Modelling Fractional Ownership in the Sharing Economy

Diffusion of Shared Goods in Consumer Coalitions

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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.

This is a thesis in papers style. Chapter 3 and Chapter 4 of this thesis are co-authored with my supervisor Dr. Tommaso Ciarli; I wish to acknowledge his contri-bution in refining the argument and improving the structural flow of the paper, through numerous iterations.

Signed:

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Summary

This thesis focuses on fractional ownership in the context of the sharing economy. It studies the conditions under which, subject to group coordination, fractional ownership and collaborative consumption generate higher consumer utility than individual ownership and consumption, leading also to higher societal benefits and more sustainable consumption.

An extensive literature studies the models and benefits of fractional ownership. On the other hand, the literature on the sharing economy has focussed mostly on the shared consumption of goods that are often ultimately owned individually, overlooking shared purchase and ownership. To trace the origins of the sharing economy in relation to the fractional ownership, and to investigate theoretical (dis)connections among the two, in the first paper I study the evolution of both literatures using bibliometric tools. I find that the literature on sharing economy builds upon the theory of psychological ownership (that is the temporary sense of ownership) but it deviates from the theory of commons and the logic of group cooperation, that are at the roots of fractional ownership. These findings indicate that the sharing economy seems to evolve along the lines of a neo-capitalistic model.

To study under which conditions fractional ownership is viable in the context of the sharing economy I develop agent-based models.

First, I model the co-evolution between coalition formation and diffusion of indivis-

ible goods that can be afforded only by groups of consumers (e.g. decentralised energy infrastructures). While coalition formation is a necessary condition for diffusion of such goods, adoption hinders coalition formation by changing the consumer network. Larger coalitions, where free-riding is minimised, are preferred over small ones because of lower costs. However, costs increase when higher quantities are purchased and owned collectively. Higher network connectivity and rapid communication increase diffusion and reduce downside effects of adoption in group, such as consumer isolation.

Second, I analyse under which conditions shared goods may replace individual consumption of goods (e.g. cars), when consumers can also purchase a public service (e.g. public transport) to satisfy their demand. Fractional ownership can reduce the negative externalities of producing goods that remain idle, while offering the same benefits of individual ownership. By exploring the full parameter space of the model, I find that fractional ownership does not diffuse beyond a consumer niche with relatively low budget, high demand and high preference for sharing. Price and infrastructure policies have a positive impact on increasing fractional ownership, reducing the inefficient use of resources.

The sharing economy literature has not yet studied options for fractional ownership to emerge. Results from this thesis show that group coordination and cooperation can prompt such ownership models, generating individual and societal benefits. Fractional ownership in the context of the sharing economy can boost the diffusion of sustainable goods and reduce the inefficient use of resources. These results are useful to inform policymakers that address consumer participation into the transition process towards a more sustainable society.

Contents

List of Figures

List of Tables

Abbreviations

ABM	Agent-Based Model
CP	Citing Publications
CR	Cited References
DES	Decentralised Energy System
DoE	Design of Experiment
EE	Elementary Effects
ESOP	Employee Stock Ownership Plans
FO	Fractional Ownership
LSD	Laboratory for Simulation Development
MPA	Main-Path Analysis
NOLH	Near Orthogonal Latin Hypercube
OAT	One-At-a-Time
RFID	Radio Frequency Identification
RMSE	Root Mean Square Error
SE	Sharing Economy
SPC	Search Path Count
WoS	Web of Science

Chapter 1

Introduction

1.1 Motivation

The 2030 Agenda for Sustainable Development of the United Nations calls for new models of production and consumption, in order to promote sustainable transition towards low-carbon and green economies and poverty alleviation (United Nation 2020). Rather than the traditional search for efficiency in production, this thesis studies models to improve efficiency in consumption: a more efficient use of resources may allow for improvements in living conditions. In particular this thesis focuses on whether social cooperation and coordination via sharing can enable sustainable consumption of goods that provide essential services to consumers.

Sharing the consumption of a good can contribute to its sustainability. First, sharing may reduce the environmental impact when the same consumer need is satisfied by smaller amount of the good. Second, sharing may increase affordable access to the good for low-income consumers which increases inclusion. However, both of these objectives depend on the feasibility of designing truly sustainable sharing practices.

The academic literature has recently debated sharing practices in the context of the sharing economy. The sharing economy is commonly understood as all borrowing, lending, renting, bartering and swapping practices that are mediated by a digital platform (Botsman & Roger 2010). In these practices, consumers give temporary access to under-utilised goods that they own, in exchange for a fee, but with no transfer of ownership (Belk 2007, Bardhi & Eckhardt 2012, Frenken & Schor 2017). Thus, the sharing economy, via sharing consumption, can reduce environmental impact, since it allows more efficient use of goods and reduces idle capacity (Heinrichs 2013, Hamari et al. 2016, Ertz & Leblanc-Proulx 2018). It can also extend access to goods for consumers who would not be able to afford to purchase the good individually (Lamberton & Rose 2012, Fraiberger & Sundararajan 2015). However, the sharing economy model of consumption without ownership (Belk 2014*b*) can also be a potential driver of inequality, by increasing polarisation and concentration of ownership and accumulation of resources (Richardson 2015, Schor et al. 2016, Slee 2017).

Is it possible to exploit the positive aspects of the sharing economy without increasing inequality? One option is the fractional ownership model in which both consumption and ownership are shared.

The first contribution of my thesis is to analyse the role of ownership in the sharing economy and the notion of both shared consumption and shared ownership. Shared consumption and ownership are discussed in the works on fractional ownership, which describe how consumers organise in groups to share ownership and consumption of a good. Most of these studies focus on fractional ownership of luxury goods (e.g., holiday homes, aircraft), which are too expensive for a single user to own. However, luxury goods do not satisfy essential needs and low-income consumers would likely be excluded a priori from their use. So this stream of work needs to be extended to include sustainable goods and goods in everyday use and to focus not on their access (as in the sharing economy), but rather on diffusion of sustainable practices that do not increase inequality.

To explore this possibility of shared ownership in the sharing economy, we need to understand the theoretical foundations of fractional ownership and sharing economy, and the extent to which these differ from or feed each other. This will allow an exploration of sustainable consumption models that boost the diffusion of a shared good that provides an essential service to consumers.

Examples of sharing practices to achieve sustainable consumption are studied in the academic literature on grassroots innovation. This literature debates forms of shared ownership and consumption to increase consumer empowerment and participation in sustainable energy choices (Seyfang & Smith 2007, Seyfang & Haxeltine 2012, Seyfang et al. 2014). The bottom-up process leading to the formation of local energy communities favours the diffusion of shared energy infrastructures and energy provision on site to satisfy consumer needs independently from the national grid (Watson 2004, Bauwens et al. 2016, Goedkoop & Devine-Wright 2016, Müller & Welpe 2018). This body of work proposes a model of consumption that includes ownership, which makes sharing more equitable and more appropriate and helps to explain the diffusion of grassroots localised practices.

Local energy communities are typical examples of groups of consumers who organise spontaneously to share ownership and consumption of the same good. Contrarily to individual adoption that does not require coordination effort, spontaneous groupings require coordination, and the diffusion of the shared good within groups is a process driven by the collective adoption decision. The collective decision is based on both individual and collective benefits, which group members may (or may not) gain from adopting the shared good. This decision does not have to be immediate; it depends on the formation of the sharing group, which is not pre-established, but is formed precisely to pursue shared ownership and consumption.

There are several theories related to different aspects of the diffusion of a shared good within a group of consumers; however, these are mostly disconnected. For example, the theory of innovation diffusion (Rogers 1962) studies diffusion as a process driven by an individual decision to adopt and does not consider potential adoption by groups that have yet to be established. The literature on collective action (Olson 1971, Hardin 1982, Oliver 1993) studies group adoption and consumption (Borcherding & Filson 2002), but with no focus on the prior step of group formation. Game theory and, in particular, the theory of coalition formation (Caplow 1956, Gamson 1961), study the process by which agents form groups to share resources, but do not consider the potential impact on subsequent common actions such as adoption of shared goods. Network theory examines how network structure affects the diffusion process (Rogers 1976, Cowan & Jonard 2004) and how networks evolve according to the dynamic and spatial-dependent formation of links among network nodes (Jackson & Wolinsky 1996, Bala & Goyal 1998, Johnson & Gilles 2000, Jackson & Watts 2002). However, this strand of work does not investigate the mutual effects of diffusion and network formation, nor diffusion and coalition formation.

A second contribution of this thesis is that it bridges these gaps in the existing literature by proposing a study of how shared goods are diffused in coalitions and by modelling the co-evolution of diffusion and coalition formation. The diffusion of a shared good is subject to the adoption decision by a newly formed group established to enable shared consumption of the good. This differs from studies of diffusion which focus on a single entity (i.e., an individual, a household, etc.) that adopts and consumes the good individually or in an already existing group. Modelling the co-evolution of diffusion and coalition formation allows us to study the sustainable consumption of two types of goods: non-movable and expensive shared goods which are not affordable individually (e.g., a shared energy infrastructure) and movable and cheaper goods which can be adopted individually (e.g., private car).

