroad. He studied Chilean agrarian development: 'It gave me a broad vision of the processes of agrarian development in Chile over those 28 years'. He completed his studies in 1982 and returned to Chile at a time of deep economic recession and more than 20% unemployment. However, Dr Chancellor was offered a job in a research institute associated with the public regional University of Talca (formerly a branch of the University of Chile, see Ch. 4):

> For six or seven years I could concentrate on studying agrarian phenomena in the most agricultural region in Chile... my research was focused ....I concentrated on trying to understand why some small farmers are successful and others are not... It gave me many scientific satisfactions; I had papers published in several international journals and made myself strong in the subject. I understood aspects related to agrarian policy and began to formulate policy recommendations.... I was keen to go further and to study the sociological side of the agricultural problem. I did a one and a half year post-doc in Germany to go deeper in the sociological aspects...I had the technical and the economic, but not the sociological expertise.

Dr Chancellor's career to the end of his post-doctoral position in 1990 can be interpreted as a period of accumulation of cultural capital. Dr Chancellor increased his cultural capital over the course of more than a decade by learning about agricultural phenomena and accumulating research experience and embodying knowledge in his subject. He collected data and published. He obtained his doctoral credential and cultivated a network of relations based on his work. He achieved peer recognition in his disciplinary field (his work was published and he obtained funding).

In 1990, his career took a different turn. He returned to Chile after his post-doc period, to a changed political scene: the period of dictatorship had ended and his university was holding elections. He was elected as Dean and then Chancellor, serving for three consecutive electoral periods from 1990 to 2006. Under his leadership, the university became an example of best practice. Dr Chancellor believed that: 'A university is good when it manages to attract and retain good academics'. The university stood out for its innovative approach and impressive results in national league tables. One of its distinctive achievements is that it combines high quality standards in higher education with regional relevance. The university achieved a leading position in teaching and research, particularly in areas related to agriculture, and housed specialised research centres, including the centre for the study of apples and pears (created in 1995) and the centre for grapes and wine technologies (created in 1996). The region of Talca is the main producer of apples and grapes in Chile.

In the period 1990 to 1999, Dr Chancellor's role in the field of fruit farming was related to championing a strategy which resulted in the university's leading position as a supplier of professionals and technological and scientific services to the fruit sector. Before 1990, its participation in the industry was confined mainly to the provision of technicians and professionals. From the mid 1990s, it became a supplier of science, technology and training. Its recognition and participation in the field resulted in university experts being invited to participate in meetings organised by the regional government on the development of the local industry. Dr Chancellor's role – as part of a collective action - had an impact on the structure of the field of fruit production, by raising new agents, and its governance, through the participation of these new agents in governance.

Dr Chancellor had entered a new arena, where his previous cultural capital was important (an influencing factor in his election and recognition), but where other forms of capital, for example, managerial and political, were valued also. The good performance of the University of Talca was seen as a measure of Dr Chancellor's managerial ability. Dr Chancellor assumed a public role through active involvement in governance of the higher education sector, for example, accreditation processes. He was active in representing his university's interests in policy discussions at regional and national level, in the areas of higher education, and regional and agricultural development. Over the years, he became a public figure – with a regular media presence – which endowed him with cultural capital, valued in the national policy field and the political arena, and which likely was instrumental in the roles he assumed in the following period.

Dr Rice had worked for the public agriculture research institute (INIA) for more than 30 years. He lived through changes to the research funding system and the increased importance of fruit farming in the agricultural sector. His case presents a perspective on adaptation to the rules that dominated in the agribusiness epoch. In 1978, soon after graduating, he went to work in one of INIA's regional branches. He accepted a stable and secure position as an agricultural engineer in the public service. For ten years, he worked on genetic improvements to rice –an important product for the region at the time. He did his doctoral degree on rice genetic improvements in the US between 1989 and 1993:

> The first thing I did when I came back in 1993 was to go to the central office in Santiago to thank the national director as was customary. The national director said: 'we are very happy that you have completed your degree, but – to be honest – the agricultural relevance of rice in Chile now is very low, there are not many resources for rice research let alone for rice improvements. What has potential in Chile is fruit. INIA is always been respectful of people, we do not want to push you, but if you think you could redirect your research to fruit improvement we would welcome this. Think about it'. To be honest I had always been interested in fruit farming, always.

Dr Rice moved to doing research on fruit[14]. He found that the work system had changed during his time abroad. He recalled that formerly INIA had relied on an annual budget from central government. As a researcher he had had his salary and a small amount for research resources (equivalent to less than four months' salary). On his return in 1993 the system was based on projects, and research institutes had to bid for funding from local and central government. Dr Rice's first projects in the new system were for local government:

> I remembered we were told there were resources to work in this rural location, home to small and poor farmers. There was 150 million pesos available as funding for projects with these producers. We submitted a project on cherries, but to be honest it was a disaster. There were many problems with the farmers, starting with indifference - we had to beg them to take part.... The project system required a joint venture with producers, you had to get the involvement of between five and ten interested producers and you would do the research and development component of the project using their land...Finding ten producers was madness, they were not interested, they made zero contribution, and we did everything....If there is one of those ten farmers still producing cherries today [more than ten years later] I would be surprised.

[14] In the 2000s rice has regained its importance in the region and in 2012 INIA had a programme in place for rice improvement.

Dr Rice worked on several different projects between 1993 and 2006, all fruit related. He followed INIA’s policy directions and complied with the funding bodies’ guidelines. He was critical of the project system’s bureaucracy and development strategy. For example, he would have liked to develop new fruit varieties for the region, but there was neither funding available nor interest in doing this.

During the 1980s and 1990s Dr Rice accumulated cultural capital and maintained his employment. Moving from rice to fruit research implied that some of his cultural capital related directly to rice was probably lost, for example, knowledge specific to rice, his network of scientific relations and objectified capital (books and materials). His doctoral credential (institutionalised cultural capital) was valued by his employer – considered in the formal evaluation process - and contributed to his job security. Also, the knowledge and experience embodied during his doctoral studies enhanced his ability to continue to learn. He was able to move to a different field, with an enthusiastic attitude and a disposition to learn. The change required time and effort and: ‘my colleagues said: ‘you are mad, how are you going to move from rice to fruit? You will have to start from zero, it will be too difficult’. To be honest, it did take two or three years, but you do get into the subject’. He learned to work within a project framework, to bid for funding and to ‘play’ by the new rules. He expressed his frustration and was critical of the project system after the results of the projects with small local producers and regional funding bodies.

6.3.3 Maintaining positions in the universities and the public sector: 2000-2011

In this last period, the number of doctoral graduates increased. The examples of recent doctoral careers are used to illustrate the greater diversity of career possibilities. Some of the features of the sector (e.g., research funding system, market driven governance) had become well established, and were the ‘rules of the game’ for new entrants.

At the time of the interviews, Dr Chancellor and Dr Rice were still working in the field. Dr Chancellor was University of Talca’s Chancellor from 2000 to 2006:

> One day in January I received a call from the President. She asked me to be a minister. Obviously one cannot sidestep service to one’s country. This was in 2006, I agreed to be Minister of Agriculture. I considered I had the technical and

> managerial competences, but not political ones; however, this was going to be a rather technical ministerial board...We proposed new topics for agriculture on the basis of theory and experience, and an understanding that agriculture does not always have to be the loser and that our farmers cannot be always crying. We can also have something powerful, like we did with the University [of Talca] by aiming to be the best public university in the country. Chilean agriculture could be transformed into a "food powerhouse" [*potencia alimentaria* in Spanish] based on innovation. This idea took hold: it has had many fathers and I was one of them....I implemented it as government policy.

Dr Chancellor worked towards positioning Chilean agriculture as a producer of Mediterranean dietary products (fruits and others) by exploiting the advantages of a Mediterranean climate - a rare world environment. This strategy implied producing more of those items that are more easily cultivated in Chile's agricultural conditions (e.g., various fruits) and abandoning competition with neighbouring countries for the production of other products (e.g., Argentina for wheat). Policies aimed directly at increasing fruit production included modernisation of small farms – representing an estimated 30% of agricultural land. One action was aimed at settling the financial debts of small farmers.

There was a ministerial reform which resulted in the appointment of ministers with political rather than technical profiles. Dr Chancellor was made Chilean ambassador to Germany, where he had had connections since his time as a doctoral student. As Chilean Ambassador, he focused on collaboration on science and technology topics, particularly programmes for exchanges and development of Chilean postgraduate education. Dr Chancellor was away from the University of Talca for four years, on public service leave as a minister and an ambassador. Four years is the period of an elected university chancellorship; on his return to Chile he was again voted in university chancellor.

In terms of cultural capital, Dr Chancellor had not been an active researcher in agriculture for 20 years. He commented that it was difficult to keep up with his scientific reading, but reflected also about how much he had learned about higher education. He has published on the role of public universities and related issues. Dr Chancellor's role as a player in the international discipline of agrarian economics, and his accumulated cultural and scientific capital in that field is historical. Over the past 20 years, he has accumulated capital in the field of higher education in Chile. He was conscious of his reputation and influence, and played active roles influencing higher education, governance of his fruit producing region, and governance of the agricultural sector.

The most recent period has seen changes to Dr Rice's work too. After 12 years of working on projects related to regional fruit production, in 2005 he participated in a proposal for a longer term, bigger project. The proposal was successful and the project has been led by a consortium of 29 partners, including the biggest fruit exporters,[15] and aimed at improving fruit varieties. Dr Rice's responsibility was research on apples. The project was funded by CORFO with contributions from participant organisations, and runs from 2007 to 2013.

Dr Rice said it had been strikingly different from his previous jobs. It was much more satisfactory to work in a five year project with private sector involvement; he liked the efficiency and pragmatism of the counterpart. The comparison made him reflect on the frustrations accumulated over previous years: 'I will retire in a few years; from 40 to 65, 25 years I had my doctoral degree. I was really effective [in using his researcher potential] for perhaps 15% of that time. There are so many ways that one could have contributed'. He felt differently about his current project:

> I am passionate about this topic, I love it. I feel sad that in five or eight years I probably will have to retire, there is so much one could do... I feel so passionate, I would like to improve other species because I think it is needed, but how do I convince people....When you work on improvement you see so much wasted potential....All apple varieties produced in Chile were introduced, they originated in environmental conditions totally different to ours in relation to sunshine, soil, rainfall... They do grow in Chile and that is great, but if you produce your fertilisation in Chile, your progeny in Chile...what you obtain will without doubt be better adapted to Chilean conditions.

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[15] Consorcio Tecnológico de la Fruta, www.consorciodelafruta.cl

Dr Rice commented on the big investment of public finance to fund doctoral studies and the waste when it was not used to its full potential. I did not expect such openness. Researchers are continuously exposed to evaluation: institutional systems, competitive funding systems and competition for positions in the relevant fields, which generally makes them focus of their achievements.

Dr Rice commented also on the contradictions in his institution's evaluation system, and the funding system based on collaboration with industry. INIA evaluation put great emphasis on publications in ISI journals and books, but collaborations with industry reduced the opportunities for publishing due, for example, to confidentiality and IPRs issues. He considered there was a lack of consideration of the differences amongst researchers related to their research subjects:

> EDI [the evaluation form] should be related to one's work. If you are an improver and need 25 years to get final results, your EDI should consider intermediate steps...One of my colleagues is a pathologist, he is lucky, insect reproduction happens instantly, whereas I have to wait 25 years to see my results [laughs]. It has happened that a farmer brings in a [damaged] plant, the colleagues identify the attacking insect, it happens to be unknown and they publish in an ISI journal...

Despite the problems, Dr Rice has accumulated cultural capital in fruit farming improvement research. He knows his region and has conducted several projects there. He sees the current consortium project as an opportunity to put his potential to work. Although genetic improvement to apples is a new topic for him, he has managed to learn and to insert himself in the specific technical field. His history as a researcher in a public institute has allowed him to accumulate social capital:

> When we started, I looked up on the internet who worked on apples in the world...The best active researchers in the US were around four. I wrote to them saying I worked in Chile for INIA, a public not-for-profit research institution. This opened many doors because if you mention a private institution they see it as competitor. I said I was preparing a technological visit and we started a relationship, we are in contact once or twice a month...If I need information I ask

> them. They had been working on apples for 40 years, whereas in Chile there is no one.

He organised technological missions to leading countries in apple production, for consortium members. He was able to meet his new international links– all university-based researchers. In a conversation about these technological missions, one of his US colleagues jokingly suggested they might more accurately be called ‘spy missions’. Probably Dr Rice should be referred to as Dr Apple at this new stage in his career.

6.3.4 Growth in doctoral graduates and slow emergence in the field: 2000-2011

A new generation of doctoral graduates has entered fruit farming since the 2000s. The cases of Dr Bio-fruit, Dra Berry, Dra Avocado, Dr Physiology, Dr Agro-economics and Dra Apple illustrate the diversity of doctoral graduates as actors in the field.

Dr Bio-fruit is a case of a doctoral graduate who was engaged in scientific research and moved to fruit farming, attracted by the research possibilities and funding opportunities in the sector. Dr Bio-fruit completed his doctoral degree in 1991 and has had a successful career in the natural sciences since then.

He did a three-year post-doc in the US, published and, in 1994, took an academic post in a big traditional university in Santiago. He remembers his university colleagues with gratitude, which contrasts with his recollections of the precarious economic conditions for doing research. When he started he had no laboratory or materials. He had some minimal ‘start up’ funding from a US institution to buy reactor materials and equipment. He was awarded a FONDECYT project as the result of a successful bid made while he was still in the US. He managed to set up a laboratory and take on teaching and research. He worked with peers and undergraduate students, publishing and presenting regularly at scientific conferences.

He was promoted up the university hierarchy, based on his publications and the quality of his research. ‘I was comfortable, even though the salary was modest’. Soon after he was promoted, he became interested in fruit related research:

> In 2001 or 2002 there were new calls for proposals [in Chile] to do research on fruit genomics. We got together to present a bid on genomics; we had no

> experience in the area, but had great enthusiasm and interest in doing it. We applied for and won the project. I was the senior in years and research experience, and was the director.
>
> I had to talk to people in the private sector, and in firms; because we needed partners who were producers...I had to face a world that was completely different from academia, and had to do with production issues. That gave a twist to what I had been doing. I did not stop my other work, I never stopped doing science, but I started getting involved with these projects...At the beginning it required huge effort getting people together who had never before agreed on these things.
>
> Fundación Chile had wanted to work on biotechnology with the Fruit Exporters Association before but they could not. The merit of this project was having, for the first time around the same table, the directors of Fundación Chile and the Fruit Exporters Association...more than differences between the institutions the leaders who sometimes had conflicting visions. We are talking about strong personalities.

Dr Bio-fruit learned about the funding system for applied science projects. He accumulated cultural capital to play in that arena by learning its rules and accumulating social capital (by working with producers and other industry organisations). He maintained his position in the scientific field by continuing to ‘do science’, and started building on applied sciences. His scientific capital was recognised by the funding agencies and was considered transposable, since he got funding initially based on his scientific career.

> This was a CORFO project, very different from FONDECYT...I learned a lot. I think that, because of that, in 2004, I was invited to be part of an advisory committee to the Ministry of Economy on the prospects for biotechnology in the fruit sector. There were five members [of this committee]... It was an enriching experience; it allowed me to air my views, to exchange opinions with people who had a different perspectives on science, it opened my horizons about what it meant to do research, and on doing research from the point of view of applications relevant to the country’s needs...how do we contribute to the

> country's development...I think that was the time when changes started for science in Chile. Science in Chile, particularly biology - where I am involved, I am very involved in basic, fundamental and emergent topics – started doing applied research, which was looked down by hard scientists.... to study plant growth, was seen almost as 'technology', but there are many underlying biological processes which it is important to understand....I think it was then that I started to get more involved in biotechnology.

By being invited to be a member of the advisory committee, Dr Bio-fruit was able to influence policy in the sector. His views of the role of science contrast with the historical origins of science in Chilean universities in the 1960s (see Ch. 4, Section 4.1), but is not surprising considering he that he studies for his undergraduate degree in the 1980s when science departments had withdrew from their social mission and were adapting to the new university conditions. The new funding for research, FONDECYT, favoured a traditional interpretation of basic science and science departments were in a comparative favourable position for competing based on credentials and publications.

Dr Bio-fruit promoted the idea of a doctoral programme on biotechnology, but could not find sufficient support in his university. He moved to a different university, and together with colleagues (some of whom had moved with him) founded a research centre for vegetable biotechnology and a doctoral programme. This was a 'risky step', but he considered that it had worked. He had been in his new university for six years and had participated in several projects; the doctoral programme had a respectable number of students. Dr Bio-fruit continued publishing and had occupied research management positions in the university.

Dr Bio-fruit built a strong position as a scientist in Chile and the international community during the 1990s. He accumulated cultural capital valued in the field of higher education in Chile, and in his scientific discipline. The scarce funding for research in Chile required him to be alert to opportunities. Dr Bio-fruit realised there were more funding opportunities for applied research and identified fruit genomics as an interesting area to develop. His cultural capital was partly transferred to this new field, the funding bodies 'gave points' for his previous trajectory –although it was not related to fruit research – and he managed to prepare a successful proposal. Dr Bio-fruit learned, and built a position in this new field. At national level, he received recognition from policy makers and was invited to discuss the future of fruit biotechnology. He had been careful to continue to maintain his position in the scientific field and to cultivate his cultural capital there: ‘my international colleagues did not mind whether I am in university A or B, for them it is the same’.

Dra Berry has been an academic all her working life, which started in 1988 on completion of her undergraduate studies. She joined the agricultural department of a big traditional university in Santiago. She taught (plant physiology and general fruit-culture) and did applied research; she was allocated production of berries as her research topic. She studied for her doctoral degree in the US between 2001 and 2004. The timing was fortuitous because it coincided with the boom in berry production in Chile. She reluctantly accepted a topic related to a particular berry variety, which ultimately was the most successful variety involved in the berries expansion in Chile:

> Coming back to the berries boom was a perfect match. I supported the development of the industry then and even up to now, by bringing in new techniques....In the first years I had those permanent support consultancy jobs, we did training for small producers, basic things but which had a great impact on the industry at the time...

When Dra Berry was studying for her doctoral degree, Chilean producers were organising technological missions to learn about berry production. The missions were funded by CORFO. Dra Berry already had a reputation in the area and she was studying in a leading berry producing region in the US, and was often asked to host Chilean producers, and invited to give seminars. By the time she went back to Chile she had strong links with the berry producers and funding bodies.

In 2010, Dra Berry was working part-time as a university academic and part time in a producer firm managing the R&D unit. She was running several projects funded by different bodies, and working with a team of students and researchers.

Dra Berry accumulated cultural capital in the 1990s, she worked on projects funded by FONDECYT and other agencies: ‘that is how researchers live in the university, we live from projects funded by the government or the private firms, and that is what you do, you prepare projects and present them to innovation funds’. Dra Berry published and did projects for the industry; therefore she had a position in the scientific field and in the industry.

Her period of doctoral studies accelerated the process of cultural capital accumulation. She embodied knowledge in her subject and has maintained active relations with producers and funding bodies. She is recognised as an expert in her subject and has been invited to participate in activities with the industrial and scientific communities.

Dr Physiology is an example of a doctoral graduate specialised in agricultural sciences who left the field. This case contrasts to the case of Dr Bio-fruit. Dr Physiology graduated as an agricultural engineer in 1995 and worked in Chile for four years in an international agricultural company. He was hired to create a new branch of this international firm, to bring genetic material to Chile, to test and eventually license and commercialise it and to collect the royalties. Through this job he met international geneticists and decided to continue studying. He managed to obtain funding and went to study with a renowned research group in the US:

> Physiology was what I liked, but when I was in the third year [2002] and it was clearer to me that I wanted to come back to Chile, I thought that as a physiologist here [in Chile] there was not much to do. Then I started in the area of innovation and entrepreneurship [as a doctoral student in the US], I enrolled for a minor in economics in the business school and got involved with the university business incubator...My doctoral thesis had a physiological part and chapters on economics, on how to apply the physiological research up to the stage of a business plan.

Dr Physiology returned to Chile in 2004 to set up a university business incubator in one of the big, traditional universities in Santiago. The incubator specialised in agribusiness, it had a partnership with the industry association and funding from CORFO. He worked there for four years and also engaged with the national association of business incubators, acting as its president. In parallel, he started his own entrepreneurial agricultural activities.

Over the years, his interests have moved from agriculture towards general application of innovation and entrepreneurship consultancy and training. In 2010 he was managing Fundación Chile’s innovation and marketing development. He began working in

Fundación Chile in 2009 to set up a project funded by CORFO to develop innovation and technology management. The project involved big companies, such as Metrogas and Arauco, and was aimed at helping them to implement innovation management processes. Having worked with different industries, he said: ‘It may be because I know agribusiness too well, I found it particularly difficult: dollar price, frost, weather, California and South Africa... Contingencies in other sectors are not as big as in agribusiness’.

Dr Physiology accumulated cultural capital in plant physiology and the economic area of agribusiness incubation. On completion of his doctoral studies, he took the path of agribusiness development in an academic setting. He had experience of starting up projects and businesses (simultaneously as a full time employee and an entrepreneur). His entrepreneurial ability was valued in several fields in addition to agriculture. He moved to a transversal industry activity (innovation management) where he approached his job anchored in academic knowledge ‘we designed innovation processes with the firms, but we had the advice of Berkeley University professors, basically, we did a methodology design’. Dr Physiology had made good use of his capital in other industries rather than in agriculture.

Dra Avocado works in a regional branch of INIA (in a different region to Dr Rice). Since she started at INIA in 2000 – as project professional – she was aware that to achieve the position as researcher in the institution she needed a doctoral degree and that to receive a good evaluation and keep her job she needed to publish and to win research funding.

Dra Avocado graduated as an agricultural engineer in 1999 and worked for a few months with the farmers’ association of Quillota and then for a privately-owned farm. She got to know local farmers and their work, but decided she wanted to do something different. She observed that the labour market for agricultural engineers had variable salaries and was not very secure.

She applied to a branch of INIA in the same region to participate in a four-year technology transfer project. Her job involved regular interchanges with local producers for training, technological transfer and diffusion activities. By the end of the project: ‘I realised I liked the institution, I liked the work. Therefore, I applied to a doctoral programme in Santiago and was accepted...The doctorate was an instrument to continue working in what I liked: research and technology transfer'.

She was awarded a scholarship from the government programme (CONICYT) and applied to INIA to express her interest in a career with the institution. She was hired as a researcher – INIA had funded researcher's studies in the past and having already obtained funding was a strong negotiating point. She completed her doctoral studies in 2008 and returned to work as an INIA researcher. In 2010 she was about to sign her first FONDECYT project as principal researcher.

Dra Avocado had worked on several projects in her area of interest - avocados and walnuts, the main products in her region. She has published and established international collaborations. She had been accumulating cultural capital and was achieving recognition in her specialism (e.g. her appointment principal researcher for a FONDECYT project).

Dra Apple is an example of a new entrant to the 2009 conditions for researchers in the field of fruit production in Chile. Dra Apple lived in the US for ten years, doing her doctoral studies and working for a big fruit producer company. She worked for the firm's product innovation area and managed several projects, some of which led to patents. Dra Apple wanted to return to Chile, to Talca, and in 2008 decided she could not wait longer.

She belongs to the second generation of agriculture engineering graduates of the University of Talca and did her undergraduate final project in the Centre for Apple Research. She contacted the Director about the possibility of a job and was offered a position based on 'soft money'; after 18 months she had been awarded funding for the next three years: 'the university does not give a penny to the centre, everyone working here except the director is paid by the centre with resources coming from projects with the industry and quality control services'. Dra Apple was proud of the centre's reputation and the facilities there. She valued the good relations between the centre and the industry: 'if producers are offered a new product, they ask 'has the Centre tried it yet' and they wait for the centre evaluation before buying it'. She considered the relation with producers as a two way interchange; the centre gave importance to 'giving something back' to the producers collaborating with them: 'we have an open seminar twice a month, free and well attended by producers and consultants, we have a 2000 email list...I came to work to a good place, I have everything I need and this meetings which provide regular contact with the industry'.

Dra Apple's cultural capital as an applied researcher is outstanding for the Chilean setting. Returning to Chile implied building a position for herself in the field as an applied researcher. In 2011 she was in the process of accumulating social capital within the local field, often recalling old relations. She was successfully learning to work with the funding system and combining academic and applied activities.

6.4. Doctoral Graduates' Practice in the Field of Fruit Growing

This section analyses the role of doctoral graduates as scientific suppliers in the field of fruit growing over time. The discussion is based on applying the theoretical model introduced in Chapter 2 as a tool to analyse the three-fold relation, supplier-producer-consumer, at a particular time. I examine the dynamic interchange between scientific suppliers (doctoral graduates) and the demand for their labour (Section 6.4.1) and between the scientific supplier and the suppliers of resources to them (Section 6.4.2). To conclude, Section 6.4.3 presents the implications for the organisational level. The analysis draws on the historical coevolution of technology and governance (Sections 6.1 and 6.2) and the effective capitals of doctoral graduates in the field of fruit growing over time (Section 6.3), I expand on the case studies for illustration.