I first study the diffusion of sustainable shared good that consumers adopt in order to produce a service, on site and independently, at a cost that is lower than the public service, but which requires an initial investment. An example here, is the case of a shared energy infrastructure, such as a Decentralised Energy System (DES), which a local energy community adopts as an alternative to the centralised national grid. This option provides higher utility and lower cost to the members of the consumer group and implies that the diffusion of a shared good fosters a sustainable model of consumption. However, the shared good does not diffuse to the whole population or include all potential consumers, because of geographical constraints to communication and the opportunity to share the good.

I also examine the conditions under which the adoption of a shared good replaces the adoption of an individual good, in the presence of the public service. I use of the example of individual ownership and consumption of private cars, which is challenging sustainability in cities. A niche of individual consumers may decide to shift to a shared good, adopted in a coalition. The niche will be increased by specific consumer and good conditions: lower income, higher need for the service and a small-sized good. The transition from an individual to a shared good reduces the number of the good produced, which increases sustainability. The transition is accelerated by a pricing policy that increases the cost of individual consumption of the good (taxation) or favours the adoption of a shared good (incentives) which provides the service to a small coalition.

1.2 Contextualising Shared Goods in the Literature

The focus on the diffusion of shared goods in groups of consumers offers insights into how sustainable consumption could be increased. There are several examples showing that adoption of shared goods can reduce environmental impacts and/or increase access and inclusiveness. In this section I first present these examples and then I contextualise shared goods drawing on key elements in the literature.

For example, the transition from a centralised (often fossil fuel based) energy infrastructure to a DES can improve the efficiency of the grid, increase the share of renewable energy and reduce energy poverty (Dóci & Vasileiadou 2015, Van Der Schoor & Scholtens 2015, Koirala et al. 2016). DES are small-scaled energy infrastructures, located close to final consumers who generate and use the energy they need independent of the central grid. The formation of a coalition to adopt a shared energy infrastructure can increase access to energy and reduce consumers' energy expenses compared to the public provision (Kanagawa & Nakata 2007, 2008).

In an urban context, the purchase and ownership of private cars is challenging the sustainability of our cities, since individual use implies more traffic congestion and more idle capacity when the car is parked (Camagni et al. 2002). Users purchase private cars because they allow more flexible solutions to travel needs and, especially, if the public transport provision is unable to meet their demand (Sheller & Urry 2000, Murray 2001, Urry 2006, McLeod et al. 2017). Studying the formation of sharing groups includes consideration of reduced individual purchase and increased sustainability in urban areas.

The sharing economy literature has also analysed cases of car sharing cooperatives in Switzerland and in Germany (Truffer 2003, Vaskelainen & Münzel 2018). These initiatives consist of groups of consumers that come together in formalised cooperatives to get access to multiple goods of the same kind, and that are shared within the cooperative. Although users' cooperatives slightly differ from the idea of fractional ownership where users share a single good rather than multiple goods, they provide important insights on how coordination and collaboration can enhance sustainable consumption by increasing access and efficient utilisation of shared resources.

Groups of consumers can coordinate to share the ownership and use of even smaller goods, such as internet routers, which are more accessible than cars, but provide an essential service. While many houses may own an independent internet connection, it might be used up to only a fraction of its total capacity. Less advantaged families often do not to have internet connection at home and are reliant on data via smartphones. This is limited to basic needs and does not provide the high quality connection which has been shown to be essential during the current Covid-19 pandemic, to allow online teaching and blended learning and home working (Nature Editorias 2020). Although reducing the number of routers that are produced may not have a major environmental benefit, shared adoption of routers would have a positive impact on access to an internet connection.

The above are present-day examples, but the economic development literature has studied the positive impact of sharing on access to other essential goods. It considers shared consumption and ownership of common resources as enablers for rural development. In the context of land property rights, shared ownership is discussed as an efficient way to manage a common resource (Ellickson 1993). For example, farmers can coordinate and contribute to adoption of an agricultural infrastructure, such as an irrigation system, to enable efficient sharing of use of the common resource (Bardhan 1993*a*,*b*, 2000).

These examples of shared consumption and shared ownership help to frame the type of shared good that are the focus of this thesis, whose diffusion could improve both individual and societal utility.

I draw on classical economic theory to study shared goods that are similar to club goods (Buchanan 1965), which require the formation of sharing groups (Lindenberg 1982) for efficient and effective coordination and cooperation. Since shared goods are not entirely public nor entirely private, they fall into a category between purely private goods and purely public goods and become common resources for the group of consumers who adopt them. I focus on shared goods that are rivalrous and non-excludable within the group, but which are excludable externally since the group has the power to exclude non-members from using them (Bowles 2004). Group members cannot be excluded from using the good (they have access to the resource); however, the portion of the good used by one consumer is not available to the others.

The theory of governing common resources (Ouchi 1980, Ostrom 1990, Ostrom et al. 1994) is used to study shared goods where the *local interaction* approach is the most adequate and effective to allow participation. Users autonomously organise into communities and, assuming that everyone has the same bargaining power, co-operate in order to achieve the maximum benefit from the common property. This is different from the two approaches studied in the theory of common resources which involve power asymmetries. In the *external regulation* approach, the government designs and enforces rules and regulations about the common property (an entirely public good, such as a centralised energy grid, or public transport). In the *privatisation* approach, one actor owns the common property (entirely private good such as a private car or an internet router) and establishes a contractual relationship, a market transaction or an exchanges mechanism (as in the sharing economy where one actor - the provider/owner of the good - sells access to it to another consumer).

To explain how shared goods affect the consumer's attitudes to consumption and ownership, I draw on the literatures on fractional ownership of luxury goods and sharing economy. Based on work on the sharing economy, I study shared goods that enable shared consumption which promotes efficient use of the goods and a more sustainable model of consumption. Drawing on the fractional ownership literature, I consider ownership of a good that is shared by the group of adopters. As in the case of the sharing economy, there is no transfer of ownership among users, but, as in the case of fractional ownership, the good is purchased in the market and, once adopted by group, all members have fractional rights of ownership of the shared good.

Therefore, I study a consumption commitment that is short-term and access-based, since it depends on consumption coordination with others. However, in contrast to the notion of sharing economy, but similar to fractional ownership, the group's consumption commitment is also long-term. This is because when the group decides to adopt a shared good, the adopters commit to using the same good for a long time. Temporary use of a shared good generates a feeling of psychological ownership, that is, the perception of ownership (Pierce et al. 2003, Paundra et al. 2017). While individual access in the sharing economy generate individual psychological ownership, I consider that collective adoption of a shared good generates collective psychological ownership (Pierce & Jussila 2010). This is reinforced by the need to share the good with others. This sharing can be asymmetric among group members since the level of individual psychological ownership relates to the different effort required for some consumers to share the good (Kovacheva & Lamberton 2018).

1.3 Research Questions and Thesis Outline

This doctoral thesis is composed of three papers which address three crucial research questions about fractional ownership and sharing economy, how shared goods diffuse in a coalition, and whether they can replace individual goods. Each paper constitutes a thesis chapter.[1] Chapter 5 concludes, offers some implications for policy, and discusses some limitations and future directions for research. Chapter 2 addresses the following main research question:

- **RQ1: Do fractional ownership and sharing economy differ, and what are their conceptual and theoretical roots?**

Chapter 2 investigates the extent to which two streams of work contribute to defining the concept of sharing: the sharing economy and fractional ownership literatures. The first focuses almost exclusively on shared consumption and mostly overlooks the question of shared ownership; this is debated in the literature on fractional ownership. I analyse the citation networks related to these two literatures, to identify the main topics studied and how these have evolved over time. I look for the existence of a common conceptual base and whether elements of one stream of work feed elements of the other stream.

The citation network analysis uses two bibliometric methods: the Leiden algorithm for community detection (Traag et al. 2019, Waltman & van Eck 2012, 2013) and

[1] Chapter 2 has been published in the *SPRU Working Paper Series* and cited in this thesis as 'Pasimeni 2020'. An early version of Chapter 3 has been published in the *SPRU Working Paper Series* (2018-24) and cited in this thesis as 'Pasimeni & Ciarli 2018'.

Main-Path Analysis (MPA) (Hummon & Dereian 1989, Verspagen 2007). The Leiden algorithm for community detection identifies clusters (or communities) of publications that are highly connected through direct citations. Analysis of the publications included in these clusters identifies the main topics studied in the literature on sharing economy and fractional ownership and the topics that connect these literatures. MPA identifies the historical development and knowledge flows in these literatures, and the key publications that link fractional ownership to sharing economy.

To answer RQ1 I address the following research sub-questions:

- *What are the theoretical foundations of the fractional ownership and sharing economy? To what extent do these foundation differ?*

I show that the theoretical foundations of the sharing economy literature originated in consumer research that discusses sharing as opposed to possession, and in work on transaction costs. The fractional ownership literature is a fairly well established body of research and is related mostly to economics and finance.

- *Do fractional ownership and sharing economy feed each other to define the concept of sharing, and if so how?*

The findings show that three aspects of fractional ownership have contributed to shaping the sharing economy literature: psychological ownership, the tragedy of the anticommons and (negation of) group cooperation. Psychological ownership refers to the exploitation of a temporary feeling of ownership perceived by sharing economy users when accessing and using the shared good for a limited time. The tragedy of the anticommons suggests that individual ownership in the sharing economy endows the right of exclusion and privileged exclusive use of the shared goods. The negation of group cooperation refers to the fact that, in the sharing economy, the benefit of group cooperation to increase access to a good and to reduce its cost by cost-sharing is undermined.