6.4.1 Scientific supplier and the demand side

Doctoral graduates 'appeared' in the field of fruit farming in the last historical epoch of agribusiness - 1980-1999 (see Section 6.2). I had referred to their role in the industry as 'scientific suppliers'. The capabilities of scientific suppliers – at the level of individual workers offering their labour - are the product of a *three-fold dynamic social construction*: of a producer of work, a demand for labour, and a supply of services and resources required to produce the work.

Scientific suppliers may be hired directly by fruit producers, but often are employed by science and technology supplier organisations (research centres and universities). The theoretical model is represented by the 'capabilities schema', applied to the case of doctoral graduates as scientific suppliers to fruit producer firms, Figure 6.1, and doctoral graduates as scientific suppliers to research institutions, Figure 6.2.

Figure 6.1: Capabilities Schema for Scientific Supplier and Fruit Producer (Demand Side)

Actors	*Scientific Supplier*	*Fruit Producer*
Characteristics	**Scientific possibilities**	**Production possibilities**
Capabilities	**Scientific capabilities** S2 S2’ KE2	D2 D2’ **Production capabilities**
Rewards	**Earnings/Scientific Rewards**	**Profitability**

Source: Adapted from Von Tunzelmann (2009); and see Ch. 2 in this thesis.

Scientific suppliers enhance the production possibilities for fruit producer firms. Dra Berry, for example, as an expert in the production of berries, had given technological advice to producer firms. Her advice had an impact on the firm’s production possibilities (S2). The production capabilities of the producer employing Dra Berry complemented her advice; they could start producing a new berry variety or reducing fruit losses (D2). The producer derived profitability from Dra Berry’s labour and paid for her services (D2’). The benefits for Dra Berry (earnings, scientific rewards, others) were sufficiently attractive for her to take on the consultancy (S2’). The relation between Dra Berry and producers was dynamic; she gave consultancy advice in 2004 on a variety of berries being introduced in Chile in which producers needed to learn basic techniques. By 2010, these production techniques had diffused and she was working on a permanent contract with one big producer.

Demand for scientific suppliers’ labour come often from the universities and research institutes that supply science and technology based services to the fruit farming sector (see Figure 6.2).

Figure 6.2: Capabilities Schema for Scientific Supplier and Research Institution (Demand side)

Actors	*Scientific Supplier*	*Research Institution Sc and Tech Supplier*	*Fruit Producer*
Characteristics	**Scientific possibilities**	**Sc/Tech possibilities**	**Production possibilities**
Capabilities	S1 KE1 **Scientific capabilities** S1’	D1 S2 **Sc/Tech capabilities** D1’ S2’	KE2 D2 **Production capabilities** D2’
Rewards	**Earnings/Scientific Rewards**	**Profitability**	**Profitability**

Source: Adapted from Von Tunzelmann (2009); see also Ch. 2 in this thesis.

Universities and research institutes act as suppliers of science and technology to the field of fruit farming. They supply production possibilities to fruit producers (S2), for example, training and support in the introduction of a fruit or improvements to fruit quality (such as the projects to improve post-harvest fruit behaviour, conducted at the Apple Research Centre). Fruit producers’ demand for production possibilities (D2) is based on their production capabilities and their expectation of higher profitability from enhanced production possibilities. Fruit producers pay for the service (D2’) to the research institution (science and technology supplier).

The research institution hires the scientific supplier on the basis of his or her offer of science and technology possibilities (S1), the employer’s internal science and technology capabilities constitute demand for the scientific supplier (D1) and the employer’s expected profitability, which translates into the salary payment and offer of a work contract to the scientific supplier (D1’). In the case of Dra Berry, the university decided in 1994 that her research topic should be berries; the university demanded science and technology possibilities in production of berries (D1). She developed her scientific supplier offer (S1) by increasing her cultural capital in the subject: she studied for and obtained her doctoral credential, accumulated embodied scientific and technological knowledge, and developed strong relations with producers, scientists and funders. Her scientific supply satisfied her university employer. She obtained funding and successfully developed several research projects, which had a positive impact on the profitability of the university and resulted in them maintaining and improving her contract conditions (D1’). Dra Berry’s scientific supply changed between 1994 and 2010; providing increased benefits for her employer and allowing her continuity in salary earnings, promotions and other rewards that she valued (S1’).

Dra Apple was hired by the University of Talca Apple Research Centre on the basis of her accumulated cultural capital in apple production. She could supply science and technology possibilities (S1) and satisfied the research centre’s demands (D1). The research centre had lost an expert in post- harvest processes and Dra Apple replaced her. The research centre offered her a contract (D1’) based on expected profitability.

The research centre is mostly self-funded and depends on bids for research projects and sales of applied technology services. Their offer was one year part-time salary based on a flexible contract and expectation that she would win external funding to cover the costs of her continued employment in the centre. Dra Apple’s efficiency impacted her valorisation of earnings and other rewards (S1’). She was confident on rising funding and accepted a ‘soft money’ contract that allowed her to return to Talca to do applied research, something she deeply wanted. Dra Apple’s accumulated cultural capital made her a technically strong scientific supplier; however, in 2009 it was difficult to obtain long term academic contracts and flexible services contracts had become common.

Doctoral graduates acting as scientific suppliers for fruit farming tend to be concentrated in universities and research institutes (science and technology suppliers). Demand for their services tends not to come from producer firms directly, neither from other science and technology suppliers. Universities and research institutes fund their research activities on the basis of project contracts. Most of their funding is awarded through competitive schemes called by public agencies, many of which require contributions from the private sector, particularly producers. Dr Bio-fruit, for example, had to find a partner for starting his research on fruit genomics:

> We wanted to work on genomics because it is an emerging topic; the limitation was that it has to be on species of productive relevance. We identified a problem, nectarines post-harvest...we knew it was important for the industry. We presented the proposal to them [the Fruit Exporters Association]. They did not

understood much but they knew it was a boat they had to jump into, it was rather intuitive at the beginning.

6.4.2 Scientific suppliers and the supply side

The relation between scientific suppliers and technology suppliers is represented by the capabilities schema in Figure 6.3. The scientific possibilities of doctoral graduates are based on their scientific capabilities and the scientific and technological capabilities of their suppliers. They depend on the provision of their suppliers to do their work.

Figure 6.3: Capabilities Schema for Scientific Supplier and Technology Supplier

Actors	*Technology Supplier*	*Scientific Supplier*
Characteristics	**S&T possibilities**	**Scientific possibilities**
Capabilities	S1 KE1 **Technological capabilities** S1’	D1 **Scientific capabilities** D1’
Rewards	**Profitability**	**Earnings/Scientific Rewards**

Source: Adapted from Von Tunzelmann (2009); see also Ch. 2 in this thesis.

A scientific supplier may have several different providers. Figure 6.3 represents the relation with one of them, a science and technology supplier, and could be replicated for other types. As discussed in Chapter 5, Section 5.4.2, there are different kinds of science and technology suppliers (e.g., external or internal to the scientific supplier’s organisations).

Scientific journals are an example of a common external technology supply mentioned in the case studies. Doctoral graduates selected and read specialised journals and made use of what they had read in their job. Their technological/consumer capability implied that they demanded journal articles (D1) and allocated resources to pay for subscriptions if they considered access to journals could improve their work performance (D1’). In most cases, individual subscriptions were unnecessary because their organisation (university or research centre) provided them access, nevertheless they mentioned that provision as an important asset for their work performance. There were differences by institutions; the wealthier ones had more subscriptions and better access to journals for researchers. Access to journal articles had an impact on the scientific possibilities of doctoral graduates (S1) and the profitability of providers (S1'). The process involved ongoing exchange among the actors, for example, doctoral graduates talked to colleagues about their scientific readings or contacted authors and exchanged papers (KE1).

Internal science and technology suppliers - for example, colleagues - may provide scientific suppliers with inputs and, also, demand services from them. In the case of Dra Apple, internal technology suppliers were important in her decision to work at the Apple Research Centre. There she had access to what she considered were excellent laboratory facilities, support from trained laboratory colleagues (students, technicians and professionals), and a permanent supply of research samples (apples).

Accumulation occurs at different rates depending on the intensity of the process, but time is crucial when dealing with learning processes. It is possible to observe the dynamics of learning and accumulation by scientific supplier (depicted in the capabilities schema) from 1990; the dynamics are even clearer from 2000. Doctoral graduates as scientific suppliers had a role in transferring and adapting international technology for fruit farming (introduction of new varieties and production improvements) and had developed capabilities related to this role.

However, the period where the capability learning and accumulation dynamic can be observed is relatively short (starting in the 1990s), especially considering seasonal harvesting patterns and fruit growing periods. This is not to imply that there was no doctoral activity in the field before, there are exceptional examples: the director of the Apple Research Centre was recognised by the industry association in 2009 for his 27 years of research on apple production. There were consultants giving technological advice to producers, although most were agricultural engineers, not doctoral graduates.

It seems that scientific capabilities, based on research routines, had a limited development before 1990 and have increased in the first decade of 2000. However, scientific suppliers are concentrated in research institutions, and are depending on competitive funding with an important public component, which implies fragile working conditions.

6.4.3 Organisational level

The fruit producer firm is at the centre of the capabilities schema in Figure 6.4, facing the fruit consumer on one side and the science and technology supplier on the other. This particular supplier – among many serving the fruit industry- is the one I considered would be most likely to employ doctoral graduates. Firm capabilities are the result of the joint efforts and capital of different agents in the organisational field, as discussed in Chapter 2.

Figure 6.4: Capabilities Schema for the Fruit Producer Firm

Actors	*Science and Technology Supplier*	*Fruit Producer*	*Fruit Consumer*
Characteristics	**Sc/Tech possibilities**	**Production possibilities**	**Product possibilities**
Capabilities	S2 **Sc/Tech capabilities** S2’	KE2 D2 **Production capabilities** D2’ S3 S3’	KE3 D3 **Consumer capabilities** D3’
Rewards	**Profitability/IPRs**	**Profitability**	**Utility**

Source: Adapted from Von Tunzelmann (2009); see also Ch. in this thesis.

The product possibilities for the fruit consumer are based on the producer’s capabilities, which shape the supply of the product (S3) and the consumption capabilities of the fruit consumer, which define a demand (D3). The efficiency of the fruit producer firm defines its costs and its profitability (S3’). The price paid by the consumer to the producer (D3’) also defines the producer’s profitability.

Fruit producer firms demonstrated producer capabilities to demand production possibilities (D2) and valued and paid for the services of scientific suppliers and science and technology suppliers, particularly research institutions (D2’). However, that demand seems often to have been coupled to public funding subsidies in the form of reduced taxes and direct contributions to research projects selected through competitive schemes. Science and technology suppliers (institutions) and scientific suppliers (individuals) depend on competitive public funding to a great extent; therefore, public agencies play an active role in engaging producers in collaborative research projects.

6.5 Conclusion: Patterns of Capability Accumulation

Sections 6.1 and 6.2 presented a historical perspective on the field of fruit growing in Chile, focused on the coevolution of systems of technology and governance. Section 6.3 located doctoral graduates in the history of the field by examining the forms of capital at play in their dynamic relationship with the field. Section 6.4 analysed the practice of doctoral graduates within the field as scientific suppliers, examining their relations with demand for their services and technological suppliers relevant to their work.

The participation of doctoral graduates in this SLS has been for most of the history of the field confined to universities and research centres. The fruit experts recognised by the SLS, for example, the Director or Talca's pome fruit centre, started to work in fruit production in the early 1980s; and INIA oriented research to fruit in the late 1980s. Scientific suppliers had developed after the development of the industry, following its growth.

Chile's fruit expansion and technological catching up joined in a mature international industry in terms of dominant technology and governance systems. In the 1980s, international production of apples, for example, had been improving for 60 years in the paradigm of intensive cultivars. In the 1980s, profits were high and there was a wide technological gap to cover, but most of the effort consisted of minor adaptations to local conditions (e.g., of techniques related to irrigation, debugging and quality control of final products). Big producers had governance systems in place to establish international prices and to coordinate national producers' actions.

The Chilean fruit SLS history resonates with Viotti's (2003: 17) observation that: 'mature technologies [for an industrialising country new to the industry] are mostly a dead end for active learning'. In a context of open, liberalised markets, competence could be expected to be based on price. Investors in the 1980s probably did not have time for long term investment (it was a period of recession). The safest option for them was to acquire already proven technologies and compete based on cheap labour and favourable geographic and climate conditions. This strategy favours passive learning and spurious competitiveness.

Scientific suppliers emerged first in the SLS in the 1990s and in a more pronounced way in the 2000s, supported by subsidies to demand. There was a dynamic of capability accumulation which - after some 15 years - implies some level of scientific capacity in the SLS, but dependence on subsidies did not seem to decrease. In the dynamic capability logic, subsidies could be superfluous to sustain the dynamic when producer's capabilities develop and are able to generate demand for product possibilities (D1) which the producer can translate into profitability and valorisation of supply (D1'). Fruit producers are working with low margins in the oligopolistic structure of the SLS dominated by distribution firms.

There seems to be a loop of subsidy dependence. On the effects of the subsidy to scientific suppliers, they transcend the SLS, because they have effects in higher education and the general scientific field. Policy is said to be directed to innovation in the SLS, but a very important consequence is related to real research opportunities for the scientific field. This outcome would be defended by several agents since there is no alternative for the development of the scientific field. These issues are explored further in the comparative analysis in Chapter 8.

CHAPTER 7. Salmon Farming

The aim of this chapter is to relate the history of the salmon industry to the experience of doctoral graduates in the field. The chapter follows the organisation of Chapters 5 and 6. It starts by mapping the field through a historical overview of the salmon industry from the perspective of the coevolution of governance and technology, then locates individual experience within this field through case-studies used to illustrate the analysis, finally, analysing practice in the field and its effects on capability accumulation at the individual level.

7.1. History of Salmon Farming in Chile

Salmon is not a native species of Chile, but the country's natural conditions are appropriate for salmon. Salmon farming has expanded rapidly in Chile and worldwide, since the 1980s. From 1992 to 2008 Chile was the second largest producer and exporter of farmed salmon in the world after Norway. The industry has contributed to economic growth and development of the poor coastal regions of Southern Chile. Up to 2006, the case of salmon in Chile was presented as a success story (Achurra, 1995; Montero, 2004; Maggi, 2006; Iizuka, 2007; Knapp et al., 2007). In 2007 the industry was devastated by a sanitary crisis, which resulted in production decreasing to less than a third of its previous levels with dramatic socioeconomic effects (Iizuka and Katz, 2011). The focus of recent research has been on understanding and explaining the crisis and its aftermath (Roa, 2009, 2011; Iizuka and Katz, 2011; Katz et al., 2011). The crisis was followed by a policy review and launching of a new regulatory framework. This section describes the historical process of Chile's construction of its important position in the international industry up to 2007.

This broad historical perspective makes the simplification of considering salmon as a general category. There are many salmon species (within all salmon and salmon trout) and several are cultivated for commercial purposes worldwide. In this thesis 'salmon' refers to all the species of salmon and salmon trout.

The Chilean salmon farming industry is concentrated in the Los Lagos region, approximately 1,000 kilometres south of Santiago, Chile's capital city. A majority of 85% of salmon was produced in a 200 km^2 area (part of the districts of Llanquihue and

Chiloé) of the Los Lagos coast in 2006, providing more than 40,000 direct and indirect jobs (Maggi, 2006). The total population of the salmon districts (Llanquihue and Chiloé) was 460,000 in 2002, which includes the capital city of Los Lagos region, Puerto Montt, accounting for 176,000 (INE, 2003).The region's economic activity is based on agriculture, forestry, fishing and aquaculture. The most favourable natural conditions for salmon farming are in the coastal areas of the Los Lagos region and two other more southerly regions. Among these, Los Lagos has the best provision of services and infrastructure.

The development of salmon farming and demand for fresh fish from high income countries caused the impressive expansion in the world market for salmon from the 1980s. There was a market for salmon before the development of the farming industry, the market for wild salmon fished off the coasts of North America, Russia and Japan (Knapp et al., 2007). Wild salmon has been fished for human consumption for centuries, but its domestication is a relatively new aquaculture achievement. Commercial salmon farming began only in the 1960s.

Although the salmon farming industry has shown impressive growth and it is important to those making a living from the activity, it is only a small part of worldwide aquaculture. Aquaculture is the fastest growing food source in the world and occurs primarily in Asia's inland waters; 47% of world fish consumption – of which salmon represents a minority - is produced by aquaculture (FAO, 2010). Several species of fresh water fish have been farmed in ponds and lakes for centuries in Asia, where the activity was traditionally small scale, non commercial and family based. China's aquaculture production in tons (consisting of fresh water, inland farmed fish) in 2010 was 14 times that of Norway and Chile combined (FAO, 2012).

The historical analysis of Chile's salmon farming industry identifies one epoch starting in 1980. This epoch is still unfolding in 2012 because the dominant systems of technology and governance have remained in place. Based on the availability of information, in this thesis, this epoch is investigated and analysed between 1980 and 2007 – the year of the sanitary crisis in the salmon farming industry in Chile. Since a market for salmon already existed, salmon farming can be considered an 'industrial technological revolution' in that it represented a radical change to the industry processes upstream of the consumer market. The Chilean salmon farming industry developed within the revolutionary technological system which became commercially available in the 1970s and was diffused worldwide during the 1980s and 1990s. The dominant system of governance of the industry was international markets and networks. Table 7.1 provides an overview of the main characteristics of the Chilean salmon farming industry. The succeeding description of the industry's history expands on the characteristics presented in Table 7.1.

Table 7.1: Characteristics of Salmon Farming in Chile

Approximate dates	1980-2007
Location of leaders	Scotland, Norway, Canada, US, Chile, Japan
Role of Chile internationally	Rapid expansion, ranked 2nd for world production since 1992
Chilean strategy 'Salmon for the country'	Export diversification; economic growth for a poor region
Demand	Increased demand for fish from the northern hemisphere (Japan, US, Europe)
Technology leaders	Multinationals (Canada, Scotland, Norway)
Technologies	Standard, to be bought and transferred (equipment, genetic material, production systems); needs adaptation and to improve productivity in local conditions, biotechnology, environmental solutions, distant control.
Automation	of transformation
Process Type	Capital; information and knowledge
Size of firm	Initially SME, increasing domination by big producer firms from the 1990s.
Advantages	Geographical conditions, cheap labour, availability of fishmeal for feed, favourable regulatory conditions, little pressure from environmental groups.
Organisation	Entrepreneurial; integrated
Industry structure	Increasingly oligopolistic (concentrated)
Type of Capitalism	Entrepreneurial; managerial
Property	National and international (increasingly international)
Mode of governance	International market, networks
Power	Capital; knowledge
Skills	Professional; specialist/expert
Education	Massification of higher education; foundation of postgraduate system
Governance actors	Large international and national players; few small firms, producers' association
Associated infrastructure	Ports, roads, bio-technology

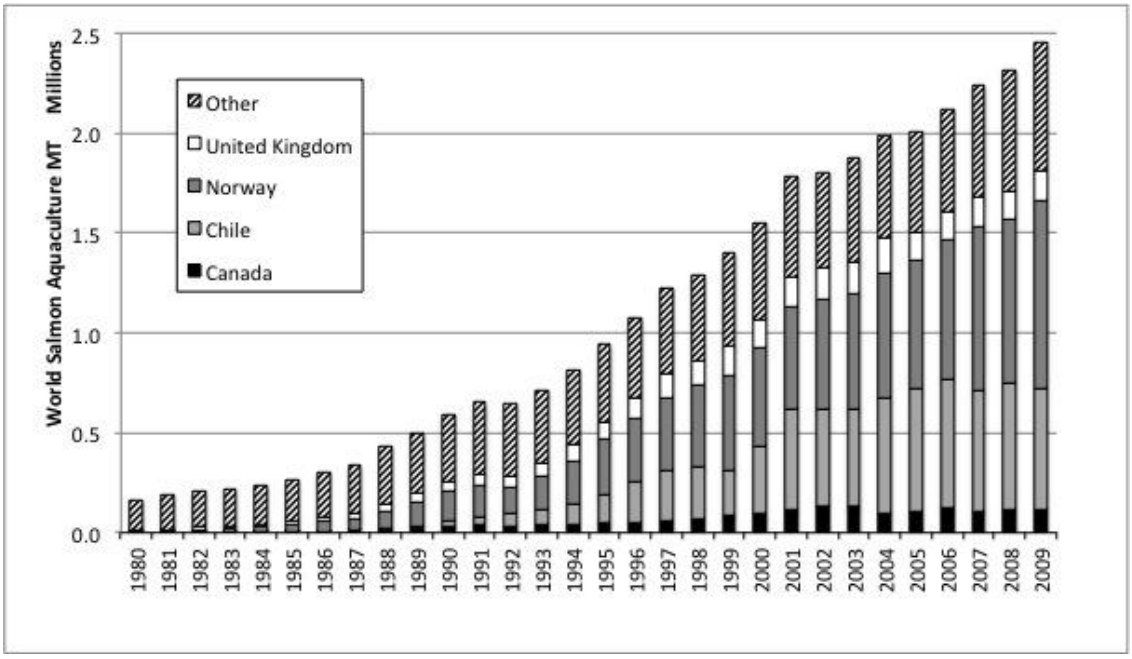
Source: Author's elaboration based on von Tunzelmann (2003) and multiple sources.

7.1.1 Technology and the leader producing countries

Salmon culture technology developed around two different technological problems. The first was reproduction and initial growth of the fish in protected (from predators and other natural risks) conditions. The processes of fertilization, reproduction and growth to the small fish stage correspond to the 'hatchery' technology. It recreates the freshwater phase of the salmon life cycle. The second challenge was to rear salmon in captivity to 'adult' weights; the stage of 'ranching' that usually is accommodated in net cages in the sea supported by floating structures. Growing salmon in captivity from reproduction to harvest – through hatchery and ranching – constitutes salmon farming.

The technology of salmon farming is relatively recent, although the origins of the industry can be traced back to the 18th century (Knapp et al., 2007). Domestication of salmon species for commercial culture has been credited to the Norwegians who established the first commercial farms in the 1960s (Knapp et al., 2007; Iizuka, 2007). Since then, production of farmed salmon has expanded significantly. In 1979 there were emerging industries in Norway, Scotland, Japan, the US, Canada and Chile, which were the industry leaders. Some were still important players in 2006 (see Figure 7.1). Chile has been ranked second after Norway, for production and exports of farmed salmon since 1992.

Figure 7.1: World Production of Farmed Salmon (1980-2009)



Source: Author's elaboration of FAO (2012) data.

7.1.2 Technology and origins of the industry

The origins of salmon farming can be traced back to the first fertilisation trials, conducted in Germany in 1763 and refined by several European countries (Knapp et al., 2007). By the mid-19th century, the technology for artificial insemination and egg incubation was well known in Europe and North America. It was developed in the wake of concern over the decline in wild salmon stocks and interest in introducing salmon to new locations. In the US, early aquaculture entrepreneurs lobbied for state support and by the end of the 19th century there were US federal research programmes in hatchery and fisheries. Fledgling aquaculture development in the US was followed in the 1920s by active programmes of education and research, including the opening of the University of Washington College of Fisheries, and a laboratory for salmon propagation at Stanford University. Fishery programmes began to be developed at several universities, and hatchery programmes expanded. In the 1950s, research on fish nutrition (for trout, a salmon species) was undertaken in several universities, hatcheries and a few government laboratories (Parker, 1989).

Wealthy Chilean families were keen to populate the rivers running through their large haciendas with salmon for recreational fishing. Salmon were introduced into Chile around 1880 and in 1905, the first eggs were imported successfully from Germany to boost the populations in Chile’s rivers. From then until the 1960s the Chilean government had programmes in place for the introduction of salmon to develop tourism (Bravo and Escobar, 2003). In the 1950s and 1960s, the US, Canada, Japan and the USSR – all involved in wild salmon fishing – implemented national programmes to increase salmon numbers through release to the sea of small fry produced in hatcheries (Knapp et al., 2007).

Salmon farming is a relatively inexpensive and easily replicable technology. Hatchery technology is more complex than ranching technology, but was available and widespread – although there was scope for improvement for farming purposes. The issues related to the ranching stage include identifying the right environment (temperature, sea currents, etc.) for fish life and growth, and managing the process to make it commercially feasible. The success of commercial production in Norway was paralleled by experimental developments in Scotland in 1966 and in Ireland, Canada and the US in the early 1970s. These early developments demonstrated the importance of a national infrastructure and national regulations for exploiting the sea. The industry makes extensive use of roads and ports; the well developed infrastructure of the Norwegian coast was a major benefit for the development of the industry in that country (Knapp et al., 2007). Governments licensed the use of coastal seas, creating distinctive national conditions for the development of the industry. For example, in the 1970s, Norway had a limitation on farm size per owner in order to avoid concentration, but in Scotland farm size was less restricted. The restrictions in Norway drove investment and expansion overseas (Knapp et al., 2007). The emerging international industry since 1979 included several countries (Scotland, US, Canada, Japan and Chile) and commercial production for export.