- *How do fractional ownership and sharing economy contribute to defining a consumption and ownership model based on a shared good?*

To make the sharing economy more equitable with shared consumption and shared ownership, the shared good model should be studied in relation to collective participation. The analysis shows that local energy communities are frequently debated in the literature on fractional ownership, to which the sharing economy literature that focuses on grassroots innovation also contributes. This is an important real experience of sustainable consumption models based on shared goods that also boost inclusiveness.

I model the key features from this specific case of diffusion of sustainable goods in local communities and address the following question in Chapter 3:

- **RQ2: How does the diffusion of a shared good coevolve with the formation of a consumer coalition?**

In this chapter I draw on the case of adoption of a DES to model the diffusion of shared goods that occurs in coalitions. While several models analyse the diffusion of goods among agents connected within a network, and several models analyse the formation of coalitions, there is no theory and no evidence related to the coevolution of adoption with coalition formation. I address this gap by developing a model that combines an evolutionary coalition formation game with a model of diffusion, within a regular network.

I develop an Agent-Based Model (ABM) derived from the sequential games in coalition formation literature (Bloch 1995, 1996, Mutuswami & Winter 2002), which is closer to the evolutionary model of firm formation (Axtell 1999, 2002). I use this ABM to model diffusion as a process by which consumers form coalitions with the intention to adopt and use a good collectively. The collective adoption decision is modelled as a spontaneous and bottom-up process driven by heterogeneous agents with bounded rationality. Agents autonomously interact and negotiate to reach agreement to form a coalition and, eventually, adopt a shared good to satisfy a demand. When the agents reach agreement, coalitions are established, leading to the adoption of a shared good, thereby increasing its diffusion.

To answer RQ2 I address the following research sub-questions:

- *How do shared goods diffuse in a coalition? What is the relation between diffusion and coalition formation?*

Shared goods are assumed to be too expensive for the individual purchase and to be only affordable for purchase by a group. Shared goods are indivisible and non-movable, meaning that, once adopted, they must be located close to the final users. The adoption decision is irrevocable, meaning that replacement of the shared good is not possible. Shared goods satisfy a need that is supplied alternatively by a general provider and is always available to the consumers. Because coalition formation is a necessary condition for the adoption of a shared good, it is also an obstacle to its complete diffusion.

- *To what extent do the geographical constraints of a consumer network hamper shared adoption and diffusion of a shared good?*

The results show that the smaller the neighbourhood that the shared good can serve, the lower is the share of adopters. This is because agents that do not enter the coalition at an early stage remain isolated by being outside the already formed coalition and too distant from agents not yet in a coalition. This geographic constraint also limits the spread of information about the new shared good, hampering the diffusion process before consumers have been able to assess the convenience related to joining a coalition.

This chapter increase our understanding of the co-evolution of coalition formation and diffusion of a shared good. However, it assumes that sustainable shared goods (such as DES) are too expensive for individual adoption whereas adoption of a good in a coalition can be a consumption alternative to reduce individual unsustainable ownership (e.g. of a private car). This leads to the following research question which is addressed in Chapter 4:

- **RQ3: Do consumers shift from an individual good to a shared good?**

In this chapter I study the conditions under which consumers may prefer to purchase and own a shared good in coalition rather than owning the good individually, in the presence of the public service. Individual ownership and consumption lead to idle capacity of goods that could be shared to improve efficiency in utilisation and reduce over-production.

I extend the ABM developed in the previous chapter in four ways. First, agents evaluate the option of individual purchase, since the cost of the (shared) good is assumed also to be affordable individually. Second, the public service is not unlimited, but it reduces in relation to the congestion impeding access, which lowers consumers' utility. Third, the shared good is movable and agents can connect in a random network. Fourth, the duration of the good is assumed to be limited in time because of depreciation. Consequently, agents need to replace the (shared) good.

Because ABMs include complex interactions among several parameters, a simple sensitivity analysis of a few parameters could overlook important effects of other parameters on the model outcomes. Therefore, I iteratively analyse the full parameter space of the model to identify the conditions under which shared adoption emerges as an option that maximises the utility of some consumers.

First, I apply the Elementary Effects (EE) procedure to reduce the dimensionality of the model parameters; this allows to study only the ones most relevant to the model output (Morris 1991, Campolongo et al. 2007). Second, I apply the Near Orthogonal Latin Hypercube (NOLH) design of experiments, to optimise the number of model sampling points to be observed for the selected parameters (Cioppa & Lucas 2007). Based on these observed points, the Kirging meta-model studies the parameter space (Rasmussen & Williams 2006), in which the number of consumers opting for shared purchase is maximised. Third, I apply global sensitivity analysis using the Sobol decomposition to evaluate the individual and interaction effects of the model parameters on the variance of the model output (Saltelli et al. 2000, Saltelli & Annoni 2010).

To answer RQ3 I address the following research sub-questions:

- *Under which conditions does adoption of a shared good replace adoption of an individual good?*

The first result is that adoption of a shared good only occurs in a niche of consumers. I focus on this niche and run a second global sensitivity analysis (NOLH, Kriging meta-model and Sobol decomposition) in a smaller parametric space. The results show that shared good is adopted by a relatively low income and high demand population with a higher preference for consumption. Coalitions tend to be formed mostly if the shared good is relatively small. The coalition is also of small size because consensus and coordination in large coalitions is more problematic and there are higher chances of defection and reversion to individual adoption.

- *To what extent does shared consumption reduce the amount of the good that is produced?*

The transition from an individual to a shared good is driven by consumers who once owned the good individually, with no change in the number of users relying on the public service. Importantly, the transition to a shared good reduces the overall numbers of the good that is produced.

- *Which policies help to increase adoption of shared goods?*

Policies that reduce the relative price of the shared good (incentives) or reduce the relative price of the individual goods (taxation) will accelerate transition. However, policies are effective only if the shared goods can be used by relatively smaller coalitions where coordination is easier.

Chapter 2

The Origin of the Sharing Economy Meets the Legacy of Fractional Ownership

Abstract

The sharing economy is changing the consumption and ownership of goods. As consumption becomes more and more characterised by sharing and access-based consumption, ownership is becoming more concentrated. The literature on the sharing economy focuses almost exclusively on shared consumption practices and rather overlooks the question of ownership despite a substantial body of work on forms of shared ownership, that is, fractional ownership. In this paper, I study the extent of the linking between these two streams of work and whether they have a common conceptual base. I analyse the citations networks of these academic literatures, using the Leiden algorithm of community detection and main-path analysis. I find that the sharing economy literature originated in consumer research that debates over sharing as opposed to possession, and in work on transaction costs. I draw on the strand of work on fractional ownership and identify three sharing economy aspects: psychological ownership, anticommons and exclusion of group cooperation. The findings allow a better understanding of the characteristics of the sharing economy and open avenues for future research on fractional ownership models in the sharing economy.

2.1 Introduction

In the last ten years, the emergence of a sharing economy has modified the way goods are consumed and owned. The sharing economy is generally understood as all borrowing, lending, renting, sharing, bartering and swapping practices mediated by digital platforms (Botsman & Roger 2010). In practical terms, consumers give temporary access to the goods they own, but which are under-utilised, in exchange for a fee, but involving any transfer of ownership (Belk 2007, Bardhi & Eckhardt 2012, Frenken & Schor 2017). This access-based consumption characterises sharing practices in the sharing economy. The novelty of the sharing economy is the temporary access granted by the owner of the good (the providers) via a digital platform. All the actors involved seem to benefit: consumers pay a low price to gain access to a good that they might not be able to afford to buy on their own, providers generate extra income by selling access to privately owned goods that are being under-utilised, and platforms exploit this new business model. Moreover, the shared consumption reduces idle capacity of goods making their consumption more efficient and sustainable.

The sharing economy promotes collaborative consumption of under-utilised goods that exhibit systematic overcapacity, which allows them to be shared (Benkler 2004, Botsman & Roger 2010, Hamari et al. 2016). Consumers use the same good at different points in time, which is slightly different from the collaborative consumption which was defined as “those events in which one or more persons consume economic goods or services in the process of engaging in joint activities with one or more others” (Felson & Spaeth 1978, p.614). This highlights the importance of joint activities and engagement in collaborative consumption. Consumption in the sharing economy is not collaborative; it does not require engagement in a joint activity. It can be described as pseudo-sharing characterised by short-term rental activity and the absence of a sense of community (Belk 2014*b*,*a*, Eckhardt & Bardhi 2015).

Also, ownership of the shared good in the sharing economy is individual, determining polarisation of ownership, accumulation of resources and risk of rising inequalities (Richardson 2015, Slee 2017). Ownership is individual whether the shared good is owned by an individual (i.e., an apartment, a car, a drill) or is a company asset (i.e., a fleet of shared cars or bicycles). For instance, *AirBnB* allows houseowners to share their house with others. Similarly, *Couchsurfing* provides accommodation for travellers in individually owned (or temporally owned) apartments. *BlaBlaCar* allows the driver of a car, who often is the car’s owner, to share the car journey with others while *Uber* drivers use their cars to transport people from one place to another. Companies such as *Zipcar* and *ShareNow* make the fleets of cars they own available to subscribers for short-term usage.