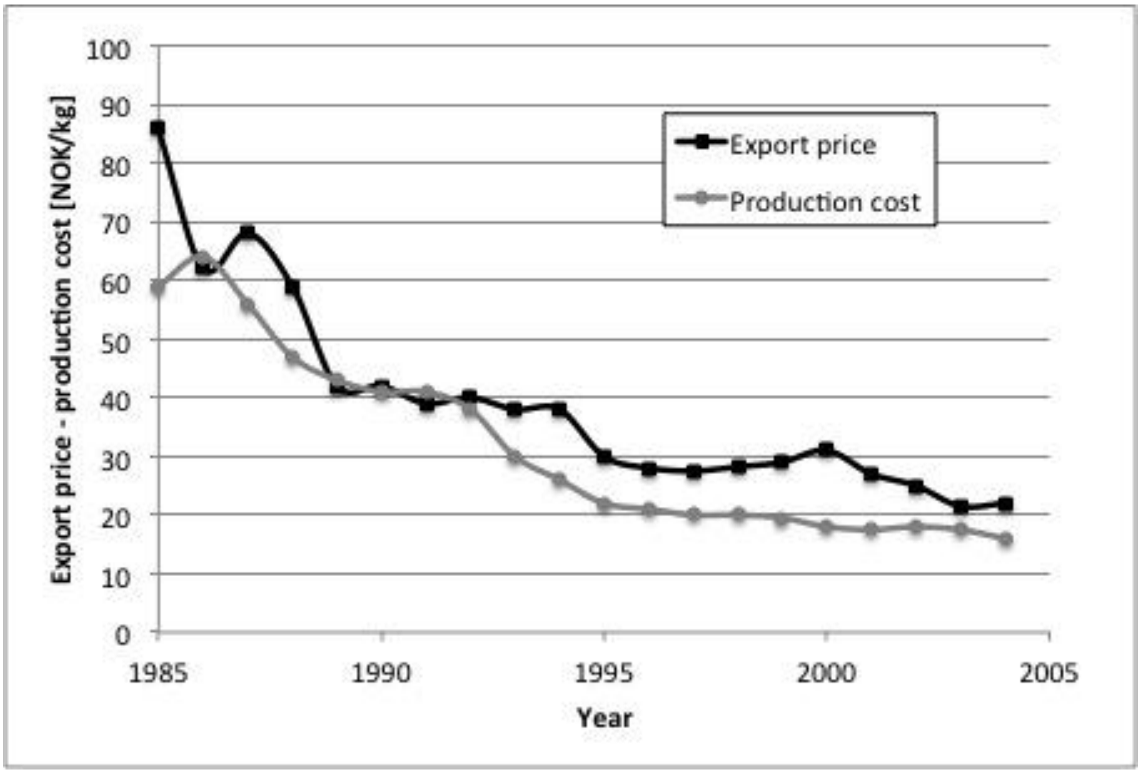
The Chilean government implemented a regional programme to survey sites with geographical conditions conducive to aquaculture and commissioned a series of studies on the feasibility of salmon farming. The programme was in place between 1968 and 1972 with the participation of various government organisations and public institutes, particularly CORFO, regional governments, the Agriculture and Livestock Service (SAG) and the Institute for Fishery Development (IFOP) (Bravo and Escobar, 2003; Iizuka, 2007). In 1972 Chile signed a cooperation agreement with Japan for production of salmon species in Chile's southern regions; however, the project did not reach the commercial stage. The first successful commercial firms were established in 1974, supported by government funding, and the first exports to Europe were in 1978 (Iizuka, 2007). Chile was a low income country, and economic growth was a continuing government priority – a developmental target maintained over Chilean history. Aquaculture represented an opportunity to develop a new industry in regions with very low economic activity.

Governance and origins of the industry

National governments played important roles in the beginnings of the salmon farming industry worldwide. However, since 1979, industry growth has been governed primarily by international markets, with government programmes to foster the industry varying across countries. Networks of producers and suppliers played a role in industry governance. In the case of Chile, in 1979 two private firms, Nichiro Chile and Mytilus SA, started activities, followed in 1981 by Salmones Antártica - owned by Fundación Chile (Bravo and Escobar, 203; Iizuka, 2007). Fundación Chile, founded in 1976, is a private not-for-profit organisation owned by the Chilean government and the American company ITT, dedicated to transferring technologies to develop the Chilean economy. Fundación Chile operated Salmones Antártica as a demonstration plant and established a centre to provide services to the local industry which worked in collaboration with local governments. Both the demonstration firm and the technological services centre are considered to have been crucial for the expansion of the industry (Maggi, 2006; Iizuka, 2007).

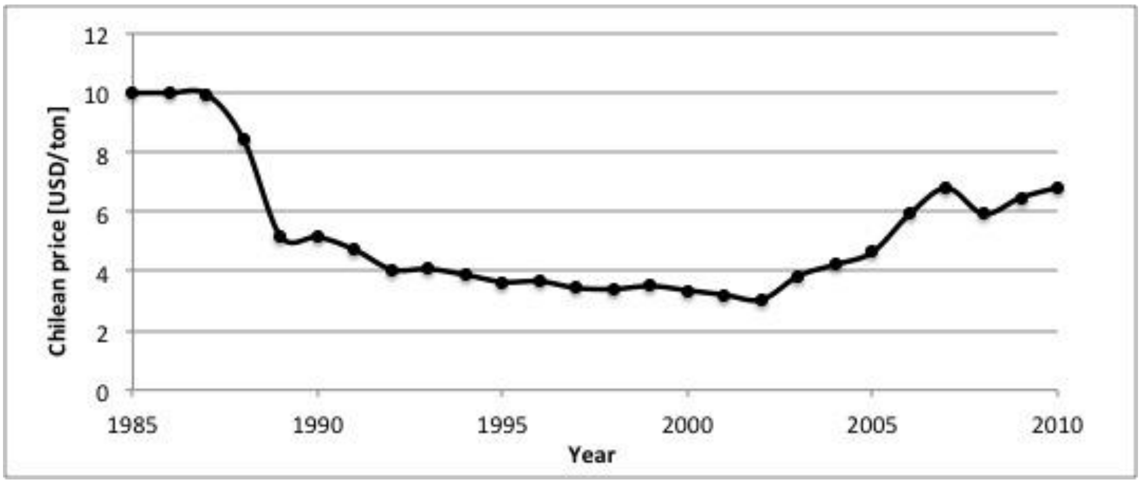
In the 1980s, investing in salmon farming - in Chile and worldwide - was an attractive business for national and international firms and entrepreneurs. International salmon prices and profits were high. Leading firms in salmon markets – from Norway to Scotland, to the US and Japan - were looking for new investment opportunities. They had experienced the effects of salmon farming regulation, for example, sea site restrictions in Norway. Also, the constraints on salmon fishing were increasing, which was leading countries fishing wild salmon, such as Japan, to consider investing in salmon farming (Knapp et al., 2007). Chile offered suitable locations (already surveyed and with information readily available to investors), cheap labour, access to fishmeal for feed, and comparatively business-friendly regulation. To demonstrate the attractiveness of this industry for investors in the 1980s, Figures 7.2 and 7.3 show the evolution of prices for Norwegian and Chilean salmon from the 1980s to 2004; although not directly comparable, they show similar trends. In the case of Norway (Figure 7.2), the evolution of production costs gives an idea of the industry profit. In the 1980s, Norway was used as a reference for investment decisions; on Chile, not much information was available. The evolution of prices and costs in the 1990s and 2000s is discussed later in this section.

Figure 7.2: Export Price and Production Cost of Norwegian Farmed Salmon (1985 - 2004)



Source: Knapp et al. (2007: 61)

Figure 7.3: Export Price of Chilean Farmed Salmon (1985 – 2010)



Source: Author's elaboration of FAO (2012) data

In the 1980s, the Chilean industry was populated by SME, mostly national companies (Maggi, 2006; Iizuka, 2007). The industry association, Salmon Chile, was created in 1986 as an initiative involving over half of the existing Chilean firms (El Llanquihue, 2003; Iizuka, 2007). These firms were similar in terms of their position in the industry (there were no dominant players) and had similar problems, for example, accessing international markets traditionally supplied by northern hemisphere producers. Network collaboration was an important feature of the Chilean industry governance mode (Maggi, 2006).

Demand and consumers

The impressive growth of the salmon market can be explained on the one side by the emergence of new producers –new salmon farmers - who offered new product possibilities –stable and abundant supply of fish. On the other side, the habits of consumers in high income countries were changing; they were showing preferences for healthier diets and higher consumption of fresh fish (Knapp et al., 2007) and fresh fruits (see Chapter 6). The volume of salmon products in the market grew impressively from the 1980s (see Figure 7.1), wild salmon capture was showing minor fluctuations (see Figure 7.4) and prices had fallen (Figures 7.2 and 7.3). Most international production of farmed salmon was being consumed by the populations of the European Union countries, the US and Japan, where demand was for fresh and frozen salmon. Knapp et al. (2007) estimated that 85% of world farmed salmon production went to those three consumer markets between 2000 and 2004. Salmon was consumed mostly by high income countries.

Chile is the only important salmon producing country without a significant local market (internal or proximate). Between 2001 and 2004 all Canadian production went to the US market, all Japanese production was consumed in Japan, and most Norwegian production was consumed in the European Union (Knapp et al., 2007). Chile's exports of salmon have diversified slightly since the 1980s following several efforts to avoid excessive dependence on one market. Originally production went to Japan (almost exclusively) and the US. Both countries continued to be the main importers of Chilean production, accounting for 82% in 2003 (Iizuka, 2007) (8% went to the EU, 6% to Latin America and 4% to other countries) (Iizuka, 2007).

Chile is a small market; among its 17 million inhabitants only a very few are high income consumers. Salmon is not part of the Chilean diet (I ate more salmon in a year, living as a student in England in a low income category, than living as a professional in Chile, on a salary that placed me among the 20% richest consumers in the country because of Chile's skewed income distribution). Chile's distance from its consumer markets had obvious consequences for transport costs, and involved some differences in the configuration of the actors shaping the dynamics of the industry. The distance from consumer markets implied greater efforts to obtain market knowledge and maintain market position, both drivers of collective action in the form, for example, of associated market research and marketing projects to establish Chilean salmon as a well known brand (Maggi, 2006; Iizuka, 2007).

7.1.5 Industry growth and productivity challenges

Salmon farming was established as a commercial international industry in the 1980s and 1990s (Knapp et al., 2007). In the 1980s, profits from the industry were high (see Figure 7.2), and there was room for 'mistakes', including high mortality rates among the fish, and low efficiency of producers. By 1985, industry processes were improving as was access to international markets. The industry association, Salmon Chile, and Fundación Chile were participating in several projects for process improvements through experimentation, and trial and error methods (El Llanquihue, 2003; Iizuka, 2007). One of the achievements in this period was local development of egg production technology in the 1990s. Previously eggs had to be imported and dependence on international suppliers was considered an important weakness of the industry (Maggi, 2006; Iizuka, 2007).

In 1991 and 1992 the pressure to increase productivity grew because of a decline in the price of salmon (see Figures 7.2 and 7.3). These were difficult years for salmon producers worldwide, and many did not survive the price drops. Knapp et al. (2007) consider that rapid growth in production and oversupply in the market were responsible for the lower prices and pressure to reduce production costs: in other words, the price crisis was caused by the industry's success. Following this crisis the industry moved towards a networked structure (outsourcing and developing industry suppliers), international firms invested in several different countries, and the industry was concentrated in a smaller number of producers worldwide (Knapp et al., 2007). In the case of Chile, foreign investment increased in the early 1990s. This was followed by several processes of mergers and acquisitions (Maggi, 2006). The industry became more concentrated, and in 2004 presented an oligopolistic structure (Iizuka, 2007).

Process improvements in the 1990s were impressive and applied to most production routines. This was reflected in the continued decrease in production costs and increase in production volumes despite the fall in salmon prices (see Figures 7.1 and 7.2). In Chile salmon production offered wide scope for improvements and the industry changed its practices related to broodstock (mature fish used for reproduction) management, feeding, disease control, cage construction, stock management, etc. (Maggi, 2006; Iizuka, 2007; Knapp et al., 2007; El Llanquihue, 2003). Salmon farming involves managing animal biology in its particular immediate environment; there was breadth for learning about adaptation of different salmon species to Chilean conditions. There was scope also for improvements to the initial technology, for example, management of broodstock to produce eggs for hatcheries destined to release to the sea differed from the characteristics required for hatcheries destined to be farmed.

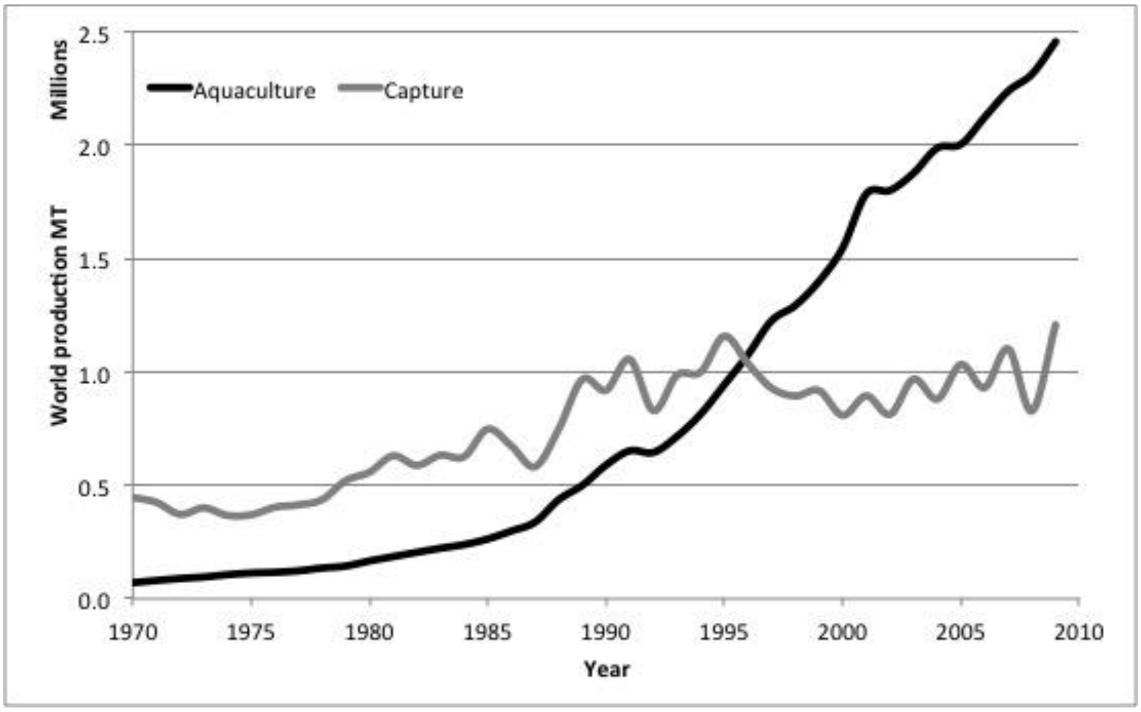
Productivity has improved over the years through the resolution of some of the most pressing problems related to cost reductions under global quality standards. There has been, for example, huge improvements in feed, which is the largest item in production costs, estimated to constitute over 60% (Knapp et al., 2007, Iizuka, 2007). Data for Norway show that in 1980, 1 kg of farmed salmon required 3kg of feed; in 1999 this had reduced to 1.19 kg of feed (Knapp et al: 16). In the 1980s, Chile was using 4kg of feed to produce 1kg of farmed salmon, which had reduced to 1.25kg of feed in 2004, just 0.25 higher than in Norwegian farms (Iizuka, 2007: 125, 128). Chile went from using wet feed in the 1980s to using mainly dry feed in the 1990s (pellets and extruded feed). Dry feed technology and formulae were purchased from northern hemisphere countries, but had to be adapted to local conditions. Feeding routines changed with the introduction of automatic feeders, which increased efficiency. In parallel, feed suppliers restructured from being part of the producer firms, to becoming part of a network of suppliers in the 2000s, concentrated on a small number of specialised firms, with increasing foreign capital ownership (Maggi, 2006; Iizuka, 2007).

Product diversification came at a later stage. In 1994-1995, Chilean producers introduced salmon fillets with no pin bones, for the US market. This product innovation resulted in an explosive growth in exports to the US (Knapp et al., 2007). In the late 1990s, having mastered farming of a sea fish (at least for part of its life cycle), Chile initiated projects to domesticate other sea fish for the same markets; for example, Fundación Chile developed a large project for domestication of cod and haddock. This can be considered a product diversification phase.

7.1.6 The old and the revolutionary industries

Fishing wild salmon was the dominant practice for production of world salmon up to 1996. Figure 7.4 shows that in 1996, salmon farming, an alternative technology system, took over. Farmed salmon increased from 2% of world supply in 1980 to 65% in 2004 (Knapp et al., 2007: xv).

Figure 7.4: Wild Salmon Capture versus Aquaculture Salmon Production (1970 – 2010)



Source: Author’s elaboration of FAO (2012) data

The technology that gave birth to salmon farming was developed around the old industry with the aim of increasing the wild population. ‘Wild’ salmon fishing changed with the introduction of hatchery technology. For example, in 2000, 38% of salmon caught in Alaska came from salmon hatcheries and this percentage was 80% for Japan (Knapp et al., 2007). Hatcheries in Alaska were developed originally with public funding and later became private non-profit organisations funded by a combination of instruments.

The main wild salmon fishing countries, US, Japan and Russia, have not developed important fish farming industries. In the case of the US, regulation is very strict (Knapp et al., 2007). Also, concerns have been expressed about the effects of farmed salmon on wild salmon life. The structure of the actors influencing policy differs between fishing and fish farming countries. In the US, for example, there are commercial, sporting and aboriginal fisheries and all are effective agents influencing policy (Knapp et al., 2007). Fisheries are strictly regulated by ‘limited entry’ management. Tens of thousands of commercial fishermen work seasonally in the US, and tens of thousands of others are engaged in processing and transport. The hatchery programme in Alaska receives government support because it provides seasonal employment for Alaskans (Knapp et al., 2007). The net effects of hatcheries on fishing are controversial – especially the effects of introduced salmon on the behaviour of wild populations - and this debate has become a political struggle (Knapp et al., 2007). The decrease in the price of salmon in the market has influenced the anti-dumping cases mounted by the US government first against the Norwegians in 1989, and later against Chilean salmon exporters in 1997 (Knapp et al., 2007).

7.1.7 Governance and the established industry

The dominant mode of governance in the salmon industry has been markets, with networks being also important part of the governance mode and corporate hierarchies appearing at a later stage. Governance modes coexist, nevertheless markets have remained dominant. The strong role of networks in the 1980s, with the creation of the salmon association and collaboration to position the industry, was less prominent in the 1990s. Pressure to increase productivity in order to remain competitive, and concerns over environmental sustainability was the motivation for a greater focus on process innovation and the creation of INTESAL (Instituto Tecnológico del Salmón SA), a technological institute for the salmon industry. INTESAL was founded in 1994 by the industry association with funding from the industry and government (El Llanquihue, 2003; Maggi, 2006). The decline in prices during the 1990s prompted a reorganisation of the industry towards greater concentration and vertical integration. The structure of the Chilean industry became dominated by big international players, which implied network relations reproduced the hierarchical structures of producers and suppliers.

Corporate hierarchy appeared as a new feature of the governance modes in place, and became more important in the 2000s (Maggi, 2006). In 2005 the Chilean industry showed an oligopolistic structure with six dominant firms (four branches of international corporations and two owned by national conglomerates), six big national firms and more than 20 SME (Maggi, 2006). There is a wide range of suppliers reflecting the level of specialisation in different activities. Salmon feed producers are highly concentrated and most of the big players are part of international corporations.

Iizuka and Katz (2011) suggest that the increase in international prices in 2002-2003 (see Figure 7.3) may explain the entry of several new large firms as a result of mergers and acquisition processes. New national and international entrants sought to widen their investment portfolios and invested in salmon farming, attracted by the increased prices. Vignolo et al. (2007) argue that the new entrants during the first decade of 2000 introduced a different management style that is more hierarchical, more profit oriented and more influenced by shareholders. They consider that this new structure has been damaging to network relations while the hierarchies in the industry have become more prominent.

Iizuka and Katz (2011) observed a decrease in the productivity of salmon producer firms since 2003. They argue that firms reduced their costs by increasing stocking density per volume of water rather than by continuous improvements to salmon production practices. The intensive use of water concessions resulted in deterioration in the sanitary conditions in farms and the environment and is seen as the main cause of the sanitary crisis in 2007 (Iizuka and Katz, 2011). Overstocking in the farms resulted in higher rates of disease and lower rates of fish growth, and increased demand for antibiotics, vaccines and diets for high density production conditions. The dominance of market governance was evident, with every firm responding to market incentives and making decisions based on maximising profit.

Government has played at least two main roles since the 1990s: regulation and support to industry growth. Regulation was concerned initially with governing the sea concessions and, later, to tackle sanitary and environmental issues. In 1990 Chile developed policy instruments to foster industry growth which consisted of different funding programmes for R&D and innovation (Maggi, 2006; Iizuka, 2007). Policy design responded to the logic of market failure and was aimed at supporting industry development, leaving decisions to the private sector, and providing financial support. Most funding instruments were directed at universities and research institutes, to work in collaboration with industry. Chilean investment in R&D is low on international scales, particularly in salmon farming (Iizuka and Katz, 2011) although salmon farming and aquaculture account for a relatively large proportion of total R&D expenditure in Chile (Bravo et al., 2007). Most of the R&D on aquaculture conducted in Chile is related to increasing productivity, investment in general knowledge related to use of the sea as a common good has been neglected (Bravo et al, 2007; Iizuka and Katz, 2011)

7.2 Coevolution of Technology and Governance in the Salmon Industry

Salmon farming represents a technological revolution in salmon production. The broad historical perspective adopted in this thesis on the development of the salmon farming industry, reveals the characteristics of industrial revolutions described in von Tunzelmann (2003). This section discusses this coincidence and the matching between the evolution of technology and the evolution of governance in the Chilean salmon farming industry.

7.2.1 Technology evolution

From an evolutionary perspective, fish farming can be considered a different 'technological paradigm' (Dosi, 1982) from fishing. Traditionally, attempts in the salmon industry to overcome the constraints imposed by time and space had been represented by technologies for augmenting fishing. There were pressures to produce more salmon fish – and more regularly – to match demand, which continued to be high outside seasonal fishing periods.

In farmed salmon, speed of production is the 'heuristic' (Dosi, 1982). Fish farming is based on a different technological logic to fishing, and the solutions to technical performance problems (e.g., density of stock per farm, disease management, feeding, etc.) are closer to those in livestock farming and aquaculture of fresh water fish, than to the technological paradigm of fishing.

The technologies supporting the industry are multifaceted: for example, in the early stages, transportation and the specific technologies related to production processes; and in later stages, automatic control and biotechnology. Governments played an important role in the industry's beginnings, investing directly in development of the technology - for production processes and also related to roads, ports and other infrastructure. The role of governments in salmon consuming countries was more subtle, and manifested in information and policies directed to influencing the dietary habits of consumers. Most of the research on the health benefits of eating fresh fish, and education campaigns on healthy eating were conducted in the Northern Hemisphere.

The farming revolution in the salmon industry added new areas of technology and removed very few. Fishing for wild salmon has not died out. There are interdependencies between the old and new paradigms: fish farming exploited hatchery technology and the accumulated knowledge on fish behaviour from the fishing industry. Fishing changed with the introduction of hatchery production. There are many tensions amongst the two industries, especially related to the effects of farmed fish production on market prices and the effects if farmed salmon was to escape into the wild. Along the development of the farming industry there have been no indications of convergence to a unique long term technology pattern, although there is specialisation by country.

Demand and supply conditions have shaped the ‘trajectory’ (Dosi, 1982) of farming technology. Unsatisfied demand for salmon products in low fishing periods and increasing demand generally, when farming proved to provide stable supplies and standardised quality, increased the pressure for faster production. Decreased prices for fish put pressure on cutting the costs related to maintaining quality. This dynamic defined the technological trajectory followed by the farming industry: producers were under pressure to produce more in each period of time from their existing physical capital (marine licences, plant and equipment), and they speeded up production. Quality issues had been related to maintaining certain standards that had to be met without reducing the returns from existing resources, which was the motivation to push the limits to production and to increase productivity.

The industry context was one of attractive high prices and government incentives for private investment. Investment in and diffusion of the use of technology increased. During the technology adoption and adaptation process, there was important technology growth, but very little productivity growth. Once the industry became established there were intense innovation efforts oriented to reducing costs. These efforts were focused on the most costly production factors, for example, feed. Technologies, which in the early stages of the industry had not been important, for example, information technology to enable automatic feeders and egg counters, and biotechnology for genetic improvements and development of vaccines, began to be incorporated.

In the later stages of the industry, innovation was directed to products and markets. In the case of Chile, innovation in products had two goals: expanding the variety of salmon products, and exploring markets and production technologies related to other fish. Chilean producers introduced filleted salmon, based on market research and technological developments. They undertook exploratory projects, for example, markets for and technological feasibility of exporting live fish to Japan.

Expanding the variety of products involved research on the domestication of other high priced sea fish species, consumed in high income countries, for example, cod, haddock and flat fish. There were expectations of transformations in the industry from biotechnology developments related to transgenic (or genetically modified) salmon (Knapp et al, 2007). For those in the industry, these developments appeared to be ‘a revolution’; from a historical perspective they were a deepening of the current technological paradigm allowed by the exploitation of available technologies. Transgenic salmon could result in the development of species that can grow in higher temperatures. One of the main restrictions on current production is the availability of coastal waters with the right natural conditions (Chile’s great advantage); transgenic fish might provide opportunities for the entry of new players in several other countries. It might provide higher profits for suppliers of eggs similar to the early stages of salmon farming, at least for a certain period of time.

People in the industry may be excited about the prospects of ‘unlimited’ expansion. A co-evolutionary perspective would recommend a degree of caution: salmon is an expensive, carnivorous fish and demand for it is unlikely to experience unlimited growth. There are also environmental and ethical concerns over the ‘invasion’ of farmed and transgenic salmon production, which is likely to displace other fishing and aquaculture activities. These concerns and consumer acceptance may explain why transgenic technology has remained at the experimental stage (FAO, 2010).

The evolution of the technology reflects the economic and social context. For example, it explains the greater efforts made in feeding technology (because the most important production cost is represented by feed), which resulted in sharp decreases in amounts of feed per kg of harvested salmon. It may also explain the smaller – at least explicit – attention paid to labour saving, first because it only represented a small proportion of the costs of production (Iizuka, 2007:108) and second because providing jobs was a policy goal and was aligned to incentives for higher employment. For example, a positive indicator of the impact of innovation technology projects enabled by government funding is direct and indirect job creation. The salmon industry is proud of the employment it has provided (El Llanquihue, 2003). Providing employment may be a personal motivation for some producers, and certainly constituted a powerful argument for industry lobbying regulators and policymakers. These factors are related to industry governance, which is discussed below.

7.2.3 Governance evolution

Chile's salmon farming industry was born early in the history of the international industry. It was not, as many think, a follower; it was one of the leaders in the industry – although not a leader in the development of the technology. The structure of the field of agents influencing regulation and policy in Chile was different from that in other leading countries. Some important characteristics are that Chile did not have fishing industry based on wild salmon; there were no industry developments in the region to compete with salmon farming and local and national government were eager to establish some industry; the interests of other parts of the fishing industry – for example, producers of fish meal – were aligned with those of the salmon farmers because both would benefit from an industry expansion. The agents involved in the governance and power struggles in Chile were better aligned for an expansion of the industry than those in other leading countries.

The role of government was one of regulation and support. As the industry expanded, the private sector gained power and became influential in the evolution of regulation. One scenario was formulating laws to foster a potential industry and a different one regulating with existing firms participating in law making - and especially in this case when firms were organised to influence regulation. Regulating under conditions of uncertainty about the effects of the industry development (which applied when the industry was being established) differs from regulating based on accumulated experience of the effects of the industry on the region in relation, for example, to job creation and economic growth. I do not include environmental effects here, because there is little or no evidence that research on the environment had an influence on regulatory decision making up to 2007. However, the sanitary crisis of 2007 shows how the scenario has changed. Expansion of the industry to the Aysén region is a topic of debate in 2012, with environmental and social issues being voiced by local organisations.

7.3 Doctoral Graduates in the History of the Salmon Farming Field

This section locates the experience of doctoral graduates in the history of salmon farming in Chile over time. My aim is to map the emergence of doctoral graduates in the field, highlight historical changes from doctoral graduates' perspectives and analyse recognition of the capitals associated with doctoral graduates and their shifts. This section draws on various documentary sources –current and historical - to deduce the likely roles of doctoral graduates in the field of salmon farming. The analysis is illustrated with case studies, constructed as 'special cases of what is possible' (Bourdieu, 1990). These cases are examples of the finite possibilities of doctoral graduates' roles within the historical circumstances analysed, using Bourdieu's concepts of field and capital (see Ch. 3).

The number of doctoral graduates active in the salmon farming field between 1990 and 2006 was less than 200. This number is derived from an analysis of the data in Bravo et al. (2007), which identifies a universe of 419 researchers in aquaculture in Chile in 2006. Their survey results, which cover all aquaculture disciplinary areas and all regions in Chile, indicate that nearly half of these researchers (48%) were doctoral graduates. Most researchers worked in more than one area and there was a concentration in science and technology related themes. The proportion of social science research in aquaculture was small.

The salmon industry generated an estimated 40,000 jobs in the Los Lagos region in 2006 - 15,000 in direct employment and 25,000 in indirect employment mostly in supplier firms (Maggi, 2006). Most (75%) of these jobs were low skilled or unskilled (Maggi, 2006). The producer firms' engagement in R&D activities – which probably involved doctoral graduates – is not clear. Maggi (2006) reports that only the six biggest salmon producers had dedicated R&D departments, and only feed suppliers were involved in ongoing research.

Bravo et al. (2007) provide an overview of the sector based on an industry survey and responses from 25 salmon producers (more than 50% of the universe of producers in Chile) and 80 supplier firms (more than 60% of firms). The majority of both salmon producers and supplier firms, particularly international companies and feed, pharmaceuticals and technology suppliers, reported engaging in research, including research project partnerships and implementation of new technologies developed by suppliers.

The provision of professionals and technicians was evaluated as sufficient and increasing (Bravo et al, 2007). Local universities have consolidated their study programmes in the field and began to offer postgraduate education. The review in Bravo et al. (2007) indicates that the availability of qualified professionals has not hampered the industry and will not be a problem in the future. They estimated that a large number of doctoral graduates worked in universities and research institutes on projects funded by competitive schemes. Most research funding comes from public sources. Although there are some small schemes provided by national and international private organisations, international funding has been decreasing since the 1990s (Bravo et al, 2007).

The following sections present the analyses by periods related to the historical review: before the onset of the industrial technological revolution (pre-1980s), during expansion of the new technological system in the 1980s, during the period of process innovation and cost reductions in the 1990s, and concentration of producers in the 2000s.

7.3.1 Absence of doctoral graduates in the field before the 1980s

Before the 1980s, numbers of Chilean doctoral graduates were small, and doctoral degree holders mostly took positions in universities and worked as academics (see Ch. 4). In the 1970s, before the development of the salmon industry in Chile, some doctoral graduates in Chile may have been involved in R&D related to oceanographic studies and feasibility for the incorporation of salmon species. In searching for examples of the pioneers of IFOP, the regional universities and Fundación Chile, I reviewed the biographies and resumes of academics and professionals specialised in the area, but none had a doctoral degree. However, they were the founders of university programmes in marine resources, and led the first projects in the area initiated by Fundación Chile.

7.3.2 Doctoral graduates positioned as university academics: 1980s

In the 1980s, numbers of doctoral graduates were still small. Most employment of doctoral graduates was still in universities as academics, and even in universities their numbers were small up to 1990. The salmon industry was growing based on market governance; investment decisions were based on market exchange transactions. There was likely no involvement of Chilean doctoral graduates in these processes. During the 1980s, research funding was limited; universities were undergoing reform (see Ch. 4) and government and research institute programmes for international collaboration and feasibility studies no longer existed. Fundación Chile's participation in the field was business driven; it was involved with producing demonstration effects (their firm was a model to be imitated by entrepreneurs) and developing services for the industry. Its staff included professionals and technicians, some of whom had worked previously in IFOP, but no doctoral graduates.

7.3.3 Emergence of doctoral graduates in the field: 1990s

The 1990s was a time of intensive technological innovation and improvement. It was necessary to learn quickly in order to reduce costs and remain competitive in the international industry. It was an exciting and challenging time for people in the salmon farming industry. By 1992 Chile was ranked second after Norway as a world producer of salmon. Foreign investment grew and the Chilean industry was internationalised. It was a time of rapid development also for suppliers, which became established as independent firms. Universities and research centres had stabilised following the reform, and were operating on the basis of self funding for research. In the 1990s, instruments to fund R&D and innovation were introduced in programmes promoting cooperation with the industry.

Under these circumstances, it could be expected that there would be doctoral graduate involvement in R&D in the producer firms working on the pressing productivity challenges. That was the case of Dr Salmon-engineer who directed the R&D unit in a Chilean branch of an international producer.

The increased involvement of university academics was likely a result of funding opportunities. Researchers in universities and research institutes recognised the funding incentives available for research on the industry. This was the case of Dra Bio-diagnostic. She decided to reorient her research to salmon since it was an area of national importance that was attracting funding and could help her to develop a career following her period of doctoral study.

At the beginning of my research, when I was defining my fieldwork and case studies, I had expected to find doctoral graduates in the salmon industry who had specialised in oceanography (my history of the industry was constructed in parallel with the case studies, as explained in Ch. 3). I found that there were oceanographers in Chile, who had completed their doctoral studies, but were working in areas not directly related to salmon. I identified only one person who had graduated as a PhD in the 1980s, and was working in academia on salmon. I was unable to find out much about her work, although she has published in international journals and written (or co-authored) reports funded by international collaborations. In 2005 she left her academic position in Chile to work for the UN in Rome.

The succeeding paragraphs discussed the cases of Dr Salmon-engineer and Dra Bio-diagnostic. Both completed their doctoral degrees in the 1980s. In neither case was their doctoral research on an area related to salmon, but they exploited their embodied knowledge (cultural capital) to move into the area of salmon R&D.

Dr Salmon-engineer's doctoral studies were undertaken in the UK, on microalgae production. After completing his degree, he returned to Chile to take up a university position: 'shortly after arriving I received a call from one of the managers of Unilever-Chile, who said he knew my name and wanted to meet me because there were projects he wanted me to develop'. Dr Salmon-engineer signed a two year consultancy agreement with Unilever while maintaining his full time academic position. He was given the task of developing an agricultural product; the production target was handwritten on half a sheet of paper, and he was handed a packet of seeds. It was a new area; it was a new problem with no instructions about its possible solution; it was an interesting challenge and an opportunity for Dr Salmon-engineer to supplement his academic salary. He succeeded and after two years Unilever-Chile made him another offer:

> They offered me to be in charge of salmon development [in Chile for Unilever Marine Harvest, one of the big international salmon producers]. They had three, brand new, sea farms, two hatcheries and two fresh water plants, but there was only a recipe to grow salmon and nothing else. They wanted to do technological development. It was the same again, I had learned you don't need to know what to do, you need the general objective and everything else depends on you. In a month I wrote a development plan with several areas and a budget; they approved it and sent me to Scotland to present it. They gave me the money to hire people and start working...The areas were: nutrition – because the feed was simple, probably not well balanced, I realized it was critical how to feed the fish...feed represented 65% or more of the [production] cost, we needed to know

> more to understand feeding, genetics – to make species with better productivity, we tried genetic and quality variables, and, finally, health...we tried to obtain species resistant to disease and also developed a vaccine programme. All these programmes began to show results, alongside the results of the engineering and logistics programmes... and there I continued to work for many years.

Unilever valued Dr Salmon-engineer’s doctoral degree, as a signal of his cultural capital, and embodied specific knowledge. They expected him to be able to solve problems based on designing a strategy and implementing a plan geared towards a given target. His competencies (potential) were observed as a capability for successfully solving production challenges in his consultancy project. The international firm knew no more than the local branch, particularly about how to grow salmon in Chile: it was a case of joint learning. Dr Salmon-engineer worked closely with the R&D teams in other Unilever branches, especially in Scotland.

When Unilever’s Scottish branch contacted Dr Salmon-engineer, it was aware that he had recently graduated from a UK university and had a qualification awarded by its home higher education system. The firm’s decision resonates with the ‘signalling theory’ proposed by Michael Spence (1974), Nobel laureate in economics. Unilever perhaps considered Dr Salmon-engineer’s doctoral degree as signalling competence, and was willing to provide him with the opportunity to apply this competence to practice, which would allow the company to observe his capability. The concept of capital adds complexity to the idea of signalling. With no history in the field, Dr Salmon-engineer’s doctoral degree may have been determinant for being recognised as holding relevant capital by Unilever, but not necessarily for other actors. Once Dr Salmon-engineer had a history in the field, the complexity of the endowments shaping his symbolic capital became difficult to reduce to ‘signalling theory’.

Dra Bio-diagnostic pursued an academic career but oriented her research towards salmon. When she had completed her doctorate in Chile on viruses - a basic biology subject –she was offered an academic position. She was convinced she needed to develop her own theme in an area that would ‘contribute to the country and attract funding’. Aquaculture was growing in the region where she had grown up and done her undergraduate degree. She began investigating the salmon region: ‘I concluded that the imported eggs brought virus into the country, no one knew because they did not have the knowhow to diagnose the presence of a virus. She embarked on research ‘in two phases, applied to develop diagnostic tools and basic to study the viruses’. Her research ran into difficulties: ‘It was politically problematic; it was not convenient to find out that the eggs were contaminated. That was my first clash with the industry, and I went to work enclosed in my lab [she had already obtained project funding]’.

Her research produced some useful findings and, through working with students, she came up with the idea for a commercial endeavour using government funding. As mentioned in Chapter 4, the completion of most university undergraduate degrees in Chile include the completion of a dissertation, which often – in science and engineering subjects – consists on a professional project involving technological innovation. Dra Bio-diagnostic and her partner – and former student - developed and commercialised diagnostic products for the salmon industry. The innovation has been documented widely in Chile as a success story. It has been presented in the annual reports of funding bodies and in local innovation seminars and conferences.

7.3.4 Doctoral graduates specialised in salmon topics: 1990s

There are two other examples of doctoral graduates exploiting opportunities in the salmon industry in the 1990s. They differ from the previous two cases in that their doctoral studies, which were conducted in the 1990s, were in subjects related to aquaculture. They chose the area because of the work possibilities in Chile since the salmon industry was already large and prosperous. The first example is Dra Salmon-vet, who is an academic located in the salmon region; the second is Dr Clean-salmon, who was the first doctoral graduate employed in Fundación Chile’s marine resources department, whose career has been built on providing services for development of the salmon industry.

Dr Salmon-vet’s undergraduate degree was in natural sciences and she went abroad for her doctoral studies. She chose aquaculture as her research topic because of the opportunities in Chile presented by the flourishing salmon industry. She returned to Chile and worked for IFOP before winning an academic position in a traditional university in the salmon region in 1998. She reported enjoying her university position and valuing her ‘academic freedom’ and stable employment. Her research topic is feeding and aquaculture, an area she developed by getting funding for research projects: ‘Salaries had to be won by projects, I learned to present and win projects... the task of the researcher is to propose and win projects... Publishing, reputation in one's area and teaching are institutional commitments'. Dra Salmon-vet is active in all these areas. She publishes the findings from projects supported by government funding through various funding instruments; some projects involve industry collaboration: 'the kinds of questions I ask are: how does nutrition impact on eggs? How can we maximize small fish growth?' She has set up a 'hatchery lab' that employs a team of three professionals: 'the difficulty is to keep their salaries, because they depend upon projects, they are on flexible contracts'. She is on a permanent contract and has built a successful career in academia, has been promoted, and has university management responsibilities.

Dra Salmon-vet, when deciding on a topic for her doctoral studies, saw specialising in aquaculture and being in the first generation of people in Chile to do doctoral research in this area would open valuable job opportunities. Over the years she accumulated different forms of cultural capital: objectified capital in the form of laboratory facilities –owned by the university, but under her direction - which made access to funding easier and enabled her to win research projects; embodied capital by learning from her field; institutionalised capital (credentials and recognition); and social capital, based on her integration in scientific and academic networks and the networks of producers, who have acted as project partners and funders.

Dr Clean-salmon conducted his doctoral studies in Germany on the 'environmental impacts of salmon aquaculture'. His fieldwork was conducted in Chile at a time when: 'I measured [he brought the equipment] and here no one knew about it, I took data back and ran a model to study and predict the impact of the nets on the environment'. In 1997, he started working in Fundación Chile and participated in several projects to introduce better practices in the salmon industry, particularly cleaner production. Much of his work has been published – in manuals and good practice primers, and in the form of training materials.

7.3.4 Doctoral graduates' careers in academia and industry: 2000s

This section follows on the careers of doctoral graduates in the examples of the previous section, under the circumstances of the 2000s and as experienced players. Chile has maintained its position as second ranked world producer of salmon in the 2000s. The local and international industry has continued to grow, but its structure had changed towards higher concentration. By the end of the first decade of 2000, it was an established oligopoly. Diseases and health issues remained the industry's greatest concern.

The academic lives of Dra Bio-diagnostic and Dra Salmon-vet have not change greatly, whereas the careers of Dr Salmon-engineer and Dr Clean-salmon have taken several new turns. Dr Salmon-engineer experienced the process of Unilever's selling off of Marine Harvest having decided to get out of the salmon business. Dr Salmon-engineer then moved to Fundación Chile to head the marine resources department. He continued doing development for the industry. After several years, he began a new career, working independently as a provider of services and consultancy.

Dra Bio-diagnostic divides her time between the university (half time contract) and the company she founded. At the university she continues to do research funded by competitive projects, she also teaches and she is involved in university management. She is high up in the university hierarchy. Her team developed a doctoral programme which already has had three generations of graduates. Her commercial enterprise had a long story of trial and error and partnerships leading to its establishment. The company has grown and at the time of the fieldwork employed six doctoral graduates engaged in R&D.

Dra Salmon-vet is the director of a new doctoral programme in aquaculture in her university. She is responsible for the university's accreditation process. Her research and teaching have continued along similar lines to the 1990s, although she is now a well established player, which increases her chances in competition over funding and getting her research published.

Dr Clean-salmon did an MBA and moved to the salmon region. He changed direction from work on the environment to business research: '[doing the MBA] complemented my scientific background with the business perspective.... I understood entrepreneurs better'. He was working in Fundación Chile on a project for the domestication of sea species, but it did not reach the stage of commercialisation and he decided to move on. Using his new business perspective he became the director of a Fundación Chile related firm. He was keen to 'do R&D and sell bio-testing services to the industry through Aquadvise [the firm]'. He wanted 'research coming from firms' needs' and is proud of his achievements: 'today, Aquadvise is one of the best [companies] in Chile in its services and that is a reason for pride, it has been achieved through discipline, perseverance and will' He no longer bids for project funding: 'the law granting tax reductions for R&D work has been beneficial for our clients'.

7.3.6 Expansion of doctoral graduates in the field: 2000s

The growth achieved by the industry has attracted larger numbers of doctoral graduates - a new generation of graduates - and researchers who are reorienting their research towards the salmon industry. Dra Salmon Vaccine and Dr Micro-ecology started working on salmon industry topics in the 2000s; they were in the same employment at the time of the interviews (2011). Dra Salmon-vaccine has been employed in a private research institute since 2001, and Dr Micro-ecology has held a position at a public university since 2005. In both cases, their undergraduate studies were in biological sciences in research oriented programmes. Dr Salmon-feed completed his doctorate in 2010 and was the first graduate from a doctoral programme in a Chilean university specialised in aquaculture. He is familiar with the salmon industry based on his undergraduate studies and work in Fundación Chile in the late 1990s and, later, in the salmon research institute.

Dra Salmon-vaccine, when asked if she would participate in the study, expressed some doubts about the extent of her 'working for the salmon industry'. She said: 'I had always worked with salmon but never with salmon producers. I work with pharmaceutical companies and partner research institutions'. She works for a private research institute founded in 1998, located in Santiago close to commercial laboratories - Novartis and Recalcine - and to the Institute for Public Health (which regulates pharmaceutical products). Her institute is in a building that was formerly a university institute. It has a huge old stone staircase, and has the atmosphere of an old, traditional university building. She was hired in 2001 to lead a new project funded by FONDEF:

> I was in charge of the salmon vaccines project. It was a project with Fundación Chile and Novartis to develop a vaccine for piscirickettsia, one of the most severe salmon pathogens...It is not easy to treat with antibiotics, there were no effective vaccines at the time and we were set up to develop recombinant DNA vaccines... One of the resulting formulae was very good; highly promising with 94% protection...We patented it and licensed it to Novartis. Now Novartis sells it in the South of Chile...I have been working in the same area ever since. I arrived

> here in 2001 for this project and other projects came later. When this worked, we got interested in other pathogens and we worked with aeromona salmonicida, streptococcus focal, virus ISA....several of the most important pathogens in Chilean salmon culture. We have several patents and patents pending. Once we finished the project with Novartis, we signed a collaboration agreement with Recalcine....It is good to have these collaborations because we in a research centre are not in contact with salmon producers... whereas the pharmaceutical companies in the area know what are the problems.

They obtain pathogen samples from the pharmaceutical companies or from Fundación Chile. The circulation of pathogen samples is restricted and regulated. Dra Salmon-vaccine works with research students – a partnership between the institute and a private university. Her job is stable, which has allowed her to accumulate knowledge and reputation in her field.

Dr Micro-ecology studied microbiology as an undergraduate and did his doctoral studies in environmental sciences. He worked in agricultural applications and in 2005 moved to his current job in a public university. He proposed a project which resulted in an offer from the university's marine research centre:

> without knowing anything of the reality, only from my theoretical background, I predicted the existence of these microbial deposits on marine soil and I proposed a study, assuming they did exist......I was awarded an Innova funded project...I arrived here to study microbial ecology on marine soil.

Dr Micro-ecology had several projects running simultaneously (FONDEF, Innova, etc). His concern was to find time for writing, managing projects was time consuming and difficult to combine with publishing. Publishing is important as an indicator of the research centre and university quality. His first project is still an important area of research for the centre, although it has been problematic:

> I didn't know I was going 'between the legs of the horses'; it has been ever so difficult to take samples. We had only managed one publication since 2005 based on the one site we had sampled, we are about to have access to a second site now, but with the ISA crisis everything is more difficult.

It took two years –2008 to 2010 – to get this paper published, and he was forced finally to publish in a less prestigious journal: 'it is the first characterization of the eco system of this carpets on the marine soil organically enriched by the salmon culture in the south of Chile...the paper has not made news yet, it has been difficult'. He was positive about the future of this area because it has been linked it to the sanitary problem – the big topic after the ISA crisis in 2007:

> …microbial communities could be used as an impact indicator, that is why people don't want to know they have it since they know it is an impact indicator. I am working beyond that. Man-made environmental changes produce a new environment ... a new scenario where we could work, even improve aquaculture....universities, firms, government are not mature enough for that...the law is black and white, forcing the producer to declare white when that cannot be true....under that position we either finish aquacultures or accept the environment changes, our position is to accept shades of grey and work to manage the microbial carpets. It is difficult to find firms willing to work with us under the current legislation.

He has projects in other areas where it has been easier to get funding and to publish, for example, public health problems caused by crimson tide algae. It was difficult to get a university position in 2005, when Dr Micro-ecology applied. He is employed on a contract that is renewable annually. In the five years he has been at university, he has equipped a laboratory with the resources acquired from different projects and now has a better base for doing his work.

Dr Salmon-feed has been involved in the industry for several years. He was already enrolled in a doctoral programme when he was offered a job in an international feed supplier branch. He managed to negotiate a solution which involved support for his studies (time for study related activities and research). He reformulated his research topic to align with the firm's interests in feed technologies. He studied functional diets, that is, diets that achieve more than just growth. For instance, they augment the immune system and prevent disease. His work is highly networked: he has projects with local universities and with other branches of the firm, for example, in Norway. Some projects are internal to the firm and some are in collaboration with external partners, depending on the topic. He has access to scientific information and to vast amounts of research resources.

7.4 Doctoral Graduates' Practice in the Field of Salmon Farming

This section analyses the roles of doctoral graduates in the field of salmon farming in Chile. It focuses on practice and its effect on capability accumulation, at the level of the individual doctoral graduate. The analysis is based on the dynamic capability schema, and considers the historical context and the shifting recognition of the types of capital associated with doctoral graduates.

The main role of doctoral graduates in the salmon industry was as scientific suppliers. In performing this role over time they accumulated the capabilities for improving salmon production and proposing and developing funded projects. This section analyses the individual processes of capability accumulation by explaining the dynamic interchange between individual labour and demand for labour (section 7.4.1) and individual labour and supply of labour resources (section 7.4.2). It expands the examples proposed in section 7.3 to illustrate how changes in the field impacted on these dynamic interchanges. Section 7.4.3 suggests how the dynamics analysed may have affected the organisational levels of the producer firms and the science and technology supplier organisations.

7.4.1 Scientific supplier and the demand side

I use the capability schema, Figures 7.5 and 7.6, to analyse the dynamics of capability accumulation between the individual scientific supplier and the organisations demanding his or her labour. First, I examine the case of the scientific supplier hired directly by a producer firm. Second, I examine the most common case of a scientific supplier working for a science and technology supplier institution, for example, a university or research institute.

Figure 7.5: Capabilities Schema for Scientific Supplier and Salmon Producer (Demand Side)

Actors	*Scientific Supplier*	*Salmon Producer*
Characteristics	**Scientific possibilities**	**Production possibilities**
Capabilities	S2 **Scientific capabilities** S2’	KE2 D2 **Production capabilities** D2’
Rewards	**Earnings/Scientific Rewards**	**Profitability**

Source: Adapted from Von Tunzelmann (2009); see also Ch. 2 in this thesis.

The 1990s in the producer firm

Doctoral graduates have been active in the salmon industry in Chile since the 1990s when the industry was established, was growing and was experiencing productivity challenges. They were hired to solve industry problems related to medium term growth and competitiveness.