I believe that the absence of cooperation and collaboration in both consumption and ownership in the sharing economy, merits further investigation. The literature on the sharing economy mostly does not discuss the situation where a group of people autonomously organise and coordinate, to share ownership and consumption of a common resource and enjoy the benefit of a collective action (Olson 1965, Hardin 1982). These cases can be described as fractional ownership, such as sharing the ownership of a luxury good, collective ownership and utilisation of land and agricultural infrastructure, cooperatives and employee-owned enterprises, or community ownership in a local energy initiative.

So why are these fractional ownership practices not a part of sharing economy research? Does the sharing economy literature have links to work on fractional ownership? What might we learn from fractional ownership about the origins of the sharing economy? Our understanding of the sharing economy would be increased by a more systematic investigation of fractional ownership and why certain aspects of social coordination and cooperation seem not to typify the sharing economy.

I address these questions by constructing a citation network drawing on scholarly work on fractional ownership and the sharing economy. Publications are interesting because they link each other via citations. Therefore, analysis of these citations allows the construction of citation network. To analyse these two bodies of work I use bibliometrics techniques. First, I apply the Leiden algorithm for community detection (Traag et al. 2019) to group the publications into scientific community clusters. The links between these communities suggest that fractional ownership and sharing economy have a common conceptual base. Second, I apply Main-Path Analysis

(MPA) (Hummon & Dereian 1989) to trace the historical development of these two literatures and identify publications which link fractional ownership and sharing economy.

The strand of work on fractional ownership is a fairly well established body of research related mostly to economics and finance. Work on the sharing economy, which is more recent, draws on several areas, such as consumer research, transport, business and management. I identified three main theoretical aspects of fractional ownership that have contributed to shaping the sharing economy literature: psychological ownership, the tragedy of the anticommons and (negation of) group cooperation. Psychological ownership refers to the exploitation of a temporary feeling of ownership perceived by sharing economy users when accessing and using the shared good for a limited time. The tragedy of the anticommons suggests that individual ownership in the sharing economy endows right of exclusion and exclusive privileged use of the shared goods. The negation of group cooperation refers to the fact that in the sharing economy the benefit of group cooperation to increase access to a good and to reduce its cost by cost-sharing is undermined. These aspects add to the narratives related to the sharing economy and how it is portrayed in the literature.

The rest of the paper is organised as follows. Section 2.2 reviews key aspects of the sharing economy and discusses the concept of ownership in the sharing economy; it touches on fractional ownership and highlights what fractional ownership has in common with the sharing economy. Section 2.3 describes the five step process involved in constructing the citation networks for the two strands of work: keywords, data collection, exclusion of false positives, data harmonisation and inclusion of false negatives. It describes the bibliometrics techniques applied to systematically analyse the citation networks. Section 2.4 describes the citation network and presents descriptive statistics for these strands of work. It presents the results of the Leiden algorithm and the MPA. The networks are first analysed separately and then in combination in order to identify connections. Section 2.5 discusses the main findings and Section 2.6 concludes the paper.

2.2 Literature Review

Key Aspects of the Sharing Economy

Research on the sharing economy has increased since 2010. New types of interaction between consumers and providers and a modified approach to consumption and ownership have promoted interest in the sharing economy. Digital platforms play a critical role in the sharing economy and create business opportunities and space for market interactions between providers and consumers (Matzler et al. 2015, Schor & Fitzmaurice 2015, Puschmann & Alt 2016, Benoit et al. 2017, de Rivera et al. 2017).

On the one side, digital platforms mediate the transactions that allow providers to grant access to consumers, in faster and cheaper ways than in the past. Almost anyone can sell access to the resources he or she owns which are under-utilised. However, these new entrepreneurial activities are challenging the incumbents, for example *Uber* and *Airbnb* have disrupted the taxi and hotel sectors (Tussyadiah 2016, Tussyadiah & Pesonen 2016, Zervas et al. 2017). On the other side, consumers are becoming more interested in sharing goods, and access to these goods is facilitated by digital platforms. Sharing has become more appealing than in the past (Botsman & Roger 2010, 2011, Bardhi & Eckhardt 2012), particularly among younger people for whom ownership is less important than for older people (Godelnik 2017, Amaro et al. 2019).

The new mode of connection between the contracting parties, based on digital and distant interactions (multi-sided platforms) is, arguably, one of the main reason behind the popularity of the sharing economy. However, these organisational changes are triggering societal tensions (Rauch & Schleicher 2015, Edelman et al. 2017) and questions about workers' right (Morozov 2013, Codagnone, Abadie & Biagi 2016, Newlands et al. 2018) and inequality (Richardson 2015, Schor et al. 2016). For these reasons, policy-makers are making efforts to regulate the sharing economy and to ensure both equal rights and fair market competition (Witt et al. 2015, Codagnone, Biagi & Abadie 2016, Hartl et al. 2016, McKee 2017).

The main characteristic of the sharing economy is that goods are used by more than one person without a change in direct ownership. This has two positive effects. First, on the consumer side, the reduction or elimination of ownership costs allows savings which can be used for other purposes. Collaborative consumption was boosted by the 2008-09 financial and economic crisis, which resulted in many consumers suffering from loss of goods and shortage of resources and this focused attention on how to avoid unnecessary expenses (Rauch & Schleicher 2015, Schor 2016). Sharing has become a viable option to reduce scarcity and increase access to goods, particular to those not affordable to most individually (Lamberton & Rose 2012, Fraiberger & Sundararajan 2015, Hamari et al. 2016). Second, goods are used more efficiently. Shared consumption allows exploitation of idle capacity which may be abundant if the goods are owned and used individually (Frenken & Schor 2017). Advocates of the sharing economy highlight its positive impact on the environment and more sustainable consumption (Heinrichs 2013, Piscicelli et al. 2015, Martin 2016), particularly in relation to the specific case of car sharing and car pooling (Firnkorn & Müller 2011, Baptista et al. 2014, Hartl et al. 2020).

However, the individual ownership characterising the sharing economy can be controversial. Richardson (2015) argues that the sharing economy creates new forms of inequality and polarisation of ownership, Schor et al. (2016) argue that class and other forms of inequality operate within this type of economic arrangement, Acquier et al. (2017) suggest that the sharing economy may not deliver on its promise and shows contradictions and Murillo et al. (2017) point to the potential for intensification of the unequal distribution of wealth. Add to these aspects is the need of higher democratisation of ownership and the governance of the platforms enabling the sharing of goods (Scholz 2016, Schor 2016), and it becomes evident that the sharing economy has not reached its full potential and needs further adjustment to increase social equity and widespread well-being.

Ownership in the Sharing Economy

The rise of the sharing economy has shifted the focus of traditional business models based on individual ownership, to new models of access without ownership (Gansky 2010, Belk 2014*b*). The post-ownership model of consumption modifies the traditional presupposition that links possession to the extended self (Belk 1988). In the past, ownership has been studied as an important determinant of social status (Furby 1980, Dittmar 1992, Beggan & Brown 1994), and possession the ultimate expression of consumer desire (Chen 2009). From this perspective, ownership is a crucial determinant of individual behaviour and social interactions, particularly for individuals who identify with the owned objects, their value and the socio-economic status they endow (Rudmin 1991, Beggan 1992).

In the sharing economy, ownership is a perceived feeling. Psychological ownership is perceived in relation to both physical goods (Atasoy & Morewedge 2018) and shared experiences (Kovacheva & Lamberton 2018), which latter are extremely relevant in the sharing economy (Paundra et al. 2017, Helm et al. 2019, Lee et al. 2019, Kim & Jin 2020). The temporality aspect of ownership is the main novelty brought by the sharing economy. It not only modifies consumers' behaviour but it has also shaped consumers' perception of ownership. The sense of ownership in the sharing economy is mainly an individual feeling, which arises when the user gets access to a good and uses it (i.e. drives a shared car). This is different from the perception of collective psychological ownership, which refers to “the collectively held sense (feeling) that this target of ownership (or a piece of that target) is collectively ’ours’” (Pierce & Jussila 2010, p.812). The collective feeling of ownership is a psychological construct which leads to co-ownership, since it intensifies cooperation, social relationships and sense of community, despite being driven self-interest (Mitchell et al. 2012).

Sharing ownership of an asset eliminates the need for formal agreements that characterise individual ownership and, which, in the sharing economy, allow an owner to grant access to others. Shared ownership can involve family members, for example, in relation to a sofa, food and domestic equipment that is available to all members of the household and does not involve formal permission being sought for their use (Belk 2007, 2010). Shared goods are seen as *ours*, they belong to the entire group and can be categorised as *common-pool resources*, since they are non-exclusive, but rival.