Scientific suppliers increased the production possibilities for salmon producer firms. Dr Salmon-engineer, for example, proposed an R&D plan for Marine Harvest at the outset of the firm’s operations in Chile. Producing in Chile at competitive costs was a challenge for which there was no off-the-shelf production solution. Dr Salmon-engineer and his collaborators exploited the firm’s resources to supply the possibility of producing salmon in Chile at competitive cost and high levels of productivity (S2). The firm valued their services and continued to demand them over time (D2). The firm involved the scientific team in knowledge interchanges with its Scottish branch (KE2), which enhanced the learning process. Dr Salmon-engineer left his university job, preferring the earnings and rewards offered by the salmon firm (S2’). The firm provided him with a salary, resources for developing a R&D unit, a research budget and opportunities for building relationships with peers in the firm’s international network (D2’). This capability dynamic was in place for most of the 1990s, during which time Dr Salmon-engineer learned to improve salmon production, developed capabilities in salmon productivity, and achieved a position in the national industry as an industry expert.

The 2000s in the producer firm

At the beginning of the 1990s the big companies were vertically integrated. There was a gradual process of industry reorganisation towards greater concentration and a network structure involving specialised providers. By the early 2000s the industry structure was an oligopoly.

Dr Salmon-engineer's circumstances changed at the end of the 1990s when ownership of the producer firm changed. The structure of the internal organisation of the producer changed, which meant that demand for production possibilities also changed (D2). The structure of knowledge interchange (KE2) and the rewards accruing to the scientific supplier were different – even if salaries were the same (D2'). Marine Harvest, a pioneer in salmon farming first established in Scotland, was founded by the Anglo-Dutch multinational Unilever. At the end of the 1990s, Unilever sold Marine Harvest and exited from all its marine businesses. Marine Harvest was initially taken over by the minerals conglomerate, Hanson, then was sold to Booker McConnell Ltd, which in turn sold it on to Nutreco, a Dutch salmon feed supplier, in 1999. In 2005, Nutreco merged with the Norwegian Stolt Sea Farm and in 2006 the company was bid for by the Norwegian Pan-Fish (Knapp et al., 2007). Dr Salmon-engineer described the experience thus:

> Unilever decided to quit all its agribusiness activities, including aquaculture...Marine Harvest was no longer Unilever and several projects were lost, research lost strength. Unilever always planned for the very long term. In fact during the very first years in Scotland they built the first plant with recycled water... aimed at preventing disease...it was a wonderful innovation, I was part of that research group from the early stages... recirculation only arrived at Chile much later in 2002 [10 years later]...Marine Harvest continued a similar strategy with different owners. Later another firm came in... They had a clear idea of what they wanted to do, they bought cheap (because Unilever sold cheap, these big companies are like that, when they want to finish off something, they just do it). They bought cheap because it was sold cheap...he [the executive in charge]

> started a media campaign, he was in all the international business journals, on the cover. They gave as the order to keep business as usual. After six months they started coming in with visitors, asking us to make presentations and show them how high tech we were – which we were indeed, there was not a university in the world with the technological resources we had, we were 20, 25 years ahead. And they advertised that in the business journals, giving it an enormous value, and they sold. Yes, the sold without investing anything. We were developing and growing with much effort and they did not put a penny in...

The reference to how the first owner, Unilever, engaged in technological innovation shows that Dr Salmon-engineer valued the scientific rewards provided by the characteristics of the producer firm. Dr Salmon-engineer remembered that 'research lost strength', but with one change of ownership 'we started to believe in ourselves again and we intensified our work'. The owners' main business was production and distribution of animal feed, although: 'the company's president had many businesses: gold mines in Australia, diamonds in South Africa...and weird things like the copyrights for Agatha Christie writings'. Recovery of the R&D department did not last: 'Their core business started to wobble ...profits went down and the board of directors called for rationalisation, everything that was not feed had to go...and we were on sale again [laughs]'.

When this sale process started and the Chilean managers became aware of it, they got together and made an offer: 'we got credit from a US bank; we wanted to buy only the Chilean branch and offices in the US and that is why they did not give us a pass'. Dr Salmon-engineer moved on to Fundación Chile and continued to pursue a successful career in salmon farming and aquaculture in Chile. He is well known in the field and recognized as an expert with a long trajectory: 'I became well known in the industry, which is what gives me a living'

This example shows misalignments in owners' and managers' interests – a principal/agent problem (von Tunzelmann, 2003). The technological possibilities offered by managers are subject to decisions made within the governance structure of the capitalist firm, and the owners have the last word in decision making. As Lazonick and Mazzucato (2012) discuss, the economic agents contributing to innovation to provide future - inherently uncertain – returns are not the same economic agents able to appropriate those returns.

When the composition, characteristics or positions of agents change, the capability dynamics also often change as a result. The case of Dr Salmon-engineer and Marine Harvest exemplifies how the new internal structure of the producer firm resulted in a discontinuity in the capability dynamic of the internal scientific supplier.

In the 2000s, Chilean industry restructured towards greater concentration of producers. The new structure of the field of producers – after the entry of new players, and the acquisitions and mergers among global producers - cannot be explained solely by the changes that occurred in salmon farming in Chile - or even globally. The case of Marine Harvest shows how corporate decisions can involve several international economic fields. Marine Harvest was the biggest salmon producer in Chile in 2006 (Maggi, 2006) and was part of the world's biggest salmon production conglomerate (Knapp, 2007).

The 2000s and the specialised supplier firm

In the 2000s, the structure of suppliers changed towards concentration and internationalisation. Once the industry was well established and there was an attractive market demanding important production volumes, international firms set up branches in Chile. The most international and concentrated was salmon feed. The dynamics of the capability schema in the case of scientific suppliers working for feed producers is depicted in Figure 7.5 and illustrated by the case of Dr Salmon-feed. In the 2000s there was demand for feed producers to develop a product designed specifically for the geographical conditions and salmon species grown in Chile (D2). In 2008, one of the biggest international feed suppliers in Chile hired Dr Salmon-feed to help develop customised feed to enhance the firm's production possibilities (S2). The company provided resources, salaries (D2') and promoted knowledge interchange amongst its internal scientific suppliers (KE2). It produced internal publications on research findings, manuals to facilitate internal collaboration, and had a platform to support regular web based communications. Dr Salmon-feed valued the rewards that came with the job, particularly support for completing his doctoral degree (S2'). At the time of the interview, Dr Salmon-feed had a long history in the field and was part of a local network of professionals in the industry, which facilitated collaborations and knowledge exchange outside the firm's network.

The 1990s and 2000s in universities and research institutions (science and technology suppliers)

Demand for scientific suppliers' labour came most often from universities and research institutes (science and technology suppliers). They provided support to the industry through academics and researchers engaged in salmon related research. This research was funded primarily by public instruments designed to promote applied research in universities and research institutes with the involvement of industry.

There is a diversity of science and technology suppliers to the salmon industry in Chile, the most important being Fundación Chile, universities (at least nine universities had run research projects on salmon) and research centres (public IFOP created in 1964, private INTESAL created in 1994, and publically funded CIEN created in 2004). All these providers received funding for their research via public initiatives designed to foster the industry and to promote linkages between industry and the research centres. The science and technology suppliers have different levels of self funding (IFOP and some universities receive direct grants, see Ch. 4). All generally organise their research in projects, and bid for funding and organise teams according to funded projects. Project team members are mostly employed on short term contracts, related to a specific project. The dynamic relation between scientific suppliers and science and technology suppliers working for the salmon industry is depicted in Figure 7.6.

Figure 7.6: Capabilities Schema for Scientific Supplier and Research Institution (Demand side)

Actors	*Scientific Supplier*	*Research Institution Sc and Tech Supplier*	*Salmon Producer*
Characteristics	**Scientific possibilities**	**Sc/Tech possibilities**	**Production possibilities**
Capabilities	**Scientific capabilities** S1 S1’	KE1 D1 **Sc/Tech capabilities** D1’ S2 S2’	KE2 D2 **Production capabilities** D2’
Rewards	**Earnings/Scientific Rewards**	**Profitability**	**Profitability**

Source: Adapted from Von Tunzelmann (2009); see also Ch. 2 in this thesis.

The characteristics of the science and technology suppliers and the construction of their demand to the scientific supplier based on ‘projects’ (D1), means that supply of science and technology possibilities most often consists of project proposals to a funding body and subsequent contracting for the proposed development (S1). Dr Micro-ecology, for example, was hired by a university centre to work on a project resulting from a proposal to which he had contributed. Supply of technology, in many cases, is through ‘funded projects’ (S1). Individuals working in academia on permanent contracts, such as Dra Salmon-vet, are also expected to bid for research funding. Their permanent contracts (D1’) cover teaching, publishing and reputation and recognition for their expertise (e.g., through requests for advice and training from the salmon industry). Publishing and recognition require additional funding for laboratories and equipment, conference attendance, etc. Research also has an effect on teaching activity by increasing its quality. It provides opportunities for final year undergraduate student dissertations and development of postgraduate studies. At IFOP, doctoral graduates on permanent contracts need to apply for project funding to augment their operational budgets and maintain their permanent positions. Graduates hired to develop already funded projects are usually on temporary contracts, for the projects’ duration (D1’). Doctoral graduates accept these conditions and value the rewards involved (S1’).

The project system has been in place since the entry of more doctoral graduates in the salmon industry (1990s). It has been the main mechanism for doctoral graduates’ involvement in the field. It is the way things work, and have ‘always’ worked. They plan and make their decisions within this framework. The funding system dictates job opportunities and contracts (permanent or temporary). It involves routine bidding and project proposals, competition, evaluation, and interim and final reports to funding bodies. Job stability requires a constant flow of projects. The application of these practices over 20 years has likely had long lasting effects on actors’ dispositions. Doctoral graduates are in a favourable position to win funding compared to other players. Success in winning funding improves capital and reputation and makes future success more likely.

7.4.2 Scientific suppliers and supply side

A scientific supplier may require many suppliers to make his work possible. In particular he may relay on technology suppliers, for example, laboratories, specialised journals, equipment, etc. Figure 7.7 represents the relation between a technology supplier and a scientific supplier - which could be replicated for any others.

Figure 7.7: Capabilities Schema for Scientific Supplier and Technology Supplier

Actors	*Technology Supplier*	*Scientific Supplier*
Characteristics	**S&T possibilities**	**Scientific possibilities**
Capabilities	S1 KF1 **Technological capabilities** S1’	D1 **Scientific capabilities** D1’
Rewards	**Profitability**	**Earnings/Scientific Rewards**

Source: Adapted from Von Tunzelmann (2009); see also Ch. 2 in this thesis.

Technology suppliers emerged in the 1990s and their number and specialisation increased in the first decade of the 2000s. Scientific suppliers began demanding services such as bio-testing (D1) for new vaccines or new diets, from firms such as Aquadvise (S1) created in 2007 by Fundación Chile. There is stable supply of technological services, training, information (local journals) and equipment.

7.4.3 Organisational level

The Chilean industry maintained its international position until the sanitary crisis in 2007, and there was increasing participation of science and technology suppliers working on salmon industry related projects. In this section I analyse the capability dynamic at the organisational level (producer firms and science and technology supplier organisations). At the centre of the capability schema in Figure 7.8 is the salmon producer, facing downstream to consumers and upstream to suppliers.

Figure 7.8: Capabilities Schema for the Salmon Producer Firm

Actors	*Science and Technology Supplier*	*Salmon Producer*	*Salmon Consumer*
Characteristics	**Sc/Tech possibilities**	**Production possibilities**	**Product possibilities**
	S2 KE2	D2 S3	KE3 D3
Capabilities	**Sc/Tech capabilities** S2’	D2’ **Production capabilities** S3’	D3’ **Consumer capabilities**
Rewards	**Profitability/IPRs**	**Profitability**	**Utility**

Source: Adapted from Von Tunzelmann (2009); see also Ch. 2 in this thesis.

Salmon producers offer product possibilities to consumers based on their production capabilities (S3). Their product ranges and product characteristics are matched to consumer demand and international quality standards in world consumer markets. Consumers are interested in fresh and frozen salmon (D3). Chilean salmon producers have done extensive market research; they interacted with consumers (KE) to improve their capability to satisfy customer demand. The levels of profitability of producers influenced the long term dynamic of growth and demand for production possibilities to meet decreasing consumer prices (D3’).

Production possibilities are based on the intersection between the supply of science and technology (S2), and the production capabilities of producers (D2). Doctoral graduates participated in the development of both aspects.

In most cases, science and technology suppliers (research institutions) propose projects (S2) to producer firms (salmon farmers, feed suppliers, other related firms), which involve public funding. To justify the project and its funding, they need proven demand (D2) and some contribution to project costs (D2') from the producer firms. The involvement of producer firms is a requirement of most funding bodies, and is considered an indicator of the relevance of the research to the industry and the potential impact on economic growth and competitiveness. Producers and suppliers (KE2) interact in the preparation of project proposals and bids for funding. Supplier institutions estimate the profitability implications of the projects (S2') based on the contributions of producer firms and the funds involved.

7.5 Conclusion: Patterns of Capability Accumulation

Chapter 7 provided an overview of the history of salmon farming in Chile with a focus on technological change and governance systems (Sections 7.1 and 7.2). Section 7.3 discussed the roles and positions of doctoral graduates in the field illustrated by case studies. Section 7.4 presented an analysis of the processes of capability accumulation by doctoral graduates, focused on their role as scientific suppliers to the industry.

High skilled professionals (without doctoral credentials) were part of the early development of the industry, working for the research institutes (IFOP, Fundación Chile) in international collaborative projects to launch the local industry. There were specialists, some of them doctoral graduates, in universities with pioneering programmes in aquaculture (e.g., Universidad del Norte).

Doctoral graduates emerged in the SLS at the time of expansion of the industry and increasing competition. There was a need to reduce costs by increasing productivity. The international industry technology was not mature; there was room for improvement and need for adaptation to local conditions. Although a non-mature technology provides opportunities for improvement, dealing with living creatures implied even greater challenges. Suppliers had to develop and they also needed to adapt to local conditions (e.g., diets depend on the particular local conditions, fish health is locally determined). Developing only production capabilities would not have taken the SLS to its prominent position in the industry once the period of high profits was over.

Accumulation of innovation capability is not clear. Basic research (e.g., domestication of new fish species) and cooperative R&D are mediated by government subsidies. Some of the science-based research – which concentrates most attention and important funding – is in vaccines and antibiotics, rather detached from the producer dynamics. There had not been major technology development reported as outstanding for international standards. One of the technological landmarks reported by experts was the production of eggs locally, which reduced dependence on imported eggs. The sanitary crisis added complexity to the analysis of innovation capabilities. This is discussed further in Chapter 8.

Chapter 8. Comparison

Chapters 5, 6 and 7 studied the three SLS – copper mining, fruit growing and salmon farming – as three cases of producer capability accumulation in SLS, focusing on doctoral graduates' participation in learning processes. They provided a historical analysis of the coevolution of technology and governance, and located the experience of doctoral graduates in these industries. Each of these chapters concluded with the analysis of practice of scientific suppliers (doctoral graduates) in the field and its implications for capabilities accumulation.

Chapter 8 compares the three SLS along the themes developed in Chapters 5, 6 and 7, that is, history, position of doctoral graduates in that history, doctoral graduates' practice as scientific suppliers, and capabilities accumulation. It also provides a discussion of alignment of targets and the practice of the different agents in the SLS in relation to the market for scientific suppliers.

The three sectors were chosen initially for their economic similarities (see Ch. 3, Section 3.3.1). All are natural resource-based, export oriented, strategic for economic policy and have become important in the international market. The analyses revealed other similarities related to the pattern of coevolution of technology and governance, the connection between participation of doctoral graduates in the field and valorisation of scientific capital, and the relevance of time in sustaining the dynamics of interchange for capabilities accumulation. However, there are differences in the accumulation of capabilities.

8.1 Historical Coevolution of Technology and Governance in the Industry Fields

The three industry fields, SLS, in the study are considered success stories in the areas of economic growth and technological catch up[16]. All three SLS became players in a wider industrial epoch by embracing a new technological paradigm that allowed the redefinition and resolution of production problems. The wider industry selection and diffusion of the new paradigm was the result of coevolution of technological

[16] In the case of salmon this evaluation held until the sanitary crisis of 2007.

development and governance systems. Table 8.1 compares coevolution patterns in the three SLS and is followed by a discussion.

8.1.2 Generative Factors

The first and second blocks in Table 8.1 present the generative factors for the installation of the new technological paradigm, at the international level (first block) and for Chile (second block). In all three SLS technological development was coupled with increased demand, better availability of infrastructure and alignment among different agents' interests. States – nationally and in leading countries - played an important role in the formation of this new epoch in all three cases, by generating demand, by taking part in technology development and by setting up the rules of the new game (e.g. regulation and macroeconomic conditions).

In the case of Chile in each SLS, the state initiated the process of access to the technologies associated with the new paradigms and contributed to constructing the actors which became main players in the established industries. In all three SLS the state was involved in the early stages of technological exploration. It created public research institutes (CIMM – copper -, INIA – agriculture - and IFOP –fisheries and aquaculture - respectively). The state 'constructed' CODELCO as the main actor in the rejuvenation of the copper industry at the local level. In the case of fruit the state intervened in sectoral planning through CORFO. In salmon farming it undertook feasibility and foresight studies and ran demonstration projects with international partners, it 'constructed' one of the first salmon farming firms in the field which opened the way to others. It reorganised land tenure, mines and coastal concessions and offered incentives for exports, which promoted the emergence activity of entrepreneurs.

Table 8.1: Coevolution Patterns amongst SLS

	Copper	Fruit	Salmon
Generative Factors: Industry Technological Revolution and System of Governance	Open pit and flotation technologies: late 1880s Capitalist entrepreneurs in the US: 1900 Rise in demand by electrification and telephony in the late 1800s, early 1900s. Railway development. Industry rejuvenation: 1970s (with ICTs, biotech, etc.)	Mechanisation. Development of intensive fruit culture (high density). Orchards management and productions inputs (1950s) Development of new cultivars (breeding programmes): pioneers 1930s and extended 1970s. Increased demand for fresh fruit in the Northern Hemisphere: 1980s	Hatchery technology and hatcheries programmes established in 1950s-1960s. Farming experimentation by entrepreneurs: 1960s. Roads and ports. Regulation of coastal usage. Increased demand from high income countries.
Factors in Chile	Nationalisation Mining infrastructure development	Agrarian reform, fruit development plan: 1960s Export incentives: 1980s	Feasibility studies and demonstration projects
Expansion and catching up in Chile	High profits, no growth, no R&D: 1950s-1960s. Intense process innovation:1970s-1990s R&D strategic planning: 1990s Network development with offshore and suppliers growth. New mines, foreign investments: 1980s, 1990s. Active Learning System	High profits, easy growth, entrepreneurial: 1980s Catching up, process innovation by updating production to international standards: 1980s, 1990s (lower prices in 1990s). Acquisition of fruit varieties (royalties and direct propagation). Leadership by international distributors in the 1990s Passive Learning System	Entrepreneurial growth, high prices: 1985-1989 Producer network (salmon association) Intense process innovation: 1990s Network of suppliers: 1990s Suppliers process innovation: 2000s Mixed Learning System
Internationalisation effects in Chile	Oligopolistic structure: 1990s Concentration and internationalisation of suppliers: 2000s	Oligopolistic structure: 1990s Concentration of distributors: 2000s	Oligopolistic structure: mid 2000s. Greater focus on profits Concentration of suppliers: end of 2000s
Government role	New mining regulation: 1983 State 'rolled back': 1990s Taxation review: 2000s	Funding for technological development: 1990s and 2000s	Development of regulation: 1990s and 2000s Funding for technological development: 1990s and 2000s
Product innovation in Chile	Development of the Lithium and Molybdenum mining industries?	Development of fruit varieties: 2000s Development of cultivars?	New markets: mid 1990s Research projects for aquaculture development in other regions, domestication of sea species: late 1990s, 2000s Research on integrated aquaculture: 2000s

Source: Author's elaboration based on Chapters 5, 6 and 7.

8.1.2 Industry expansion and learning processes

The processes of industry expansion, technological catch up and internationalisation (third and fourth blocks in Table 8.1) show a similar pattern with different temporality. Technological catching up is represented here as the expansion of production possibilities to a level comparable with that of international competitors.

The Chilean copper industry became an agent in the international scene in the 1970s – from being an operational facility of a foreign agent. The dominant technological paradigm was technological rejuvenation, and the industry had entered a phase of intensive process innovation. Leaders in this new technological paradigm, such as Australia, had begun learning processes for this new epoch, 20 years earlier. However, the Chilean industry was able to catch up by the end of the 1990s and maintained a strong position in the international market. During this period, learning processes were active. CODELCO and CIMM developed new technologies. There were R&D teams, productivity in Chile was competitive, production augmented and Chile attained a leading role in the international market. A network of specialised suppliers to copper producers developed. The copper industry became an 'active learning system' (Viotti, 2001, and see Ch. 2, Section 2.2).

Expansion of the Chilean copper industry included foreign investment, particularly big international players, who were invited to join in order to expand the industry; the reason for doing so cannot be explained by lack of technological capabilities of the existing players. During the 1990s the structure of the copper industry in Chile became oligopolistic. New technology suppliers entered the country - following international producers - and partly crowded out local suppliers in a process of concentration of players.

In the 1980s, the Chilean fruit growing sector joined the international field, which had been working within a new technological paradigm since the beginning of the 20th century. It had moved towards intensive agriculture, mechanisation and transformation. Chile caught up by employing a strategy of imported technology, imitation of production processes in leading countries, and adoption of global production standards.

The fruit industry initially was populated by entrepreneurs, but it soon became concentrated towards an oligopolistic structure. There was increasing specialisation among the agents. Distribution required market expertise and strong networks. Distribution became increasingly concentrated in international agents which dictated the structure of the field. Industry learning was passive, that is, technological efforts were directed to assimilate production capability. The focus on R&D did not start until the 1990s and 2000s when government funding was provided to support research projects involving partnerships between science and technology suppliers and producer firms.

In the field of salmon farming, Chile was an early player, participating in the very early stages of development of an industry that was promoted by a new technological paradigm. Chile was one of several salmon producers in the market. Chile initially acquired technology developed by leading technology firms, but was forced to develop the capabilities for technology adaptation and exploitation to produce in local conditions and to keep pace with international players. In the first stage learning was active and intense in improvement efforts. However, the later transformations to the industry did not provide incentives for sustained active learning in all parts of the industry. Science and technology suppliers are highly dependent on government funding.

Government funded at least two studies to assess research, technology and innovation in aquaculture in Chile: a diagnosis by Universidad Austral (Bravo et al., 2007) and a prospective study for CNIC (Parada, 2010). Both studies concluded that it is not possible to establish the impact of research projects on the development of the industry. This is a controversial issue for every project is funded on the bases of expected impact and it is reported on the same grounds. Results of the studies may indicate that obtaining funding is the main driver of salmon related research.

The diagnosis by Universidad Austral (Bravo et al., 2007) provides detailed information of the aquaculture projects involving public funding, between 1990 and 2005. They conclude that a majority of the research had concentrated on improving technology for production. The assessment of innovations needs in Chilean aquaculture published by CNIC (Parada, 2010) discussed the consequences of the project oriented routines of science and technology suppliers. Projects do not reach the investment stage for there is a gap between R&D results and commercialisation. In some cases project results are filed away or were awaiting investors in order to conduct a pilot stage or were taken prematurely to the commercialisation stage with high probabilities of failure.

In the early 2000s the Chilean salmon industry moved towards an oligopolistic structure of producers and suppliers. There were also changes in the internal fields of the firms – as a result of processes of mergers and acquisitions. Firms adopted a variety of strategies towards the development of their business, some become dominated by stakeholders who had entered the field to diversify their portfolios and capture short term profits.

8.1.3 Policy and new industries

The fifth and sixth blocks in Table 8.1 show concomitant changes in policy and potential derivatives from the later stages of product innovation. In the 1970s copper production grew and rich new deposits were discovered, then preoccupation became how to expand production further. The political balance of the various agents' divergent views resulted in the decision to open the industry to foreign investment and offer new mines to concessionaries rather than leaving development to the public company. This decision took form in new regulation, which defined a new configuration of the agents in the field and the rolling back of the state.

Industry performance and copper prices provoked revisions to law on taxation. Producer firms were influential agents in this process. In the later stage of intense process innovation, which allowed CODELCO to catch up technologically, mining activities took some new directions. For example, CODELCO began to mine molybdenum. However, there is ongoing struggle over the strategies, targets and rules of the games related to the exploitation of minerals such as molybdenum and lithium, where demand is increasing and forecast to continue to do so.

In the 2000s the fruit industry intensified diversification into new products, for example, avocados and berries. The state played an important supporting role in the early stages of these new developments. It funded technological missions (visits to leading producer countries' fairs and technology suppliers' facilities) for potential producers, and provided incentives for technological development. Several government supported projects were established for the development of new cultivars for important export fruits (e.g., apples, grapes and raspberries). Most government funding followed a logic of market failure and was led by private sector 'demand', rather than being the result of strategic planning or developmental targets.