In contrast, individual ownership of an object defines full control (Kanngiesser et al. 2010), enabling the right of exclusion and formal permission for its utilisation (Neary et al. 2009). The sharing economy, ultimately, is characterised by individual ownership. Access to goods is granted formally in exchange for money, making the shared goods excludable and rivalrous. Some scholars wrongly associate collaborative consumption of goods in the sharing economy to the case of a common good (Bradley & Pargman 2017, Albergaria & Jabbour 2019). This association does not hold because the sharing economy rarely leads to the social dilemma of the tragedy of commons (Hardin 1968).

Literature on Fractional Ownership

Sharing resources with others is not a completely new model of consumption; it has existed for decades as a way to govern the commons (Bowles 2004, Ostrom 1990, Ostrom et al. 1994). Buchanan (1965) and Lindenberg (1982) suggest that sharing groups are the optimal formation to control and access a club good and to benefit from cost-sharing. For similar reasons, Bardhan (1993*a*,*b*, 2000) considers the agricultural infrastructure a common asset that tends to be managed in common by local farmers, Thornton (2009) shows that community-based agriculture secures ownership rights to rural groups and alleviates poverty and Sims & Kienzle (2016) suggest that group ownership can accelerate agricultural production. Fractional ownership is another option to achieve cost-sharing and efficient shared utilisation of luxury goods, such as holiday homes, private jets and yachts (Hastings et al. 2006, Yang et al. 2008, Lawson 2010), whose ownership individually is not affordable for most people.

Fractional ownership favours the formation of local communities to manage social projects, reduces poverty and increases access to critical resources. The US *Community Land Trust* is an alternative land- and home- ownership structure, run by non-profit communities, aimed at providing affordable housing to people on low incomes (Gray 2008). In 2014, the UK government launched its *Shared Ownership Framework*, to exploit synergies between companies and local communities to allow shared ownership of renewable energy projects (Goedkoop & Devine-Wright 2016), which supports the argument that fractional ownership may be important for the green transition (Hasanov & Zuidema 2018, Pasimeni 2019). However, there is no consensus in the literature on the benefits of local cooperation (Benkler 2011, Sharzer 2012), and the formation of sharing communities faces coordination problems which do not arise if goods are used and owned individually (Pasimeni & Ciarli 2018).

The sharing economy literature related to shared mobility initially focused on fractional ownership as a sub-model of car-sharing (Shaheen & Cohen 2013, Shaheen & Chan 2016) and then was extended to cases of "true sharing" with specific reference to the case of *Göteborgs Bilkoop* in Sweden, (Belk 2017, Dreyer et al. 2017, Czakó et al. 2019). Bilkoop involves members of a cooperative who own a fleet of cars and share their use and is a good example of fractional ownership: cooperation and coordination permit shared ownership and consumption of shared resources via a community based on long-term relationships and mutual trust (Hofmann et al. 2017, Crucke & Slabbinck 2019). These cases show that there are situations when fractional ownership is a good way to organise communities and to manage ownership and collaborative consumption of shared resources. There is a small strand of work on the sharing economy in relation to fractional ownership, which suggests a common conceptual base.

Common basis between Fractional Ownership and Sharing Economy

Both fractional ownership and the sharing economy focus on shared consumption as a way to increase efficient utilisation of goods and promote sustainable models of consumption. Both enable temporary access to allow consumption, but in the sharing economy this is time limited depending on the access granted and paid for. In the case of fractional ownership, this is time limited only by the fact that the good is shared by a group so its use requires some coordination within the group.

The temporal aspect of consumption generates a perceived feeling of ownership in the case of both fractional ownership and sharing consumption. While in the former it is a collective psychological ownership because it is shared with others, in the latter psychological ownership is individual and, again, lasts for as long as the duration of the access to the good is granted (or paid for). In fact, ownership in the sharing economy ultimately is individual; the good does not belong to the consumers. Ownership in fractional ownership is shared among a group of individuals who organise exactly for that purpose. One of the main differences related to these two modes is that the sharing economy is mediated by a digital platform while in fractional ownership it may not be necessary, but could be used to match consumers potentially interested in fractional ownership (Lowies et al. 2018).

Fractional ownership and sharing economy are separate concepts, but they have many similarities. Therefore, I argue that there is a need to understand why fractional ownership is not more prominent in the sharing economy literature. I believe that a better understanding of fractional ownership would increase our understanding of the origins of the sharing economy. Analysis of these two literature strands should provide evidence of connections between fractional ownership and sharing economy. The academic literatures includes publications which are linked via cross citations, which makes it possible to build a citation network and identify the links between these bodies of work. The next section describes the method of analysis.

2.3 Method

I describe the procedure followed to build the citation networks for the academic literatures related to fractional ownership (FO) and sharing economy (SE) (Section 2.3.1). This involves five steps which are described below. The first step consisted of identifying keywords needed to find relevant publications. The second step was data collection. The third step was checking the dataset to exclude publications not related to FO or SE (i.e., false positives). The fourth step involved data harmonisation, to eliminate data inconsistencies. The fifth step extended the dataset by including publications in the search communities of FO and SE not detected using the keyword search in the first step (i.e., including false negatives to ensure high recall).

Having defined the scientific publications dataset, I built the citation networks for the two literatures. In these citation networks, nodes are publications and links represent the directed relationships among them, where one node cites another or, in the opposite direction, a node that is cited by another node. In the network, publications that are cited, but that do not cite are source nodes, while publications that cite, but that are not cited are sink nodes.

At the end of this section, I present the two bibliometric methods (the Leiden community detection algorithm and the MPA) applied to systematically analyse the citation networks (Section 2.3.2).

2.3.1 Building the Citation Network

Step 1: Keywords

Table 2.1 lists keywords chosen to extract publications of the literature on FO and SE.

FO-keyword	
Co-Ownership	Employee Ownership
Collaborative Ownership	Fractional Ownership
Collective Ownership	Group Ownership
Combined Ownership	Joint Ownership
Common Ownership	Mutual Ownership
Communal Ownership	Shared Ownership
Cooperative Ownership	Sharing Ownership
CoOwnership	Timeshare
SE-keyword	
Access Economy	Peer Economy
Access-Based Consumption	Peer-to-Peer Economy
Car Sharing	Platform Economy
Collaborative Consumption	Ride Sharing
Collaborative Economy	Share Economy
Gift Economy	Shared Economy
Gig Economy	Shared Mobility
On-demand Economy	Sharing Economy

Notes: FO and SE keywords searched within article titles, abstracts and keywords. The keyword search was run in Web of Science and Scopus, limiting publications published up to 2019. From the dataset of publications in both literatures, false positives are excluded (precision) and false negative included (recall).

Table 2.1: Selected keywords for fractional ownership and sharing economy

Keywords related to the FO literature were selected to extract publications that study ownership of material goods. Ownership is shared among a group of people, where participants concur via a monetary contribution. To identify this literature, I used various synonyms for the words *Fractional* and *Shared* which were selected and associated to the word *Ownership*. I also used *Employee Ownership* because this refers to employees who contribute to jointly own and manage an organisation. I included *Timeshare* which defines fractional ownership of holiday homes. I excluded from the list of FO keywords, terms related to publications studying shared production of services, software, publications or algorithms that do not refer to shared ownership of material goods. However, if other literatures contributed to FO, the inclusion of false negatives would ensure they were captured and included in the dataset (the fifth step).

For SE, the keywords were selected from those proposed in the literature (WEF 2017, Ertz & Leblanc-Proulx 2018, Görör 2018, Botsman 2019, Curtis & Lehner 2019).[1] To make the SE and FO literatures comparable, the selected keywords were aimed at extracting publications on access to material goods and shared consumption (*Access Economy*, *Access-Based Consumption*, *Collaborative Consumption* and *Collaborative Economy*) and sharing practices mediated by digital platforms (*Gig Economy*, *On-demand Economy*, *Peer Economy*, *Peer-to-Peer Economy* and *Platform Economy*). *Gift Economy* identified publications analysing consumers' attitudes to ownership compared to traditional forms of possession and transfer of ownership. *Car Sharing*, *Ride Sharing* and *Shared Mobility* identified work in the SE literature on shared mobility which considers fractional ownership practices.

I did not include keywords related to the digital infrastructure enabling implementation of sharing practices or work that referred only to the act of engaging with others, but not shared consumption. This choice is likely to not be able to include in the

[1] I also thank Prof. Koen Frenken for his suggestions.

analysis the literature concerning ICT practices that resemble the characteristics of the sharing economy business models but have connections to concept of fractional ownership. For example, the idea of *product-as-a-services* consists of users paying to access an individually owned good (e.g., a cloud space) to satisfy specific needs such as computing, storing files or running applications. Business models and organisational frameworks developed in this area can be of further inspiration to define the sharing of goods.

Step 2: Data Collection

The publications were downloaded from all the databases included in the Web of Science (WoS) core collections, and Scopus, the cross disciplinary database provided by Elsevier Science. WoS and Scopus are not completely overlapping and so widened the spectrum of publications; use of just one or the other could overlook or exclude relevant papers (Gavel & Iselid 2008, Archambault et al. 2009, Vieira & Gomes 2009, Mongeon & Paul-Hus 2016, van Eck & Waltman 2017). Publications were downloaded in February 2020, limiting results to publications published up to 2019.