In the case of the salmon farming industry, when the size of the industry became significant in the early 1980s, the need for regulation over sea and coastal use was unavoidable. That sea concessions were a restriction and needed regulation had been known for some time, but in the 1980s became a pressing problem. Given the political circumstances of the country at the end of the 1980s (transition from dictatorship to democracy), it was not until the early 1990s that new regulation was introduced. Regulation was general, including both aquaculture and the fisheries sectors. The balance of power and alignment of agents' interests resulted in a loosely regulated sector, with several areas left unregulated.

The salmon sanitary crisis of 2007-2009 forced government to undertake the postponed review of the regulatory framework. Similarly to the case of fruit, in the salmon industry supply of science and technology had been heavily dependent on government support, under the logic of private 'demand'. During the late 1990s and early 2000s several research projects were aimed at diversification of Chilean aquaculture based on the lessons learnt from the experience of the salmon industry. These were long term projects which have not received consistent treatment; funding schemes often require early involvement of a commercial investor partner. Since the development of aquaculture technology to domesticate wild fish can take 20 years, the early involvement of investors in the expectation of short term results may be detrimental (Parada, 2010).

8.1.4 Differences in SLS

The three SLS present similar characteristics, but their performance in terms of learning is different. Copper presents the characteristics of an active learning system, whereas fruit characteristics are those of a passive learning system. The salmon SLS seems related to processes of passive incremental innovation, even though there are examples of in-house R&D in the big producer and supplier companies.

Fruit and salmon product innovation and process technology development (functions associated to innovation capability) are highly dependent on government subsidies. These subsidies have been directed primarily to promoting linkages between universities and public research institutes. Subsidies are an important explanation for the upsurge of SLS science and technology suppliers within those institutions. Research in universities and public institutes depends on these subsidies. Policy intertwines SLS and the scientific field by subsidising demand from producers (who lead the direction of investment) and generate indirect demand (from producers, not from the funding state) for science and technology suppliers. In the case of copper there is demand for science and technology possibilities directly from producers and intermediated by public subsidies. Subsidies for science and technology come from mining royalties.

The SLS are similar but they demonstrate differences in accumulation of producer capabilities. Following the comparative logic of the research design (See Ch.3, Section 3.3.1), the explanation for different learning patterns may lie in the differences between SLS. By examining the depiction of SLS in Chapters 5, 6 and 7, I identified as differences: characteristics of the labour market, length of time of accumulation of capabilities, and power structure of the industry.

The conditions of employment in the SLS vary, even though the number of workers involved is similar[17]. Historical data (Meller, 1996) between 1890 and 1990 show that up to 1920 the labour market was not regulated (e.g., workers had no written contracts, agreements or pensions; child labour was common and there was no maximum number of hours per working day). In this context of poor labour conditions, the conditions for the peasant population were much worse. A majority worked under tenant-worker contracts and their salaries were the lowest in the economy (six times lower than those of miners). Important differences in salaries among these two industries continued until 1990 and are probably still in place.

There are also historical differences in degree of unionisation. In the 1930s, several labour market laws were in place, including the right to form unions. In 1932, the mining sector had almost 55 thousand unionised workers and there were no agricultural sector unions. In 1970 – when union activity reached a peak – unionised copper workers numbered 436,974 with only 114,112 in agriculture (a sector with the bigger total number of workers) (Meller, 1996: 110). These differences persist; ILO reports a 10% unionisation of total Chilean workers in 2006 (Reinecke and Velasco, 2006) and the GCM committee reports 85% unionisation in its industry in 2008 (Consejo Minero, 2008). Workers in the mining sector have the highest number of years of schooling per

[17] 1% for copper (INE, 2002), estimated 2% or less for fruit (fruit counts for 26% of agriculture, which employs 7% of the total labour force); however, numbers are regionally significant.

worker in the economy, and agriculture the lowest (see Chs 5 and 6). Employment in the salmon industry is concentrated in low skilled workers.

There are differences in the length of time the capability dynamic had been in place and the maturity of the technology when the SLS became part of the international market. Copper had a lag in the 1970s in relation to international competitors, but once the dynamic of capability accumulation started, by the end of the 1990s there was technological catching up and accumulation continued. Fruit farming joined an international market were competitors had 60 years of advantage in intensive farming technologies and breeding of new varieties. The Chilean strategy consisted of catching up by introducing technology (including fruit varieties) without need of major adaptations.

The dynamic of producer capability accumulation did not include scientific suppliers – at least not to a great extent – until the industry was well established and government provided subsidies for R&D. In the case of salmon farming the industry joined at an early stage in the international industry, the capability dynamic had been observed but related to subsidies and, in the 2000s, activity has concentrated on suppliers that were at a distance from producers (e.g., partnerships between research centres and pharmaceutical companies to develop vaccines). The capability dynamic in agriculture and salmon farming is weak, dependent on subsidies and had been active for relatively short time.

Although the three SLS had moved towards an oligopolistic structure of producers and a network of suppliers, power structures differ. In the copper sector, the GCM producer companies are the most powerful governance agents, whereas in fruit power is concentrated in the distributors (some of which are also producers) and in salmon the concentration of suppliers (particularly feed suppliers) seems to be impacting the mode of governance. The dominant agents in each SLS show differences across sectors. They have different profitability in economic terms and also in relation to company missions. These differences are discussed further in Section 8.4 on the alignment among agents from the perspective of doctoral graduates.

The next section redirects the focus to doctoral graduates, comparing their experience within the SLS.

8.2 Comparison of Doctoral Graduates' Horizons

Each of the three SLS analysed offered career possibilities for doctoral graduates. This section summarises and compares these possibilities and the boundaries to each field – copper mining, fruit growing and salmon farming.

The analysis is circumscribed to the role of doctoral graduates as scientific suppliers. It considers they may act in different networks and different fields. As von Tunzelmann (2010a) points out, individual agents are likely to engage in quite diverse networks. In our own practice as academic researchers we can identify several different networks relevant to our work (e.g., our institutional and disciplinary networks). Doctoral graduates' most common roles in the three industry sectors were scientific suppliers to the relevant industry – through direct employment in producer firms or working for research institutions or universities. Doctoral graduates frequently combined roles in the industry sectors with other economic activities, particularly in the national science field.

Chapters 5, 6 and 7, Sections 5.3, 6.3 and 7.3, identified types of capital effective in each SLS, which explained doctoral graduate participation at certain times in the history of these fields. These sections focus on the gradual transitions made by doctoral graduates acting as scientific suppliers, to achieve a position in the respective fields. Doctoral graduates became part of the field when they took positions in which they had an effect on the field and the field had an effect on them. Effects can be explained by the valorisation of capitals at play in the field. The logic of these effects for each field was analysed, based on the capability schema (Chs 5, 6 and 7, Sections 5.4, 6.4 and 7.4).

Doctoral graduates had become active in their particular fields because they possessed the necessary properties that enabled them to produce effects in their fields. They are linked to their fields by objective relations (material and symbolic) that give them a singular point of view or position, from which to construct their particular vision of the world and of the fields.

8.2.1 Doctoral graduates in the field of copper mining

The historical review of the copper sector (Ch. 5, Sections 5.1 and 5.2) shows that, before the process of nationalisation (1966-1971), the space for scientific suppliers to the copper mining industry was very limited. The active role of the mining engineers' association in the nationalisation debate shows that there was limited space in the industry even for professional technological services. At that time, the few doctoral graduates working on copper related topics were university academics teaching undergraduate engineering programmes. Scientific capabilities were rare and production capabilities were not sufficiently complex to generate demand, which resulted in limited production possibilities for the Chilean copper mining industry. The industry was dominated by large foreign companies, which retained the more complex activities in their headquarters, requiring local suppliers to engage only in basic operations.

In the 1970s the public producer firm, CODELCO, and the public research institute, CIMM, hired scientific suppliers. The process of nationalisation resulted in national engineers – engineering programmes had expanded in the 1960s - taking over production management, and the expansion and strategic direction of the industry. There was agreement about the importance of science and technology for industry development. New large scale investment brought urgent science and technology challenges and revealed the need for technological upgrading. In this context scientific knowledge was valued and welcomed for application to production problems. CIMM, created in 1970, was a natural space for scientific suppliers. Over the 1970s, CODELCO accumulated producer capabilities, which translated into demand for production possibilities. The scientific and technological capability dynamics (see Ch. 5, Section 5.4) started and grew steadily up to the 1990s, even during the recession and period of low copper prices in the 1980s.

CODELCO was established as a result of changes to the law and regulation and to the relationships between Chile and foreign investors. Its explicit mission was capability building. From the 1970s Chilean copper production expanded significantly following a period of stagnation in the 1950s and 1960s, and Chile became the world's leading producer of copper (see Ch. 5, Section 5.1). The investigation of production outcomes shows there was no 'lower' level of Chilean producer capabilities compared to international competitors, and no diminishing production possibilities. Science and technology suppliers populated the industry; some as a result of CODELCO's outsourcing strategy during the 1980s. A local science and technology supplier base developed. Local producers and science and technology suppliers accumulated capabilities by maintaining the active capability dynamics analysed in Chapter 5, Section 5.4.

In the 1990s universities and research institutes, such as CIMM, were reliant mostly on competitive funding and private contracts. Most schemes set up in the 1990s required partnerships with industry. CIMM and some universities were science and technology suppliers to the industry among many others (private engineering consultancies, private analytical laboratories, etc). Projects with government funding (direct or through tax reduction) were only a part of the contracts involving scientific suppliers.

The hybrid nature of the field in the 1990s and the first decade of the 2000s, involving public and private, national and international agents, offered a variety of possible positions for scientific suppliers and also set some boundaries. Scientific suppliers are employed by private and public producers, and public and private science and technology suppliers. They also provide independent scientific services to producers or suppliers.

8.2.2 Doctoral graduates in the field of fruit growing

The analysis in Chapter 6 suggests that doctoral graduates as scientific suppliers had a place in the field only when the first period of 'easy' profits (in the 1980s) ended. International competition increased in the 1990s and the fragility of Chilean industry was evident, particularly after incidents such as the poisoned grapes in 1989. In the 1990s the competitive funding schemes offered by government agencies became the norm for funding research and the numbers of doctoral graduates grew. Before the 1990s (see Chapter 6, Section 6.4) a capabilities dynamic involving scientific suppliers – particularly doctoral graduates – in the field of fruit production was not observable. This suggests that production capabilities were not sufficiently complex for there to be demand for expanding production possibilities, which resulted in limited production possibilities for Chilean fruit farming.

In the 1990s, several doctoral graduates were involved in agriculture, some of whom were specialised in fruit growing. They achieved positions in universities, research centres and government, which provided them with economic stability and required no direct involvement in the production field. In the 1990s, with the publication of several competitive funding schemes and greater pressure for self-funding, doctoral graduates gradually took up roles as scientific suppliers to the industry in government funded research projects. Doctoral graduates working in universities saw their scientific knowledge, credentials and university positions as valuable capitals for applying to the newly created research funds. They were able to play relevant roles in the provision of scientific supply, for example, by leading the new university units (research centres) created to supply the industry. Once they started working for the industry in a sustained dynamic, they began to accumulate capabilities in the field.

Doctoral graduates working in government probably contributed to the design of policy and had some indirect involvement in the inclusion of scientific suppliers in the production dynamic of the field of fruit growing. Doctoral graduates in managerial positions in universities contributed to constructing university science and technology suppliers for the fruit sector. Those science and technology suppliers units attracted funding, built reputation, and had impacts on the industry field and on university teaching activities. Scientific suppliers recognised as experts in the field of fruit production are consulted about developments in the sector and the fruit growing region. This participation is an instance of influencing the field.

In the 1990s and 2000s the number of universities increased, which also increased competition for research funding. Producers faced a context of greater concentration of the industry and domination of commercialising companies. Firms with the resources to fund long term projects in the 1990s and up to 2010 were likely to be big commercial organisations with upstream integration into production, and producer associations. Most big commercial firms are international companies and their decisions about investment in research, technology, development and innovation are related not just to Chile. In this scenario government funding has been important for scientific suppliers. Most government funding is allocated to short and medium term projects and goes to a wide variety of competing institutions.

The fruit industry as well as the salmon farming industry, attracted researchers from the life sciences able to use their skills for biotechnology applications. Biology and biochemistry graduate and undergraduate education is oriented towards a research career. The employability of the graduates from these disciplines outside academia and research institutes had been limited. Chile has no pharmaceutical or other industry that would provide employment for substantial numbers of life sciences graduates. Biotechnological applications represented a labour opportunity for them.

8.2.3 Doctoral graduates in the field of salmon farming

During the industry's gestation (1960s-1970s), there were several specialists in government and research institutions working in the field, but most were not doctoral graduates, the area was new, and the few doctoral graduates in Chile were employed mainly in universities. It was not until the end of the 1980s that the situation began to change, and during the 1990s the focus on process innovation increased the value of scientific capital. Projects conducted by private companies and in partnerships with science and technology suppliers based on public and private funding, flourished. The number of doctoral graduates involved in the salmon farming field grew in the 1990s, in part as a response to the attractive job possibilities.

In the 2000s, doctoral graduates from areas such as biological science moved to the salmon industry which they saw as offering good research opportunities, they reoriented their research towards salmon farming applications. In the 2000s the first national doctoral degrees in aquaculture were offered. Most science and technology supplier activities continued to be dependent on public funding.

8.3 Failure in the SLS

The principal point of this section is to show that even though policy had been designed to overcome market failure, many other failures have been present in the history of the three SLS under study. The market failure policy rationale resulted in providing a market for scientific suppliers based on subsidies to producers' demand – and avoiding the direct discussion of research funding in universities and public research institutes. This solution does not seem to be resolving the problem of weak producer capabilities. Policy inefficiency can be explained in part by exploring its assumptions. As a first step, this section identifies other forms of failure that could be having an effect on the SLS performance.

The historical reviews in Chapters 5, 6 and 7 provide several examples of failures in the SLS, at different times some of which are summarised in Table 8.3. Table 8.3 is constructed drawing on the propositions in von Tunzelmann (2010b) which attributes specific and systemic failures to different governance modes.

Table 8.2: Examples of Failure in the History of the SLS

Governance Mode		Specific Failure	Systemic Failure
Market	Copper	2002: Oversupply	Price decrease
	Fruit	1940s: Product under/supply 1981-1982: Bank bankruptcy Automatic adjustment Late devaluation in 1982	Export dependency (20% foreign currency used to buy agricultural products) Negative effect on balance of payment and inflation. Economic recession.
	Salmon	Early1990s: oversupply	Price decrease
Corporate	Copper	1930s to 60s: Capture by international firms. Price fixed by home country and main consumer.	Stagnation of production and growth.
	Fruit	1930s-1960s Low returns in Agro	Rudimentary technology
	Salmon	Multinational and big companies capture of concessions	Restrictions to new entrants
Government	Copper	1950s: Conflicts with international companies. 1990s onwards: Ambiguity in role and policy for public companies.	Different conditions for firms, uneven ground.
	Fruit	Before Agrarian Reform: MP landowners 1980s: subcontracting	Political power of land owners over tenant/workers Under-regulated labour market
	Salmon	Sanitary problems	Lack of regulation
Network	Copper	1950s and 60s: Foreign owners not integrated to the local networks	Isolation of the mining sector, enclave.
	Fruit	Before Agrarian Reform: Concentration of the land Fixed prices (to favour urban workers and industrialisation) and low taxes	Interests of landowners over-represented (in comparison to workers, country export balance, industrial policy)
	Salmon	2000s : weakening of Association	Under-representation of small and medium producers and suppliers in policy debate and industry planning.

Source: Application of von Tunzelmann (2010b) and Chapter 5, 6 and 7.

The two most important historical issues in the SLS had been the Agrarian Reform and the Nationalisation of Copper. Both can be understood as rooted in network failure and in both cases the solution involved a struggle, and in both processes change took place under democracy. The main tools were legal instruments –effectively implemented – and they were pacific and led by the government. Both brought together wide social and political support and were associated with a country vision. As is widely recognised by historians, both changes were profound and permanent, Chilean society did not return to the old structures (or at least has not so far). The solution implied aligning the objectives of all intervening agents (e.g., the Chilean government compensated the US companies for their losses without the need for legal proceedings).

The most important issues related to salmon farming were the sanitary problems affecting production, which derived not from market failure, but from network failure. The 2007 sanitary crisis resulted in the formulation of regulation which previously was absent in the system.

8.4 Alignment of Systems and Networks for Doctoral Graduates

Given the importance of alignment for SLS governance for developmental aims, this section explores the issues of alignment in the SLS from the perspective of doctoral graduates' accumulation of producer capabilities and participation of doctoral graduates as scientific suppliers. The aim is to assess alignment of agents' rewards and factors affecting the structure of actors across the network in each industry field. The analysis focuses on the dynamics of practice involving doctoral graduates acting as scientific suppliers to the three industry fields. That is, the market for scientific possibilities where the scientific supplier provides labour to a science and technology institution, which supplies producer firms with technological possibilities.

Table 8.3 summarises the rewards for the production triad of scientific supplier, science and technology supplier and producer firm, and the factors that affect the structure of these actors beyond the dynamics of interchange between them. The last row in Table 8.3 indicates whether these factors are generic or sector specific. The first column has been added to those in the 'capabilities schema' (von Tunzelmann, 2009) to include the state as an agent that affects the structure of actors and their dynamics, through different policies. The state also has its own 'interests', here named 'targets'. Table 8.3 is followed by a discussion of alignment issues by agent. This is a comparison of agents within a SLS, rather than across SLS.

Figure 8.3: Agents' Alignment (for supply of scientific possibilities)

Actors	State	Scientific Supplier	Science and Technology Supplier	Producer Firm
Targets/ Rewards	Developmental Goals	Earnings/Scientific Rewards	Profitability/ IPRs	Profitability
Generative Factors	Geo-political conflict Economic Stability	Doctoral graduates' expansion policies	Funding policy Higher education field dynamic Different rules for different agents	Concessions Tax policy Foreign investment policy Differences between CODELCO and private firms
Field	Generic/sectoral	Generic	Generic	Sectoral

Source: Author's elaboration based on von Tunzelmann (2009) and previous chapters in this thesis.

8.4.1 The state

The state and those able to impose their views through it contributes substantially to producing the market where the capabilities dynamics of the scientific supplier takes place. The market for scientific possibilities is the product of a three pronged social construction to which the state contributes crucially at the construction of each of the three actors: supplier (doctoral graduates), producer (research institutions acting as science and technology suppliers) and consumer (producer firms in each sector). The state contributes to the construction of the supplier by participating in the production of doctoral graduates, who embody individual dispositions and cultural capital. The state takes part in the construction of producers (research institutions) through policies for funding for research institutions. The state also takes part in the construction of the consumer (producer firms) through regulations related to their participation in the market and their profitability (e.g., tax system).

The state's aims are considered to be developmental targets. At the general level they are economic growth and export diversification. In the case of copper , the state's strategy historically has been oriented to maximising revenues for redistribution. The aims at national and regional level (local governments in the northern regions and the other regions) are contradictory. The regional level claims a larger share of the industry revenues for local development.

The fruit industry had contributed to the target of exports diversification to decrease dependence on copper and national economic vulnerability. It has been also an important source of employment for the populations in the poor regions in the central valley, although it is low quality employment (temporary, low wage and often subcontracted). Together with salmon, it has been cited as an example of the effectiveness of economic policy. Scientific suppliers are not tied to the region, some important science and technology suppliers are located in Santiago.

The salmon industry had responded to similar targets and in this sector the significance for regional employment is even more relevant. The southern regions had no major industries and they present not only issues of poverty but also geo-political ones (the aim of innovation policy was discussed in Ch. 1). Scientific suppliers had moved to the region.

8.4.2 Scientific suppliers (doctoral graduates)

Regulation and financial assistance (loans, grants, tax exemptions, cheap credit, etc.) play a part in making a place for doctoral graduates to act as scientific suppliers in the industry field. This assistance contributed by directly or indirectly guiding the decisions of the various agents in the field. For example, every measure aimed at increasing the number of doctoral graduates – through the provision of scholarships and loans, and grants to universities to develop their doctoral programmes – had an effect on the scientific supplier structure (see Ch. 4).

Scientific suppliers are commonly part of industry networks and also science and technology networks beyond the focal industry field. This implies that their practice and valorisation of rewards consider both fields. Rewards, although individual, are likely to include scientific rewards (peer recognition, scientific challenges, facilities for developing scientific capabilities) as well as economic rewards.

8.4.3 The science and technology suppliers (universities and research centres)

A policy such as that implemented by the 1982 universities reform and the reform of public research institutes, which imposed self funding, redirects universities and research institutes towards taking on the role of scientific supplier to industry fields. The policy for funding research institutions contributes to defining institutions’ positions within the structure of the field of scientific producers and their conditions for accessing the market (see Ch.4).

Research funding is important for universities, but their main source of finance is student fees. In Chilean universities faculty usually multi-task (with engagement in at least teaching and research); it is unusual to have research only faculty except among people employed on temporary contracts associated with a project (a precarious job situation). In engaging in applied research in partnership with industry, universities have to assess their rewards within the wider context by considering the effects on the field of higher education. Projects can bring prestige, reputation, objectified capital (e.g., equipment and laboratories) and publications, all of which attract students and public funding not directly related to the industry field. Applied research has also direct effects on teaching.

8.4.4 The producer firm (consumers of production possibilities)

The state contributes to the construction of consumers through the allocation of resources in the form of state assistance to producers to buy science and technology services, as defined in the law and regulation.

Rewards to producer firms were taken to be profit maximisation. Considering the firm as a field in itself - a structure of actors and networks involved in a dynamic of practice (Bourdieu, 2005) - there may be different views of the rewards inside the firm. In market ruled industries – such as the three studied in this thesis - stakeholders, who care about their capital investment, have the final say. The internal dynamics of the industry field and other characteristics (eg., property) determine the firm’s profitability, which need not be solely economic.

8.4.5 Alignment of agents

This section takes the relationship between the salmon industry and the universities to discuss alignment of agents around the policy of R&D subsidies. Policy instruments promoted linkages between universities and the productive sector where universities acted as scientific producers (or suppliers).

Universities need firms’ involvement to access funding. Producer firms may be different in terms of their interest in undertaking R&D. Some may seek short-term profits and be unwilling to pay the full cost of scientific possibilities; others may have weak producer capabilities and may not see the benefits of expanding scientific possibilities, or may be unable to profit from them; yet others may be operating within very tight margins that do not allow them to consider investment, even though not investing may worsen their situation; finally, some may have regular demand for scientific possibilities. In all these possible cases, subsidies would be welcomed.

On the other side, science and technology suppliers depend on research funding to do their job. Research not only determines their possibilities to publish and to participate in the scientific field, it also informs their teaching and postgraduate education. In conducting projects for industry they may have expectations of rewards that go beyond the industry field.

The two sides have good reason to collaborate, and that is what seems to be happening according to the diagnosis and evaluations for the sector (Bravo et al., 2007; Parada, 2010). Scientific suppliers may nurture relations with producers (e.g., in the expectation of future projects or for personal reasons), but there is a conflict between their short term publicly funded efforts and the firm’s real enhancement of technological possibilities. In a sense, the policy instrument, the scientific supplier and the producer firm are perfectly aligned. There are increased university-industry linkages, the scientific supplier is able to do research and the firm has the opportunity for involvement in R&D at minimum cost and with potential benefits. However, increasing linkages between science and technology providers and producer firms, does not say much about the direction of those linkages or the accumulation of capabilities they foster. It is likely that a policy target focused on ‘number’ of linkages is too narrow to be effective.

Maintaining the routines of well aligned agents described in the preceding paragraph has several consequences. For example, the relationship between scientific suppliers and producers may imply difficulties for the former to provide science and technology services to other clients (e.g., requests for third party environmental monitoring). Although there may be no other market beyond production applications in the current circumstances, even if there were to be one, scientific suppliers have not been involved in learning activities in other areas. This implies that they may have competences but have not accumulated capabilities and there would be limitations to develop other areas.

State developmental targets had implied a strategy of ‘unconditional’ support for industry. The industries analysed in this thesis have all demonstrated rapid expansion, but the sanitary crisis in salmon shows that extreme convergence in the aims of the state and the industry can lead to the state neglecting its regulatory role which, in this case, resulted in a sustainability crisis, which reduced the industry’s expected rewards. The state’s neglect had perverse results. Its involvement probed important for the long term alignment of targets and rewards.

If the current funding for research, development and innovation was dysfunctional for the long term development of the aquaculture sector in Chile, as Parada (2010) concludes, scientific suppliers within the field may be blind to it. Proposals for improving research, development and innovation performance tend to be around increasing the amounts of the current funding instruments or creating new ones. These propositions come from outstanding researchers (well positioned players) invited to contribute to policymaking.

Maintaining the system of research funding might be explained by habitus and the tendency of agents to maintain and improve their positions in the field. We – humans - are trapped in our own embodied limitations. We only think of solutions to improve what we take for granted, the funding system is taken for granted. Managers and advisers to the research funding system are scientific suppliers themselves (e.g., members of scientific committees and project evaluators collaborating with CONICYT). They had proposed and pushed forward initiatives such as the creation of new research centres of scientific excellence – as they are called – for example, CIEN in aquaculture. They had been influential and active in creating a demand for scientific possibilities under existing conditions. They act within their space of influence, they probably have little or no influence over the industry field, but they may act within their space of influence and try to expand their work possibilities and their students’ work possibilities too. That is part of their interests which they may rightly see as perfectly aligned with the developmental goals of the country and the industry sector.

Another perspective on alignment and collaboration of agents can be observed between the state and producers. The Chilean coastal zones suitable for salmon farming are vast. Salmon farming has developed in only a fraction of them. Agglomeration of production sites in the sea had been a factor for the deterioration in sanitary and environmental conditions of production, a situation well known in the industry[18]. A constraint to expanding production is access to sea sites. Government decides on the location of production sites by granting marine concessions – which involves legislation as well as management of political powers among agents in the field. Another constraint has been the lack of infrastructure – roads, ports and services in producer communities. Government policy does not consider expansion of infrastructure and services (many infrastructure works in Chile, for example roads, are concessions based on a return on investment evaluation). Although producers have tried to exert pressure for expansion of coastal concessions, producers have 'collaborated' with current policy conditions.

8.5 Conclusion: Comparison of Agents for Alignment and Collaboration

The alignment perspective presented in Section 8.4 may suggest an alternative interpretation of agents' behaviour and a different disposition of researchers towards policy advice. This concluding section explores the implications of alignment with policy advice in practice, using an example from the salmon industry.

Researchers had often assumed that policy makers are not well informed and that, if they had sound evidence, they would do the 'right thing'. For example, Iizuka and Katz (2011) refer to the reasons for the 2007 sanitary crisis as due to the short-sightedness of firms and lack of capabilities for administering a common pool resource. They believe that: 'The firms opted for an opportunistic path of short term profit maximization instead of long term sustainable path...blinded by the overall climate of success and rising international prices, the firms started to overexploit the CPR [Common Pool of Resources]' and that firms' behaviour was rational in maximising profits but had 'a collective outcome that resulted in the disregard of the CPR, thereby exposing the industry to the catastrophe' (Iizuka and Katz, 2011: 278).

From an alignment perspective, one would question why all producer firms should be interested in long term sustainability. During fieldwork Dr Bio-ecology mentioned that

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[18] E.g. fieldwork conducted in 2011 by a SPRU PhD student, Verónica Roa, included more than 80 interviews with industry members. A majority of the interviewees acknowledged 'everyone knew' production conditions were likely to result in a sanitary crisis. It was common knowledge in the sector; in my job at Fundación Chile in 1997-1998 I heard about it. However, robust scientific evidence had been scarce. This is likely due to the fact that funding for research is awarded for technological improvements and scientific suppliers do not want to damage their relations with producers.

he had found partners in small family-owned salmon producer firms, because they were interested in maintaining the business for their children. While doing site observations in Chiloe Island I met mollusc producers who were second generation in the family firm. They commented on their differences compared to the big salmon producers; they were keeping their business running for the long term sustainability of their families. These examples show that some firms, and not necessarily just small family-owned firms, may be interested in the persistence of the industry, while others may not. In contrast to Iizuka and Katz, I assume firms did know the potential effects of overstocking of the fish (I think they were neither myopic nor blind). It would be difficult to prove because acknowledging it would make the informer unpopular. If some firms were not interested in long term survival of the industry (which doesn't mean every one of the members of the firm wasn't, it means the balances of forces within the firm field resulted in a short-term business strategy) and they operated within the legal framework, why should they be blamed? They could be on the basis of moral considerations, but that would probably not change their perspective.

Iizuka and Katz (2011: 279) assert that:

> Chilean firms acquired 'competence' in the production of salmon, but they did not attain capability to deal with technological issues associated with environmental sustainability and biological and oceanographic forces impacting sanitary conditions... Furthermore, firms did not understand that they needed to spend more on R&D activities.

Following the alignment perspective, one would ask, why should they have if they were not interested in the long term and moreover, is it their sole responsibility to look after a resources they use as 'tenants'.

Then we obviously turn to the role of the state. Iizuka and Katz (2011: 280) conclude that:

> Due to the novel nature of the industry, private sector knowledge is always more advanced than that of the public regulatory body...In short, the knowledge gap with which the public regulatory body has operated, the emphasis public officials have put on promoting exports and the lack of resources and political

> will to ensure compliance by firms to the existing environmental rules contributed to the environmental collapse of the industry.

The state aligned its interests and collaborated with producers in fostering economic activity in a poor region, promoting exports and leaving space for producers interested in short term profits. In this collaborative attitude, the state deliberately did not use and, therefore, did not develop capabilities for greater control and regulation. It seems somewhat paradoxical why and how the agriculture and livestock service, SAG, was excluded from the industry (despite its participation in the very early stage). It is difficult to believe, for example, that it was not common knowledge that imported eggs could be contaminated. The country had experience of crisis and capabilities to control live material, accumulated in SAG networks across the country and at border controls. There were competences in genetic material imports which, in the case of salmon, could have translated into capabilities.

Finally, Iizuka and Katz (2011: 281) regret:

> If only the instruments of evolutionary economics had been used successfully here, a new set of institutions might have helped the agents and public sector organizations to understand the role of biological, sanitary and environmental forces and could have helped the effective strengthening of the long term exploitation of the common under sustainable conditions.

An alignment perspective moves away from the idea that agents need to be better informed to make the right decisions, an idea that becomes problematic if we question who decides, for example, who decides that long term sustainability is better and for whom. I would argue that although researchers may have their own beliefs in terms of what is morally and developmentally right, decisions in this area should be legitimised by the socio-political context.

Alignment policies work under the assumption of potentially diverse and even conflicting, unresolved views. The relations of force between agents depend on the overall economic situation, which they refract according to their own specific logic.

Chapter 9. Conclusion

Producer capabilities and technological change can be approached from several angles. For my doctoral research, I chose to focus on the roles and positions of doctoral graduates within industry fields, which I refer to as SLS. This concluding chapter starts by focusing on the research questions, Section 9.1. The succeeding sections, Sections 9.2 to 9.5, provide a more detailed account of the contributions of this thesis under the topics of: sectors (SLS), agents (doctoral graduates), theory and methodology.

9.1 Responding to the Research Questions

This section refers to the research questions formulated in Section 3.1.

9.1.1 How do doctoral graduates participate in the accumulation of producer capabilities in SLS?

How do doctoral graduates emerge to take up positions in the history of different SLS?

In the three cases presented in this thesis, doctoral graduates became part of the corresponding SLS during periods of intense– often incremental - technological innovation. The historical evidence presented in Sections 5.1, 5.2, 6.1, 6.2, 7.1 and 7.2; the individual case studies in sections 5.3, 6.3 and 7.3; and the discussion on doctoral graduates' horizons in the three sectors, across time, in section 8.2 provided the basis for identifying periods of intense innovation as the relevant historical circumstance for the emergence of doctoral graduates in the field. This intensive innovation, in all cases, was aimed at technological catching up to sustain competitiveness. Chile entered the three industries studied during conditions of high profit, which attracted new entrants and led to the establishment of the local SLS. When profits later decreased– due in part to lower product prices - pressure to improve the productivity of the SLS increased and efforts were made to develop the required 'improvement capabilities'– in the case of copper mining 'innovation capabilities' (Viotti, 2001). The technological functions associated with these two types of capabilities typically are related to doctoral graduates' capital, that is, their ability to undertake major adaptation to suit local conditions, training – and continuous learning, R&D, etc.

Chile was a late-comer in the new technological paradigm - in all three cases and with different time lags (see Sections 5.1, 6.1 and 7.1). The technologies at the base of the new paradigm were developed elsewhere. In the early stages of technological development Chilean doctoral graduates were not involved; however it is likely that doctoral graduates in the pioneer countries participated in the related R&D because it involved high levels of university participation (see Sections 5.1.2, 6.1.1 and 7.1.1).

What roles and positions do doctoral graduates assume in SLS?

The distinctive role of scientific supplier, that is, a provider of production possibilities for the SLS, was taken on by doctoral graduates – alongside other highly skilled professionals. This role has been deduced from the analysis of economic practice in each of the three SLS (Sections 5.4, 6.4 and 7.4) and observed in the illustrations provided (Sections 5.3, 6.3 and 7.3).

Scientific suppliers' practice facilitates the stretching of producers' possibilities for transforming resources into products and/or improving the efficiency of this transformation. Scientific suppliers act in different positions in the SLS: for example, they may be hired directly by producer firms - as employees or consultants, they can work for science and technology suppliers (organisations providing services to producers, e.g., research centres, engineering consultancy firms and universities), or they can become entrepreneurial scientific suppliers.

The SLS evolved into networked structures of producers and suppliers. During the period of emergence of supplier firms, there were opportunities for doctoral graduates to become entrepreneurs. In this capacity, they created specialised research centres in universities and - at least in the case of copper mining and to a lesser extent in salmon farming - created private firms to provide science and technology services and equipment.

Doctoral graduates were influential in the construction of SLS, particularly in relation to production possibilities. They contributed to the construction of their agents and institutions. For example, doctoral graduates were involved in the education of highly skilled professionals, and the development of a national system of doctoral education, both of which activities expanded the pool of scientific suppliers available in the SLS. Doctoral graduates were influential in policy related to funding R&D, which was important for generating demand for production possibilities and generating employment in the SLS for doctoral graduates. Once funding policies were in place, doctoral graduates took an active part in their implementation (e.g. the processes of evaluation and selection of R&D and technological innovation projects).

Even though doctoral graduates may be crucial for innovation processes and possessors of important knowledge valued in SLS, their position is that of employees or external specialised suppliers, which imply limited power - at least in the three cases studied. The roles identified imply that doctoral graduates take positions which may be stronger that those of other workers in SLS, for example, they display lower rates of unemployment (doctoral graduates are still scarce in Chile). Their work often involves challenges to solve technical problems and to learn, which make their job satisfactory. There is also social recognition and the possibility of maintaining parallel activities in more than one field, for example, higher education and an SLS. This provides greater employability than for other workers and tools for negotiation. Nevertheless, their power within producer firms or as scientific suppliers is relative to the power of other agents in the field. In the three industries of the study, the greatest power is exercised by the owners of capital and – to a certain extent and sometimes with conflicting views – by managers.

What are the practices of doctoral graduates in relation to SLS?

The logic of doctoral graduates' practice in SLS can be explained by their different roles affecting or affected by the SLS. I deduced practice by applying the capability schema in each SLS (Sections 5.4, 6.4 and 7.4), complementing my understanding of practice with the analysis of individual case studies (Sections 5.3, 6.3 and 7.3) and, finally, conducting comparative analysis of the three SLS to extract common, distinctive features of practice (see Section 8.2) .

In the role of scientific suppliers, doctoral graduates' economic activity was that of provider of production possibilities and/or science and technology possibilities. They engaged in market transactions for their services with consumers (final product producer firms and/or research institutions) and with the suppliers of technology which provided inputs for their work (e.g., laboratory, equipment, software and information services). They engaged in non-market relations, particularly knowledge exchange with consumers, suppliers and peers (who might be competitors). Market and non-market exchanges with consumers occur when the capabilities of the scientific supplier meet the capabilities of the consumer, that is, when consumers demand product possibilities because they have the capabilities to assimilate this supply, and their utility implies that they are able to pay for these services. In the SLS studied demand involved important subsidies, particularly in the cases of fruit growing and salmon farming.

Doctoral graduates are agents that often assume different roles simultaneously. For example, they may be university academics providing teaching and research and also consultants to the SLS or providers of services through a research centre. Some of their practice, in various fields, affected and was affected by the SLS and, therefore, shall be considered when analysing the logic of doctoral graduates' practice in the SLS. For example, the reputation and recognition provided by an academic position helped to establish a parallel role as expert scientific supplier. Reciprocally, good linkages with industry were seen as useful to attract funding and student enrolment, leading to offers of university positions. Given the funding structures for universities and research institutes, doctoral graduates were more or less obliged to cultivate parallel roles as scientific suppliers to the SLS.

Once doctoral graduates became established agents in the SLS, they tended to direct their energies towards maintaining or improving their positions in their field. Doctoral graduates championed policies to augment research resources and to support the creation of specialised research centres in each of the SLS.

What are the differences and similarities in doctoral graduate participation, across the three SLS?

The comparative analysis of doctoral graduates' horizons in the three SLS presented in Section 8.2 shows that differences and similarities are related to the history and characteristics of the SLS rather than to differences in doctoral graduate provision. Periods of high and 'easy' profits are less conducive to doctoral graduate participation than periods of intense competition, when technological challenges need to be addressed. Both periods can be observed in the three SLS, but at different times. Less mature technologies offer higher possibilities for doctoral graduates' participation than mature technologies, which can be bought off the shelf in the international market and need only minor adaptations. The period of intense competition in salmon farming, for example, took place in a context of technological development, which offered broad opportunities for improvement and, therefore, greater space for the participation of doctoral graduates. In contrast, the context of the period of intense competition in fruit growing was one of a mature technology which was adopted by Chilean growers with comparatively few adaptation challenges.

The comparative analysis in Section 8.2 shows also that, in all three sectors, funding sources for R&D and innovation have been important for opening spaces for the participation of doctoral graduates. The three SLS benefited from government funding for R&D and innovation, because they are strategic for development policy. Doctoral graduates have been active in developing scientific services for industry using government funding. In the case of copper, producers outdo those in other sectors for performance of R&D and innovation activities based on direct funding (particularly CODELCO, which is very prominent in the national patent register). This structure conforms to more opportunities for doctoral graduates' participation in the SLS, working directly for copper producers and suppliers and fewer similar opportunities observed in fruit growing. In all three cases (copper mining, fruit growing and salmon farming) there is a neglect of research activities related to supporting policy and regulation. These areas receive comparatively less funding and, therefore, offer comparatively fewer opportunities for participation of doctoral graduates.

What producer capabilities are they likely to accumulate?

The concluding sections in each of the SLS chapters, that is, Sections 5.5, 6.5 and 7.5, discuss patterns of capability accumulation based on the evidence and analysis in each of the corresponding chapters. By synthesizing the sectoral discussion it can be concluded that, in the role of scientific supplier, doctoral graduates accumulated improvement and innovation capabilities. Accumulation of improvement capabilities was based on involvement in major adaptations to local conditions – often related to the unique characteristics of the environment and the natural resources (e.g., geographical and climate conditions, biology of species, mineral ore grades, etc.), implementation of quality control systems and standards, provision of continuous training, improvements to processes, adaptations to equipment, search and evaluation in relation to new technological opportunities (external knowledge and skills, and better practices to copy and imitate) and R&D activities. Accumulation of innovation capability was based on engagement in complex process innovation; R&D, collaborative research, and licensing own technology to others.

What are the implications of doctoral graduates' practices and capabilities accumulation for the SLS?

Following on Sections 5.5, 6.5 and 7.5, doctoral graduates' practices in the SLS related to technological adaptation to local conditions and product and process innovation contribute to personal capabilities enhancement and to capabilities accumulation for the SLS. Doctoral graduates' practices take place in a historical and social context and are part of a collective effort. When the conditions for doctoral graduates' participation are open, they can develop practices conducive to the accumulation of producer capabilities for technological innovation and improvement. Doctoral graduates' embodied capabilities are only one dimension of the capabilities at the SLS level.

A complementary deduction is that in areas where there is no doctoral graduate involvement in R&D and innovation activity, it is unlikely that doctoral graduates will accumulate capabilities or will contribute to their accumulation at the organisational and sectoral levels. This would apply, for example, to the lack of R&D and innovation in areas related to government policy and regulation. Although during the period studied, the state was a stakeholder supplying subsidies and commissioning reports, doctoral graduates' provision of scientific services to the state was marginal. This originated in the state's limited direct engagement in R&D programmes (e.g., continuous environmental monitoring, evaluation of natural resources, R&D to inform regulation, non-commercial R&D stages of new industrial developments). The implementation of regulation in the period studied consisted mostly of operational routines. Sporadic revisions and changes to regulations required the commissioning of policy evaluations and problem diagnoses. As a result, capability accumulation in these areas at the individual (doctoral graduate) level was limited (see e.g. Section 7.3, on the small minority of researchers and projects in aquaculture related to areas of environmental monitoring), as well as, at the sectoral level (see e.g. Section 7.1.7, on R&D and innovation activities concentrated on increasing productivity for individual firms and neglecting environmental issues that affected the whole industry).

What can be inferred about how capabilities accumulate?

From the discussion for each sector (Sections 5.5, 6.5 and 7.5), it is possible to conclude that producer capabilities are likely to accumulate in areas where there are regular routines of practice in place and the dynamic is maintained for a sustained period of time. For example, regular practices and associated routines for incremental innovations in copper production –in which doctoral graduates played a part - were maintained for over 20 years (1975 to 1999) and resulted in technological catching up in the 1990s (see Section 5.1.3).

Routines related to the specific practices associated with incremental technological development and product and process innovation needed to be maintained over time in order to become embodied knowledge. Knowledge and skills (embodied cultural capital) became embodied in doctoral graduates through learning by doing. Doctoral graduates' existing competences implied shorter learning times (e.g., experience of good research and project designs, conceptual understanding of the phenomena, etc.); however, they needed to engage in experimentation and learning to develop scientific capabilities in the SLS. Learning by doing also allowed the accumulation of social capital, for example, identification and cultivation of relations with research partners and reliable providers of analytical tests and equipment. Doctoral graduates built a position for themselves in the SLS which could provide access to objectified capital relevant to their work (e.g., specialised equipment and laboratory facilities).

Accumulation of different types of capital required for producer capability at the organisational level (a research centre or unit employing the scientific supplier) also took time. Laboratories were often equipped through funding associated with different projects, and this had to be maintained and teams of researchers built by maintaining a continuous flow of projects and contracts. Over time, based on real results, these organisations built a reputation and a position in the SLS. Doctoral graduates are part of the process and their participation extends to and contributes to producer capabilities.

9.1.2 Which factors are important for capability accumulation by doctoral graduates in the SLS?

What types of capital are important for the participation of doctoral graduates in SLS?

Doctoral graduates entered the SLS when the capitals they hold were valued by the field (see discussion for each SLS in Sections 5.3.2, 6.3.4 and 7.3.3). Doctoral graduates in Chile entered already established SLS in periods of intense incremental technology assimilation and innovation. Their capitals were seen as valuable: for example, embodied scientific knowledge in areas related to SLS technologies, R&D competences, and links with national and international research institutions and disciplinary networks. In some cases their doctoral credentials (institutionalised capital) signalled their capitals; in others doctoral credentials were recognised through the formal evaluation process of competitive bids for funding.

Doctoral graduates can contribute to the early, non-commercial stages of R&D, as was the case in the countries that first developed the early SLS technologies. In these cases, doctoral graduates' capitals were seen as valuable by states commissioning early research in the area unrelated to market dynamics. This did not apply to the Chilean cases studied because Chile was a latecomer to these international industries, which were obliged to catch up to the dominant technological paradigm. However, doctoral graduates were involved in the education of professionals who had the basic competencies required to assimilate the technologies in the early phases of the SLS. In the academic sphere, the capitals of doctoral graduates were valued – particularly their formal credentials (institutionalised cultural capital) - and they had comparative advantage over other professionals in academic positions.

What characteristics of the SLS are important? The three SLS were chosen for their similarities but it was found that they have contrasting performance in learning and capability accumulation. For example, copper presents characteristics of an active learning system where doctoral graduates have had opportunities to take part in innovation projects and the building of sectoral capabilities, whereas fruit growing characteristics are those of a passive learning system with comparatively fewer opportunities for doctoral graduates' participation. Therefore, important characteristics for capabilities accumulation may be found in the differences between the SLS studied.

As discussed in Section 8.1.4, differences in the characteristics of the SLS may be important for explaining divergent performance, and they could be assessed by future research. The SLS studied differ in: the characteristics of their labour markets, length of time of capability accumulation and power structure of the industries (see Section

8.1.4). The biggest contrast can be seen in the cases of copper mining and fruit growing. The copper mining labour market is characterised by the highest average years of schooling, the highest salaries and the highest levels of unionisation in the Chilean economy; in this sector, the capability dynamic has been maintained for the longest period of time among the three SLS studied. Copper mining is dominated by big producer firms which are the most powerful agents in the field. The work force involved in fruit growing is weaker, the dynamic has been observed for a much shorter period, and the industry is dominated by distributors. Fruit producers absorb most of the risks inherent in their industry (climate changes, international currency values, etc.)

What are the differences and similarities in the factors related to the three SLS?

The SLS present different opportunities for learning and developing individual capabilities. Active SLS – where the predominant firm strategy is active learning and technological innovation - offer challenges and provide opportunities for individual learning. When individuals exploit these opportunities, the effort involved implies a reinforcement of the active character of the SLS. The property ‘active’ is not immutable, and the characteristics of the SLS change alongside their histories. In the early periods of high profits and population of the SLS by new entrants, there is a predominance of accumulation of the basic production capabilities required to enter the market. In periods of industry maturation when competition increases, there is pressure to improve productivity, which can lead to periods of active learning. In periods of concentration of the industry in oligopolistic structures supported by networks of suppliers, there is a tendency towards more passive learning.

The three sectors studied show important differences. Copper was an active learning system that provided important challenges and learning opportunities; salmon provided mainly improvement challenges; and fruit growing provided improvement challenges, but the pace was slower than in the case of salmon. The practice that allowed capability accumulation was the threefold capability dynamic of supplier-producer-consumers sustained over time. The capability dynamic explains the engagement of doctoral graduates in the SLS as scientific suppliers and as influential forces in the construction of the agents and structures at play in the capability dynamic.

What doctoral practices are important?

Capabilities accumulate in areas with repetition of regular activities (i.e., there are routines in place and relations of recurrent exchanges). Once the capability dynamic is established and can be maintained, agents develop routines and relations which build to become capital. It is most unlikely that capabilities will be accumulated in areas where there is no capability dynamic. In the cases studied, capabilities were concentrated on improving production processes. Activity around other SLS issues, such as monitoring of natural resources and environmental effects was small, resulting in the capability accumulation in those areas being limited.

9.1.3 What are the implications for public policy?

What are the lessons for public policy from the three cases and their comparison?

The study suggests that the effectiveness of subsidising the supply of scientific possibilities may be limited and that other approaches should be considered. A possible approach might be the generation of strategic demand by the state. History shows that the early stages of non-commercial R&D in potential new industry derivatives were supported by state funding; policy could focus on generating demand for strategic research projects and the accumulation of capabilities related to policy and regulation. There may be a difficult edge in commissioning government research to doctoral graduates - scientific suppliers - because of the way that current funding policy reduces independence among the different work fields. Scientific suppliers need to maintain good relations with producer and supplier firms in order to have partners with whom to apply for funding. Also, the profitability of doctoral graduates depends on maintenance of and extensions to existing SLS funding policies and continuation of funding programmes, even if their main job is in another field (e.g. higher education, public research institution). Policy should consider that SLS and the scientific field are entangled fields.

An example of a demand lead policy could be the generation of sectoral journals, which take into account the importance of publishing for the scientific field and of applied relevance for the SLS. In the case of copper, where the state plays a role through CODELCO, incentives could be offered to generate demand for technology and innovation. CODELCO could sharpen its policies to favour the supply of projects with innovative components and orientation to current industry challenges, such as environmental issues. CODELCO would need some margin for experimentation to support a demand side innovation policy; otherwise it will be disadvantaged compared to other large firms. Strong competition among large mining companies does not favour risk taking or experimentation in the current period of an established oligopoly with high prices for copper.

There is also a recommendation on how policy could be designed – rather than which policies should be applied – coming from the alignment analysis applied in the thesis (see Section 8.4). The discussion on alignment suggests that an explicit consideration of agents' interests could contribute to designing and implementing policy effectively. The state does not need to maintain too cosy relations with the private sector to be effective in aligning agents towards a vision of common interest – a vision which has been absent in the later period of the SLS. A certain degree of struggle does not have to stop mutual benefit from network alignment. Perhaps what has been missing in the SLS in the study has been a clearer role of the country's interests (e.g., protection of its natural resources for the long term, and quality of employment) in the alignment of agents that gives direction to SLS development. Governance by 'consensus' and democracy 'to the extent of what is possible' (the post dictatorship mantra) has been based on fear. To lead alignment, tolerating and managing conflict, needs courage. Chile's social movements, which organised open manifestations of discomfort with social inequality in 2011 and 2012, reproach the Concertación's governments for not having been strong enough to represent people's interests and demand solutions from the current government[19]. In a democracy the government is the legitimate representative of citizen's interests, by not fulfilling that role its legitimacy is questioned.

9.2 Empirical Contributions: Sectors

The three cases are natural resource-based industries and offer greater scope for incremental improvement and innovation than other types of industries. Although any new industry requires minor adaptations to local conditions, natural resources-based industries involve particular improvements because local natural conditions are unique. This is an opportunity if seen as providing an avenue for active learning in the SLS.

[19] This seems unlikely from an alignment perspective, since the current government includes many former executives from private companies who will be probably interested in going back to high positions in the private sector.

The cases presented consistent patterns of development. During the preparatory stage of technology development and other conditions for the future emergence of a new technological paradigm (e.g., changes in demand), states play important roles in commissioning and funding technological development. In the later establishment of the industry, explained by coevolution of technology and governance systems, there was a period of high profits and limited innovation, followed by a period of greater competition and intense process innovation, and a later period of concentration towards oligopolistic structures and probably moderate process innovation (this stage is too recent for persuasive, well documented evaluations). Timeframes varied by sector.