In WoS and Scopus, I ran a multi-keyword query to search on the selected keywords (Table 2.1) within article titles, abstracts and keywords. Bibliographic information were obtained for all the publications extracted, such as author(s) names, publication year, article title, type of publication, journal title, volume, page, DOI. The identified publications from WoS and Scopus were merged to produce a unique list. I checked for duplicates by matching DOI, then title and eventually the string combining author(s)' name, publication year, volume and page.

Publications extracted through the keyword search are the nodes in the citation networks. These are called Citing Publications (CP) because they refer to previous work, by citing another publication. Backward citations, or Cited References (CR), of CP publications were also downloaded from WoS and Scopus. CR publications are additional nodes introduced in the networks, each one linked to its own CP. A CP node can also be a CR node if it is cited by another CP publication. Also, several CP nodes can cite (i.e., can be linked to) a CR publication.

CP in under the following categories are maintained in the network, being part of the academic literature: journal articles, proceedings or conference papers, book chapters, reviews, editorial materials. Book reviews, meeting abstracts, news items and discussion or correction papers were excluded. From the list of CR publications, I excluded grey literature (i.e. press articles, government or institution documents, policy literature, reports and other documents not part of the academic literature). Books in both CP and CR were retained given their relevance in the academic literature, although it was not possible to extract their citations from either WoS or Scopus. Hence, books in the citation network are source nodes.

Step 3: Precision - Exclusion of False Positives

The keywords in Table 2.1 could result in false positives, that is, CP not related to the two literatures. To detect and eliminate false positives and to increase the precision of the two datasets, 10% of the CP extracted based on keywords were assessed (for each keyword) for their relevance to the literature. The assessment was done manually by reading the title and abstract of the publications. If the share of false positive was higher than the 10% threshold, the keyword search was adjusted with additional search conditions. The objective was to obtain a dataset with above 90% precision.

The keyword *Shared Ownership* generated false positives in the FO literature. It retrieved publications studying entry mode choice by multinational corporations in foreign markets, where shared ownership refers to ownership of foreign subsidiaries. It also retrieved publications on the public-private shared ownership of organisations. To increase precision, I excluded publications whose title or abstract included any of the following terms: *foreign ownership*, *foreign acquisition*, *foreign affiliates*, *foreign direct investment*. *Group Ownership* retrieved publications on Radio Frequency Identification (RFID) systems as the protocol for ownership transfer of goods in logistics. These publications are beyond the FO literature and I excluded papers with the terms *radio frequency identification* or *RFID* in the title or abstract.

The keyword *Timeshare* generated false positives in the FO literature. This term is used in publications studying technological aspects not related to fractional ownership of holiday homes. Examples are: display and computer technologies, remote timeshare applications, timeshare systems for analysis and laser optical timeshare. Given the limited number of publications identified using this keyword (around 100) the entire set of publications was assessed and only those referring to shared common property (such as a holiday home) were retained, the rest were excluded.

In the dataset of publications related to SE, *Car Sharing*, *Ride Sharing* and *Shared Mobility* introduce several false positives. These terms identify publications that developed models or algorithms to optimise car sharing or ride sharing systems, including optimal distribution of charging stations for electric vehicle and minimisation of travel distances or relocation efforts. Some publications dealt with intelligent communication systems among autonomous vehicles and human-vehicle. These were excluded from the SE literature since their focus was primarily on the technology infrastructure enabling the functioning of the shared mobility, and car sharing or ride sharing were related solely to technical applications. To systematically detect these false positives, publications in the disciplines of engineering, computer science, mathematics, decision sciences, operations research were excluded.

Step 4: Data Harmonisation

To build the citation networks, it was necessary to identify each unique node/publication. CP and CR publications were labelled with a string composed of the following elements: first author's surname, first letter of first author's name, year of publication, volume number and first page number. Unfortunately, bibliographic information on CR publications are not always reported correctly or are incomplete. Inconsistencies lead to different identification (strings) for the same publication, hence, multiple rather than one node in the network. I manually harmonised bibliographic information to build strings that recognised uniquely both CP and CR publications. Table A1 in Annex A.1 provides an illustrative example of the data cleaning process.

During the process of data harmonisation, references to books are treated differently, specifically if they are second or third or other editions of the original book. Authors produce subsequent editions of books to provide updates and other small improvements. However, subsequent editions do not include substantial changes and maintain the same theoretical frameworks, fundamental ideas and contributions to the literature. Based on this rationale, references to subsequent editions of the same book were harmonised to the original edition.

It should be noted that this harmonisation of book references had no impact on the citation networks. This is because books are source nodes because it was not possible to extract their cited references. So, the harmonisation of subsequent book editions to the original edition reduced the number of source nodes and focused on the original edition, which represents the moment in time when a theoretical novelty was introduced in the literature.

Step 5: Recall - Inclusion of False Negatives

The citation networks of the two literatures was extended further by including false negatives, to ensure high recall. False negatives are publications not detected by keywords in Table 2.1 but relevant to the literature. Since it is impossible to know a-priori which publications have been left out and which additional keywords might be needed, I followed the approach in Batagelj et al. (2017). This consisted of searching the most cited backward citations (i.e. CR publications) within the search community of a literature. In other words, false negatives emerged autonomously from the relevant literature on FO and SE, already identified in steps 1-4.

To include false negatives in the citation networks, top cited references were included as CP nodes together with their CR publications. These are among the top 1% of the total publications in a given literature, ranked by number of citations received. Bibliographic information was extracted from either WoS or Scopus. Figure A1 in Annex A.1 provides an illustrative example of how the networks expanded with the addition of false negatives.

Backward citations further extended the original networks defined through keywords. This historical extension of the citation networks means that the literature includes previous work that influenced development of the FO and SE literatures. Although this method does not consider forward citations, the more extensive search and knowledge of the two literatures reassured me that the method did not overlook major publications related to FO and SE.

2.3.2 Bibliometric Methods

The five steps described above allowed the construction of the two separate citation networks for FO and SE, and a combined network. Descriptive statistics help to characterise these bodies of work (i.e., number of publications, top cited publications, top publishing journals, top cited authors). However, to enable their systematic analysis, I apply two bibliometric methods: the Leiden algorithm of community detection and the Main-Path Analysis.

Leiden Algorithm of Community Detection

The Leiden algorithm of community detection (Traag et al. 2019, Waltman & van Eck 2012, 2013) enables recognition of clusters of network nodes that hare highly connected and which have fewer links to other clusters that, instead, closely link other nodes. The algorithm starts with singleton nodes that move iteratively between network partitions, which are refined and aggregated to obtain final communities with the highest levels of connectivity among nodes.

Communities in the citation networks are quasi-independent clusters of publications that contribute to a specific topic. Also, communities link one another. Therefore, by running the community detection algorithm on the citation network merging the two literatures, I can study the connections between clusters of publications related to FO and SE. To label clusters in the citation network, I ran co-word analysis using VOSviewer software (van Eck & Waltman 2010). This scans and extracts all terms present in publication titles and abstracts and creates a co-occurrence map based on text data. The most frequently occurring words are used as labels.

I apply the Leiden algorithm to analyse the citation networks among CP publications only, since CR publications are sink nodes and titles and abstracts were not downloaded and, hence, they cannot contribute to the co-wording analysis. The results of the community detection were visualised using Gephi software (Bastian et al. 2009), which provides a graphical representation of the publications clusters in the citation networks and their proximity.

Main-Path Analysis

MPA was proposed originally by Hummon & Dereian (1989) and was extended by Verspagen (2007). In the citation networks, MPA considers the links between nodes and identifies the historical development or knowledge flows, in a particular literature, allowing graphical visualisation to ease interpretation of the results. I use MPA to follow the historical development of FO and SE, based on the most important path from source to sink nodes/publications. In the combined analysis, the MPA identifies key publications which connect FO and SE.

The objective of MPA is to identify relevant links in the network and, consequently, relevant nodes, which define the main-path or the main search stream in the literature. Batagelj (2003) proposed Search Path Count (SPC) as a way to quantify the level of connectivity among nodes. SPC counts how many times a link is crossed by all possible paths in the network. A path starts chronologically from a source node and ends in a more recent sink node. This value is the accumulated traversal count of a link and measures the indirect influence of each publication in the historical development of the literature, regardless of how many times it is cited. I use local key-route MPA (Liu & Lu 2012) to detect the historical development of a literature. First, it selects the top 40 links in the network, ranked by their traversal or SPCs and then connects these links (backward and forward) to other links to reach a source node and a sink node. Local key-route MPA produces a broader pattern of the knowledge flows within a literature and allows for multiple paths. Figure A2 in Annex A.1 provides an illustrative example of how the traversal count is computed and how the key-route main-path is selected in a network.

The MPA is run in Pajek (Batagelj 2003, Mrvar & Batagelj 2016). By definition, a citation network should be acyclic, since a more recent publication cites necessarily an older one, or a publication in the same year. However, if two publications in the same year cite each other (for example, it may occur when these are forthcoming) the network becomes nonacyclic, breaking the temporal consequentiality rule of the development of a literature. Therefore, before starting the traversal counts, in Pajek it is necessary to run a preprint transformation. This transformation adds preprint publications to publications that cite each other and are published in the same year. The original node cites its own and the preprint version of the other publication. Figure A3 in Annex A.1 provides an illustrative example of preprint transformation.

Different disciplines could have contributed to the development of the FO and SE literatures; the citation rate of these disciplines may be not the same. The divergence in the citation rates of different disciplines will have an impact on the descriptive network statistics, such as top cited article, journal or authors, but will have no impact on the outcome of the two bibliometric methods. The community detection algorithm considers only if there is a link between two publications to determine clusters of publications with high level of connectivity. Similarly, the MPA considers the traversal counts of all the links in the network and then searches for the main-path. Neither method considers how many times a publication is cited.

2.4 Results

In this section, I present the citation networks (Section 2.4.1) and the descriptive statistics for the two literatures (Section 2.4.2). I analyse the citation networks using two bibliometric methods: the Leiden algorithm of community detection (Section 2.4.3) and MPA (Section 2.4.4). In both cases, I analyse the two citation networks in isolation and then merge them to find the connections between FO and SE.

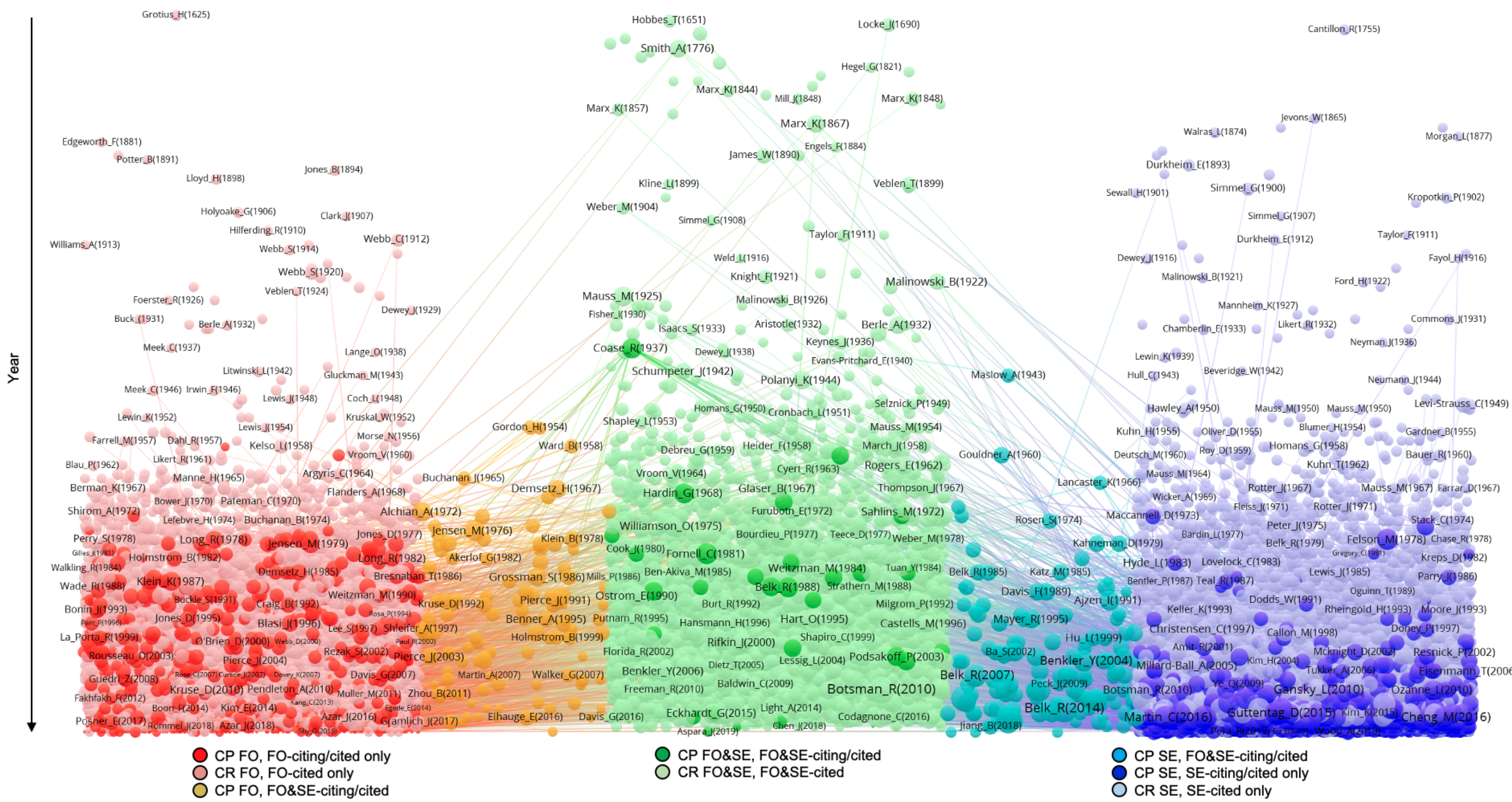
2.4.1 Citation Network

The FO literature includes 2,356 CP (2,072 of them identified through the keyword search and cleaned of false positive, and 284 added as highly cited false negatives) and 68,709 CR publications. The SE literature includes 4,241 CP (3,898 plus 343) and 109,889 CR publications. The two literatures have 32 CP in common, 9 of them retrieved by the first keyword search and 23 added as highly cited false negatives.

Figure 2.1 depicts the full network of publications/nodes for the merged FO and SE literatures. Nodes are organised chronologically, meaning that those at the bottom are more recent publications and those at the top are the older publications. The network shows that there are eight categories of publications.

The red nodes on the left of the figure are CP from the FO literature, which cite only or are only cited by other FO publications. The light red nodes are CR publications cited only by red nodes. The blue nodes are CP in the SE literature that cite or are cited by other SE publications. The light blue nodes are CR publications cited only by CP nodes in the SE literature. The green nodes are the 32 publications common to both literatures and the light green nodes are CR publications cited by CP nodes in both the FO and SE literatures. The orange and azure coloured nodes are CP related respectively to the FO and SE literatures; these publications cite the common literature (green and light green nodes) or cite each other.

On average, the FO publications (red and red light) are older than the SE publications (blue and blue light): average publication year for the red nodes is 2008 and for the blue nodes is 2016 (Table 2.2). Red nodes are more distributed across time, while the blue nodes are concentrated towards the bottom of the figure. Green and light green nodes are the circa 5,000 publications cited by both the orange and azure nodes, with an average publication year of 1993 feeding both the FO and SE liter-



Notes: The figure shows the citation network that merges FO and SE literatures. Nodes on the left (red, light red and orange) are FO publications. Nodes on the right (blue, light blue and azure) are SE publications. Nodes in the centre (green and light green) are publications in common to the two literatures. Years are on the vertical axis: nodes at the bottom are most recent publications. For visualisation purposes, not all links between nodes are shown and CR publications with one citation only are excluded. VOSviewer is used to create and visualise the citation network (van Eck & Waltman 2010)

Figure 2.1: Citation network combining the literature of FO and SE

atures. The orange and azure nodes are older than the red and blue nodes in the respective literatures (1995 for orange nodes and 2003 for azure nodes) and have the highest ratio of citations per node in the respective bodies of work, indicating their high relevance to the topic (Table 2.2).

Literature	Type	Avg. Year	Num. Nodes	Total Cit.	Cit. per node
FO	Red	2008	2215	3781	1.71
FO	Red light	1996	5123	14345	2.80
FO	Orange	1995	109	1719	15.77
FO & SE	Green	1993	32	1389	43.41
FO & SE	Green light	1993	4758	23424	4.92
SE	Azure	2003	136	6583	48.40
SE	Blue light	2007	15227	51251	3.37
SE	Blue	2016	4073	18399	4.52

Notes: Characteristics of the eight categories of nodes in the citation network. These are: the average publication year, the number of nodes/publications, the total number of citations that publications have received, and the ratio of citations per node in each category.

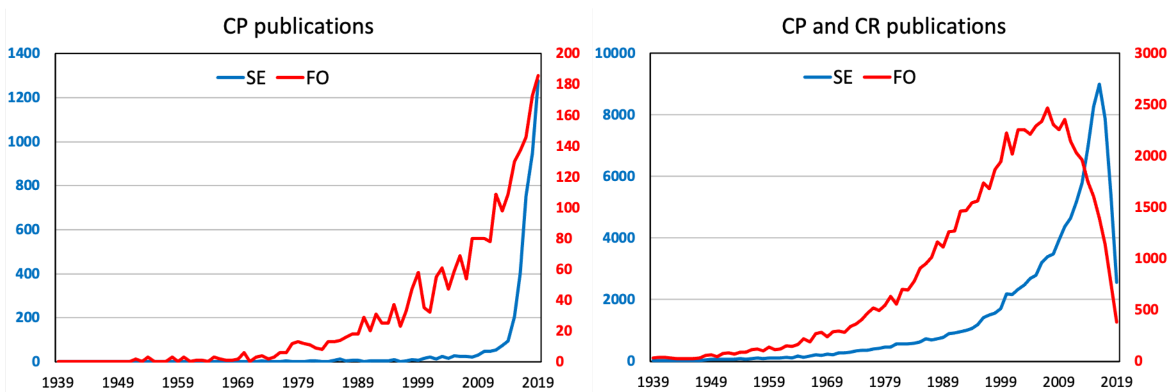
Table 2.2: Characteristics of the eight categories of publications in FO and SE literatures

For example, the orange nodes include seminal work on the ownership structure of firms and their governance (Jensen & Meckling 1976, Shleifer & Vishny 1997, Grossman & Hart 1986) and the role of psychological ownership in organisations (Pierce et al. 1991, 2003, Van Dyne & Pierce 2004). Similarly, azure nodes group key SE publications which have contributed to framing the sharing economy (Benkler 2004, Belk 2010, Bardhi & Eckhardt 2012, Belk 2014*b*, Hamari et al. 2016) and to developing peripheral, but important theories such as planned behaviour (Ajzen 1991) and technology acceptance (Davis 1989). This suggests that key publications in both literatures build on similar references and they cite each other, which is the first indication of a connection between the two literatures.