The cases studied are all SLS that caught up in industries where the dominant technologies had been developed abroad. The case of salmon farming – where Chile entered at an early stage of the international industry development - suggests that the less mature the technology is, the more opportunities for active learning and market growth. The contrasting case of fruit growing – where the international industry was well established – suggests that mature technologies may offer rather simple learning challenges and the emphasis is located in developing capital formation at competitive cost, which could easily lead to traps of cheap labour. The SLS studied suggest that periods of high profits do not generate important incentives for developing improvement or innovation capability.

The cases of salmon farming and fruit growing showed a disconnect between scientific efforts and productivity, which can be explained by the limited active learning in those sectors and periods of passive learning.

The historical analysis of the three SLS could be used as a base to develop an argument for criticising the economic reforms of the 1980s. This has not been an aim of the thesis and has appeared as a sidetrack which is only recalled briefly here. By reflecting on historical perspectives offered by the sources consulted and by constructing the cases, the decade between 1975 and 1985 in Chile appeared to me as years of deep social and economic loss. The success of sectors which became examples of the effectiveness of the economic reforms - which include fruit and salmon – was not clear cut in a long span historical perspective. Arguments like this had been made before, but within the still polarized debate on the economic achievements of the economic reforms of the 1980s and the unrecognized grounds for success seeded by previous governments.

A Chilean reader would know from the introduction to this thesis that I am not a supporter of the dictatorship[20]. My position is based on a human rights stand; I had not been interested in being part of the debate referred above. I would not suggest that there could be an 'objective' approach to Chilean economic history which could contextualise the economic reforms of the 1980s, but I would suggest that an understanding of economic history in relation to that episode is limited and limits the possibilities for learning from previous experiences. The debate remains locked in two insurmountable political positions (in most cases tacit), which – understandably – may never converge to any sort of consensus. The construction of the cases implied asking questions about the origins of the structures and agents in SLS which resulted in an alternative historical perspective (which scope was not planned in advance but a result of the enquiry). This perspective could be developed further to contribute to the inclusion of more voices and enrichment of understanding.

In relation to areas for further research, the study of the sectors in this thesis reveals a lack of academic knowledge of the history of economic activities in Chile. The three sectors studied in this thesis have not been subject of rigorous, historical, academic study. The available documentation includes general historical country studies, economic studies providing some historical background, and historical accounts written by practitioners or researchers recalling industrial and technological developments. Industry studies do not focus on the historical angle and, although valuable, tend to be anecdotal claims with no evidential base. Affirmations are repeated from previous accounts, from which it is not possible to trace reliable sources. Accounts tend to be non-reflexive about historical interpretations and sources used. An exception is a study of the fruit sector that investigates the varieties of fruits cultivated and traded in Chile

20 Clear from my reference to the regime as a 'dictatorship' rather than a 'military government' or 'military regime'. There was heated debate in Parliament and in the media in 2011 about which term should be used in school history books.

between 1700 and 1850 (Lacoste, 2011[21]), and is based on notaries' and judges' archives, which have legal validity.

This thesis contributes by providing a historical overview of three important economic sectors combining historical academic work and industry studies. It analyses a longer time span and covers more dimensions than previous industry studies. It reveals the need for and importance of advancing knowledge in Chile's economic history. Research in the humanities and social sciences on Chile experienced a renewal in the early 2000s, following many years of stagnation. Its advancement could greatly enrich discussion and understanding of Chile's economic development.

Economic history, and particularly the history of labour, is a part of Chilean culture that has been under-researched. Understanding and valorising Chilean culture in relation to work would provide an important research contribution, especially in light of the rather distant relationship of the Chilean people with the industries analysed in this thesis. Many of the products they generate are unknown to large proportions of the population and are not part of their everyday lives.

The still influential idea of the natural resource curse tends to direct policy attention towards high tech and manufacturing sectors, while natural resources are Chile's main source of wealth. During my research work on the case studies, I identified strongly with all sectors and felt grateful to copper. My reflections resulted in a conference paper (Ibarra, 2011a) in which I presented Chilean copper mining as an example supporting theories of natural resources blessings (which are a response to the ideas of natural resource curse). One of the comments I received expressed surprise at the active learning and technological improvement and innovation in copper mining in the face of policies treating it as little more than a cash provider. There is much to be learned about how to sustain and benefit from Chile's blessings.

Reflecting on how Chile overcame the deep economic recession of the 1930s, Gabriela Mistral, Nobel laureate, Chilean poet and educationist, wrote:

[21] Lacoste is originally Argentinean and, before moving to Chile, worked as an academic in Mendoza, researching the history of agriculture production in the region. In contrast to Chile, Argentina has a tradition of science and technology historical research.

> Without abandoning the mountain, metal box and motherhood of our lives, and without losing sight or arm of the Central Valley, agrarian kingdom, Chile went down to the sea to exploit it as an instrument of commerce and cordiality. Thus, the country completed the triangle of its natural reality: mining, agriculture and sailing. To none of these three additives to its richness is it possible to consign, without becoming people deaf to their geography, which signs are determined and are determinants. (Mistral, [1937]1994, my translation)

While in agreement with this beautiful thought, studying the sectors in context (by positioning them in the field of power, as Bourdieu recommends), made me wonder about the intense focus on 'strategic clusters' and the lack of attention to the sectors concentrating GDP and labour, for example, the financial sector. In the international banking context, it was impossible not to recall one of the historical explanations for the long maintained system of landownership in Chile before the Agrarian Reform. This is that landowners - who were highly influential in public opinion, some of them MPs and owners of the main newspapers – managed to divert attention away from agriculture by focusing interest elsewhere, for example, on the strikes in the mining sector. This makes it more urgent to make a recommendation for future research on neglected, social and economically influential sectors.

9.3 Empirical Contributions: Doctoral Graduates

Doctoral graduates are agents that tend to take roles in different fields more or less simultaneously. This characteristic added complexity to the study, disentangling sectors was hard work and maybe illusory. The movement of bodies from one field to the other (e.g., higher education and SLS) constitutes a bridge between fields and makes the fields related in a way that – for some practices, particularly the ones studied in this thesis – one field cannot be understood without the other. For example, the market for production possibilities in a SLS can be better understood having as context the characteristics of the field of higher education.

Doctoral graduates' roles in SLS are marginal in relation to their roles in other fields, particularly in higher education. The empirical study has touched on some of those other roles opening venues for further research. For example, doctoral graduates played key roles in the development of a national system of doctoral education. This observation led to revisiting sources focused on participation of doctoral graduates in national doctoral education (Ibarra, 2011b and forthcoming).

Having criticised in the previous section focusing policy attention on problems that are a small part of the global economic picture, studying doctoral graduates implied looking at a minimal fraction of the labour force, particularly small for these SLS where doctoral graduates are not even all of the scientific suppliers. This study presented one perspective in the history of the SLS, one of an agent which – having been defined by a credential rather than a role in the fields – was not particularly influential in the SLS. The consequence is that the thesis provides a very limited perspective on agents' participation in SLS. It opens the scope for future studies which – having identified agents and their importance in the field – can cover wider perspectives.

9.4 Theoretical Contributions

This thesis provides empirical examples from which to reassess theories of growth and structural change. Producer capabilities represent the real choices made by an individual to transform resources into profits, choices that are constrained by the individual's values, life circumstances, and command over resources (Ch. 2). Using Bourdieu's concepts, we could say real choices are constrained by habitus (which includes values), field of action (life circumstances), and capital (command over resources).

Bourdieu's concepts enrich the idea of capabilities and enable a deeper understanding of the constraints on choices. For example, habitus is a much more comprehensive concept than individual characteristics, as it is a field in comparison to life circumstances. Also, capital rather than command over resources offers a wider perspective to a person's possibilities for making choices or identifying opportunities. The strength of Bourdieu's concept of capital for studying producer capabilities lies in its multi-dimensionality and dependence on the field. The discussion of producer capabilities (Ch. 2) covered different perspectives, some focusing on knowledge (close to embodied capital), some others on networks (close to social capital), but none as comprehensive and integrated as Bourdieu's capital.

The study of practice of doctoral graduates challenged assumptions underlying human capital theory. Effectiveness of an SLS depends to a limited extent on individual competencies (the focus of human capital theory). The analysis showed how capability accumulation is a collective enterprise, historically located in a particular SLS.

While some of the findings challenged mainstream economic theory – the economic rationality assumption and human capital theory-, others pointed at patterns long observed by the classical economists. The dubious effect of subsidies for developing a market for science and technology possibilities reminds of the bounties to the herring fishery studyied by Adam Smith ([1776]1999), where he proposes the catch may be for the bounty rather than the fish. The lack of opportunities for active learning during times of high profit recalls Smith's hostility towards high profits for going against an effective capitalist role (Rosenberg, 1974).

In terms of economic theory, the thesis made some contributions with elements of critiques of neoclassical economics and scope for reflections on classical economic thought. However, the main area of theoretical work of the thesis was on empirically applying evolutionary economic theories of: historical coevolution of systems of technology and innovation, SLS, dynamic producer capabilities and networks alignment.

The thesis uses theory from a critical perspective. Theory is 'put to work' in practice, without compromising with 'making it work'. The approach is experimental and critical, because it is not aligned to theoretical results. If theory does not hold empirically, that could be as good a conclusion as if it does.

The thesis research involved a permanent dialogue with theory. Using a coevolutionary approach to describe SLS implied asking questions new to the literature on them. For example, most salmon sector histories start with the Norwegians and ranching, whereas if one is looking for the origins of the technological paradigm, one needs to dig deeper. Then one founds some mentions to the early fertilization trials and the hatcheries. Bits need to be put together, the state is rarely mentioned and it has to be deduced that university researchers in Scotland describing the salmon cycle in the 19th century were state funded. The key to using theory was guiding the enquiry towards theory based questions.

The theories applied in the thesis did explain empirical findings and could be predictive. The application of coevolution theories resulted in an interpretation of SLS development patterns. The analysis of the role of scientific supplier based on the producer capability schema allowed explaining the three-fold interactions between suppliers, producers and consumers and the processes of capabilities accumulation. Finally, alignment analysis helped to attempt preliminary explanations of the direction of change of SLS and of the dynamic of capability accumulation. These three theory corps look now as a unified theoretical framework, however they were not so clearly connected in the literature and a contribution of the thesis is to have use them coherently.

Although the whole theoretical framework – bound together by the overarching approach discussed below – was suited to empirical findings and elucidated possible interpretations for explaining the phenomena, there is perhaps one element of disagreement, that is, the idea of misalignment. Alignment of networks implies using an agent's influence and power to purposely direct the network towards its interests. The agent considered as legitimate in using its power for alignment is the state. If one considers a system is 'misaligned' implies making a judgment based on the particular views of one agent (the state in this case). Empirical results showed that, in the process of coevolution, agents tended to align themselves within the historical circumstances. In some cases – for example, before the Nationalisation of copper – alignment was against developmental aims, but very convenient for US firms. Misalignment could name periods of high struggle conducive to important changes in the field's structures of power or shifts in targets, but otherwise systems – in their inertia of routine functioning and struggles of the game – were perfectly aligned. This may be a small reason for criticising theory; however, it is proposed to prompt reflection on the moral, rational consensus basis dominant in policy advice, which does not question the legitimacy of researchers to decide what is desirable for society. Networks alignment and misalignment breaks with that tradition, but discussion of how and who decides the directions and visions for alignment remains tacit.

Organising different theoretical bodies of evolutionary economics into a coherent set of tools to examine capability accumulation in industry sectors was based on an overarching theoretical approach. Pierre Bourdieu's historical, relational, philosophical and social theory guided the integration of evolutionary theories. It allowed these theories to be expanded to explain the empirical results. A base only on evolutionary economics theories would have been too narrow.

Bourdieu's life work informed what he called his 'principles for an economic anthropology', which are at the base of this thesis. He is better known for his work on culture, consumption and education (e.g., Bourdieu, 1984 ; Bourdieu and Passeron, 1990). His work on economics has not yet been taken further significantly by any academic field (Swerdberg, 2011). Thinking from a Bourdieusian perspective implied going beyond it, because the closer one looks – as evolutionary economics does – the more aspects Bourdieu did not observe. Having been based only on Bourdieu's theories would have been too general.

This thesis built an integrated theoretical framework drawing on previous theories. Experimenting with them informed their integration and explained the phenomena. The thesis remained at the level of understanding, which was where effort concentrated. Its biggest shortcomings are related to measuring and evaluating the extent or magnitude of the processes and results. These issues are discussed further in the next section.

9.5 Methodological Contributions

The ontological perspective of this thesis is to understand humans as agents that do not discover the world, but constitute it (Maturana and Varela, 1987). This thesis attempts to understand human behaviour from a representation that does not assume the rationality of agents and which does not use theoretical representations (models) that do not hold in practice. In my experience as an engineer I have seen that models of economic rationality and production theory were not what I observed in every day practice. It is true that there was always possible to explain how assumptions did not hold for my factual reality: markets had imperfect information, there was imperfect competition, etc., but after a certain time one starts wondering whether those perfect conditions do occur and concludes that not very often and possibly not at all. Although evolutionary economics, which I started studying 15 years ago, provided new explanations, I needed to root my understanding in the learning individual.

Based on these principles, I have identified theoretical work sharing similar paradigms – although rarely linked -, and developed explicit heuristics to apply the theories to three case studies, as part of a comparative strategy. I started the study of economic fields by explicitly and systematically applying a theoretical framework. This resulted in a series of heuristics for the different research stages, which could contribute to work on and provide motivation for future studies of economic fields.

The first heuristic for the study of the fields is an operationalisation of the ideas of coevolution of technology and governance in industry sectors. It starts by ‘finding’ or ‘identifying’ technological systems or the previous dominant technology and governance system, and characterising the system using dimensions related to technology and governance. The heuristic could be developed further using analytical tools such as fuzzy set analysis (Ragin, 2000; Rihoux and Ragin, 2009), which focuses on diversity and systematic comparison.

To study economic practice, I applied the capabilities schema. At the level of explaining the phenomena, its application was straightforward, but much work would be needed to develop it into a formal model. Dynamics producer capabilities explain practice, but do not explain change, these was overcome through application of alignment analysis. Again, this was an experimental application oriented towards explaining the phenomena in general and from the perspective of only one agent. Alignment analysis could be formalised and systematised in future research by extending the analytical tools and applying methods coherent with the relational nature of alignment, for example, correspondence analysis, a relational data analysis technique (Greenacre, 1984). It could also consider basic measurements, such as allocation of resources to different agents’ interests.

The propositions of expanding analytical tools are related to the limitations of measuring and complementing explanations with sound evidence, which could inform policy. In other words avenues for future research to overcome the main downsides of this thesis.

This thesis is on the line of advancing innovation studies to a more interdisciplinary perspective, towards bridging between different disciplines –social sciences, higher education studies and innovation studies. Although my initial aim was to develop text that might appeal to different disciplines, this was not achieved. Interdisciplinarity proved to be challenging, and the final thesis, in its last version, was addressed mainly to an innovation studies community for their interest in the research questions.

However, I acknowledge that the influences and elements of the thesis brought from other social sciences were determinant for its realisation and for my satisfaction in approaching the problem from a new perspective.

The production of this thesis for me has been an exercise of synthesising experience, education, new practices and reflection. As Maturana and Varela (1994) assert, it is reflection what allows us to escape from any trap, because ideas, like history, are cultivated possibilities and not mechanic determinism. Ideas are not fixed or immutable and each epoch is blind to the assumptions it takes for granted. This thesis induced my reflection on assumptions that are trapping societies in inequality and poverty.

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Appendix 1. Consent Form

(asking for agreement to participate in the research, whether anonymity is preferred, and preference for receiving interview transcripts, etc.)

Declaración de Consentimiento para participar en el proyecto de investigación de tesis doctoral: "Participation of Doctoral Graduates in Industry Learning Systems", realizado por Cecilia Ibarra en la Universidad de Sussex, Inglaterra.

Por medio de esta declaración confirmo me libre consentimiento de participar en el proyecto, haber recibido información suficiente respecto de la propuesta de investigación y conocer mi derecho a retirar mi participación.

He accedido a conceder al menos una entrevista sobre mi historia laboral y mis visiones respecto a la participación de los doctores en la vida laboral y la relación con la industria en Chile. Se me ha ofrecido acceder al material generado a partir de la entrevista y a los resultados de la investigación. Entiendo que los datos serán usados para fines académicos tales como: documento de tesis, presentaciones y artículos.

Nombre: ______________________________

Firma: ______________________________

Fecha: ______________________________

Respecto de la difusión de los resultados, quisiera agregar: (marcar sólo si corresponde)

__ Quisiera recibir copia de las transcripciones, audio, imágenes de mi participación (subrayar ítem)

__ Prefiero que mi participación sea anónima.

__ Si se usa mi nombre o mis fotos, quisiera ver previamente el material.

Otra condición:

Appendix 2. Case Study of Dra Apple

What is this case an example of?

- The 2000s and the deterioration of contract conditions (changes in the field)
- Working in projects based on proposals as the normal way of working (adapted habitus)
- Accessing the capital of the workplace, the students, the freedom it allows
- Adapting to the new conditions
- Ten years of capital accumulation

The region where Dra Apple worked is predominantly agricultural and concentrates most of Chile's production of pome fruits (apples and pears). She works on the campus of a regional public university, Universidad de Talca, located in the regional capital. There is a direct train from Santiago to the regional capital (a 3 hour trip on – unusually for Chile - convenient public transport). The capital is the seat of many important decisions (e.g., related to research funding). I visited Dra Apple for a work history interview and site observation. On my arrival at the train station, the sights of the station and the city were desolating, the historical buildings were literally on the ground. Most parts of the city had suffered bad damage in the earthquake of February 2010 (seven months before the visit). I could remember how the city had looked before and it was impossible not to feel sadness.

The university campus is on the outskirts of the region's capital city. Before the earthquake, the university campus was a feature of the city – famed for its modern buildings, gardens and permanent art exhibitions. At the time of the visit the contrast between city and campus was immense; the campus was well cared for, the few buildings still showing earthquake damage were being repaired - there were cranes, notices giving the dates of planned engineering work, and sources of funding, and security precautions around the building sites. The gardens housing sculptures by local artists (not a usual feature in Chilean universities) were spacious and well maintained.

Dra Apple worked in the Centre for the Study of Pome Fruits, which sits proudly at the centre of campus. It is a single storey building, well sign posted, and spacious compared to many Chilean university laboratories. The windows overlook the campus gardens and some orchards. The smell of apples greets the visitor at the front door and gets stronger in the experimental areas. Apart from the receptionist, everyone wears white coats. The centre looks immaculate, matching the university’s general appearance.

Dra Apple had a comfortable office with a connecting door to the laboratory area. Dra Apple spent 10 years studying and working in the US before returning to work in Chile in 2009. At the time of the interview she had been in Chile for a year and a half.

Dra Apple studied agronomics at the University of Talca. She was a good student in the second cohort of agriculture engineering students to graduate from the university. She has fond memories of her undergraduate years (five for agriculture engineering), and remembered the excellent lecturers who had recently returned to the university after completing their doctoral degrees funded by the university. I related this to my reading of the university strategy and case studies of this successful university, and especially to my interview with the then Chancellor of the university. The Chancellor of the University of Talca had told me about the appointment of these lecturers, and how difficult it was for the university to attract people who were willing to settle in the region, how they had adopted the strategy of hiring young people and supporting their studies abroad. He believed that was key to the university’s success and considered that they had an excellent agriculture faculty. The story of Dra Apple perfectly matched that previous account, from the perspective of a student.

Dra Apple’s area of interest and her undergraduate dissertation were the production of pome fruits, and she was keen to continue research in the ‘world state for apple production’. She was funded by a Fulbright Foundation scholarship and Chilean government funds, to do a masters degree in the US. After completing her studies she transferred to a doctoral programme funded by the host university (under a studentship contract). She felt that her undergraduate degree had been good preparation and that her good performance was evidence of the excellence of her education.

She had planned to return to Chile after completing her doctoral degree –she has already delayed her return which was a condition for her scholarship – but she could not find a job and her return became difficult. She went on to do a post doc in the US in the curse of which she was hired by a fruit producer company to join its R&D team. The ten years spent in the US had resulted in the accumulation of cultural, social and economic capital: cultural capital in the form of embodied knowledge and credentials (her doctoral degree and also publications and patents); social capital through work relations with colleagues in academia and industry, and economic capital from her contract with the big fruit producer firm.

Dra Apple and her family had enjoyed a comfortable life in the US. Her husband had travelled with her, studied and was employed in a private fruit producer firm. Dra Apple remembered that by then she asked herself ‘is this all I want’ and to feel homesick for Chile and rather unhappy. She had an urge to return to Chile while her children were still young:

> I wanted to come back because I was nostalgic but also because of academia. Work for the private industry is fascinating but it is also limiting. The company evaluates your contribution based on profit calculations, how much revenue your project will give them... There was a time for me when the material was not the most important and in the US I did not have what I value most.

The return to Chile was ‘difficult and complex, I had to sacrifice income but it was what I wanted’. Dra Apple contacted her undergraduate dissertation supervisor in Chile, who was the Director of the Talca research centre. She knew about the research centre and had a good opinion of it: ‘The centre is a very good base to work. I came for little money but knowing I had a structure to back me up’.

The research centre specialises in pome fruits and depends on the University of Talca, although it is self-funded by research and services contracts. The centre offered a one-year part-time contract on the understanding that during that year Dra Apple would raise funds and publish. ‘That is how I arrived, as researcher for the centre with 30 hours to apply for projects. The centre has thousands of data that have not been made into publications and I am working on that too’.

Dra Apple reflected on how she took this low income, unsecure offer. She did it only because her husband was the main family economic provider. The husband made failed attempts to find a job in the Chilean agricultural industry and, finally, reached an agreement for keeping his US job by distant-working, commuting and working partly in the company’s branch in Chile.

Dra Apple has a positive evaluation of how things went during the first year: she managed to secure funding for research projects and contracts with the local industry; by the end of the first year she had several publications in the pipeline, and she was involved in occasional teaching at the university and as a policy adviser to the regional government.

> I like applied research and the centre is well tuned with the local industry. It has a name, a good reputation amongst producers and that helps. I listened to producers to get ideas for new projects, if you find a big problem; you have a good justification for a project...The beauty of academic work is that it is has freedoms.

She had been able to exploit her accumulated capital to make a position for herself in Chile – at least initially – in the fields of higher education and the fruit industry. Dra Apple mentioned English as a second language, as an additional asset for her work. It helped her to keep up to date with the literature and news in the field. It helped relations with colleagues since projects for the national research fund (FONDECYT) and academic publications have to be written in English. She had also maintained active relations with her colleagues in the US:

> The most important states for fruit production in the US are two. I lived in one of them; I know colleagues, my university advisor, my husband, researchers.... I am bringing one of them over to collaborate in my FONDECYT project; he is from my university in the US.

She was still working on greater familiarity with national researchers and agents in her fields:

> Networks build up little by little. I just met the researcher expert in after-harvest process from PUC and other researcher from Concepcion in a seminar in Reñaca. I had met the expert in PUC before because she studied with me in the US, PUC had sent her to study in the US and she came back right after finishing...Even though the centre is a flag for Universidad de Talca, the money does not go to Talca, it goes to Santiago, to the Universities there and to Fundación Chile, they win the projects.

The centre provides access to objectified capital. To develop her projects she uses all three laboratories in the centre: ‘The centre works quiet well. The people at the labs, when I arrived, were students doing their undergraduate theses and supporting research projects, some of them stayed after graduation to work on short term contracts for the research projects’.

Dr Apple worked in the US for a private company where ‘everything is highly regulated, job contracts, everything’. This contrasted with her perception of the situation in Chile: ‘In a public university you have all contrata and honorarios, that is wrong. I did not have maternity leave as such, just a good will agreement with the Director of the centre’. She was fond and proud of her university, which is widely considered in Chile to be the most successful public regional university: ‘The university is well managed but the bad thing is the contracts, there is a debt with academics...There are so many scholarships to study abroad and there are not post to come back to’.

In the short time she had been working in the centre, she was learning to adapt to the rules. In terms of the evaluation system, she had concluded that:

> The only thing that matters is publications, in English; they go into your evaluation. Technical meetings with producers and all that doesn’t count, only publications. How can they evaluate academic work in agriculture with the same measure as chemistry or physics? We can produce as many papers; our plants take time to grow and to repeat the experiment you need to wait for another season. The evaluation system needs re-thinking.

After a two-hour interview I spent the rest of the day in the centre. I visited the laboratories and had informal conversations with technicians and students. I was shown the equipment, the cameras for controlling temperature (there was some expensive investment involved) and the different activities related to current projects were explained to me. They were working on research projects and also had regular activities of quality control and other routine services for local producers. They had transport to enable them to visit orchards, to pick samples, and interact with producers; two of the members of the team were out working in the field on the day of my visit.

I talked with students about their research and saw reports in progress. They were doing applied research on the effect of sunlight on pome fruits. I used a computer in the lab to look at web pages and observed work practices for an hour or two. I later gathered other information on the research centre, especially its history and the career of its director, who was one of the first doctoral graduates in Chile specialised in fruit growing.