Among the green nodes, nine publications are common to both literatures (and were extracted by the multi-keyword search based on both the FO and SE keywords). A review of these nine publications indicates that certain research areas have analysed cases of fractional ownership in the context of the sharing economy. These include housing sector, shared mobility, organisation of digital content and firm structure research. Furthermore, shared ownership in the sharing economy is seen as occurring more frequently in local rather than global contexts, and as a modern example of reciprocity. This gives an initial understanding about which research areas are more likely to embody both topics.

2.4.2 Descriptive Statistics

The left side of Figure 2.2, plots the number of CP related to the two literatures (FO in red, SE in blue) by publication year, that is how many publications are published every year. On the right, curves plot the sum of CP and CR publications for the two literatures by publication year. This indicates the number of publications (including their citation) that each year are added to the two citation networks.



Notes: Trend of publications in the citation network of the two literatures (FO in red, SE in blue) published from 1939 to 2019. Plot on the left shows the number of CP publications, while plot on the right shows the number of both CP and CR publications.

Figure 2.2: Trend of the number of CP and CR publications in FO and SE literatures

The curves on the left in Figure 2.2 indicate that earlier CP of FO literature are published in the 50's. Since then the number of CP in FO literature continues to grow, until 2019 when the number of publications reaches about 190. SE literature is much younger than FO. CP concentrate almost entirely in the last 5 years, with a much larger quantity compared to FO. SE publications continue to increase each year, up to about 1300 published only in 2019. Despite its infancy, the SE literature has more publications than FO: in total, it includes about twice the number of CP.

The curves on the right side of Figure 2.2 show the difference in how the two citation networks develop over time. FO shows a publications peak (about 2,500) in 2000 while SE publications reach a high in 2017 (about 9,000) and can be expected to continue to increase. The early decline in FO publication is indicative that this literature stream has reached maturity and that recent publications cite older work very frequently. In contrast, the number of SE-nodes continues to grow; the final fall in the curve is due to the citation time lag between year of publication and time needed to be cited.

Table 2.3 lists the top 10 cited publications in the two literatures. The number of citations counts publications cited by CP, since CR publications are sink nodes and their citations are not extracted.

In the FO literature, the most recent and highly cited publication was published in 1990, confirming the earlier origins of this literature compared to the strand of work on SE. The latest SE publication year among the top 10 cited publications is 2016. The most cited FO publication has 102 citations, five times less than the most cited SE publication (581 citations).

A review of these publications suggests that the top FO publications focus on the theory of the firm and the theory of the commons. They also study the ownership structure of organisations, analysing whether collaborative ownership by employees might represent an opportunity or a threat for the firm. The top SE publications tend to define the sharing economy and use consumer research to explain the emergence of collaborative or access-based consumption and the drivers of sharing attitudes among consumers.

Author(s)	Year	Title	Type	Cit.
		FO		
Jensen & Meckling	1976	Theory of the firm: managerial behavior, agency costs and ownership structure	Article	102
Alchian & Demsetz	1972	Production, information costs, and economic organization	Article	85
Pierce et al.	1991	Employee ownership: A conceptual model of process and effects	Article	75
Grossman & Hart	1986	The Costs and Benefits of Ownership: A Theory of Vertical and Lateral Integration	Article	72
Williamson	1975	Markets and hierarchies	Book	72
Williamson	1985	The economic institutions of capitalism: Firms, Markets, Relational Contracting	Book	71
Hardin	1968	The Tragedy of the Commons	Article	69
Klein	1987	Employee stock ownership and employee attitudes: A test of three models	Article	68
Ostrom	1990	Governing the Commons. The Evolution of Institutions for Collective Action	Book	68
Hart & Moore	1990	Property Rights and the Nature of the Firm	Article	63
		SE		
Belk	2014*b*	You are what you can access: Sharing and collaborative consumption online	Article	581
Botsman & Roger	2010	What's Mine Is Yours: The Rise of Collaborative Consumption	Book	581
Hamari et al.	2016	The Sharing Economy: Why People Participate in Collaborative Consumption	Article	511
Bardhi & Eckhardt	2012	Access-Based Consumption: The Case of Car Sharing	Article	427
Guttentag	2015	Airbnb: disruptive innovation and the rise of an informal tourism accommodation sector	Article	315
Belk	2010	Sharing	Article	301
Möhlmann	2015	Collaborative consumption: determinants of satisfaction and the likelihood of using a sharing economy option again	Article	299
Botsman & Roger	2011	What's Mine Is Yours: How Collaborative Consumption is Changing the Way We Live	Book	277
Sundararajan	2016	The sharing economy: The end of employment and the rise of crowd-based capitalism	Book	267
Ert et al.	2016	Trust and reputation in the sharing economy: The role of personal photos in Airbnb	Article	266

Notes: Top 10 cited publications in the citation network of the two literatures, FO (top) and SE (bottom). The number of citations only counts publications cited by CP publications, since citations of CR publications are not downloaded.

Table 2.3: Top 10 cited publications in FO and SE literatures

Table 2.4 lists the top 10 publishing journals, ranked relative to the number of distinct publications contributing to the two literatures, including both CP and CR publications. This gives an idea of the top disciplines that contributed to the FO and SE literatures. The FO literature centres on journals publishing on economy and finance, and management and business. Interestingly, the *Journal of Applied Psychology* is among the top journals publishing work on FO. This is linked to the perceived feeling of ownership (psychological ownership), which is an important topic in the FO literature, as discussed in Section 2.2.

FO top journal	Publ.	SE top journal	Publ.
American Economic Review	457	Journal of Cleaner Production	664
Journal of Financial Economics	457	Journal of Consumer Research	569
Journal of Finance	404	Tourism Management	497
Academy of Management Journal	373	Management Science	478
Strategic Management Journal	302	Journal of Business Research	448
Academy of Management Review	285	Journal of Marketing	443
Journal of Applied Psychology	265	Transportation Research Record	435
Journal of Political Economy	236	Transportation Research Part A	430
Administrative Science Quarterly	234	Harvard Business Review	420
Quarterly Journal of Economics	229	Annals of Tourism Research	410

Notes: Top 10 publishing journals in the citation network of the two literatures, FO (left) and SE (right). The total number of publications published by journals counts both CP and CR publications.

Table 2.4: Top 10 publishing journals in FO and SE literatures

In the SE literature, the *Journal of Cleaner Production* is the top publishing journal, followed by the *Journal of Consumer Research*. This suggests that understanding why consumers participate in the sharing economy and the impact of more sustainable consumption are major research areas. Consumers and their choices are central in the SE literature, leading other disciplines to study the sharing phenomenon, for example, tourism, transport, marketing, business and management.

Table 2.5 lists the top 10 cited authors in both literatures, based on name of first author. The top 10 cited FO authors account for about 2.68% of total citations in the FO literature and the top 10 cited SE authors account for 3.98% of the total citations in the SE literature. The top FO cited author accounts for around 20% of the citations received by the top SE author.

FO top authors	Cit.	SE top authors	Cit.
Williamson Oliver E.	312	Belk Russell W.	1673
Jensen Michael C.	291	Botsman Rachel	1175
Jones Derek C.	278	Shaheen Susan A.	874
Blasi Joseph	266	Schor Juliet B.	670
Kruse Douglas L.	238	Hamari Juho	607
Long Richard J.	237	Zervas Georgios	571
Pierce Jon L.	236	Tussyadiah Iis	566
Hart Oliver	221	Bardhi Fleura	484
Rosen Corey M.	181	Guttentag Daniel	475
Ostrom Elinor	178	Sundararajan Arun	390

Notes: Top 10 authors in the citation network of the two literatures, FO (left) and SE (right). To count the number of citations, only the first author of each publication is considered.

Table 2.5: Top 10 authors in FO and SE literatures

The academic provenance of the top authors and their field of expertise can be used to qualitatively categorise the two literatures. Almost all of the top FO authors are American economists with a major influence on economic sciences. Three are also Nobel Prize winners, namely Williamson Oliver E., Hart Oliver and Ostrom Elinor, who contributed to economic governance, contract theory and the theory of the commons. FO authors are responsible for pioneering studies on financial economics, political economy, worker cooperatives and employee ownership and profit-sharing. The top 10 SE cited authors are equally distributed between the USA and Europe in terms of academic affiliation. Their fields of expertise are diverse, reflecting the number of disciplines that contribute to work on the SE. They include: business, marketing, ecology, sociology, information and communication technology, engineering, tourism management and transport.

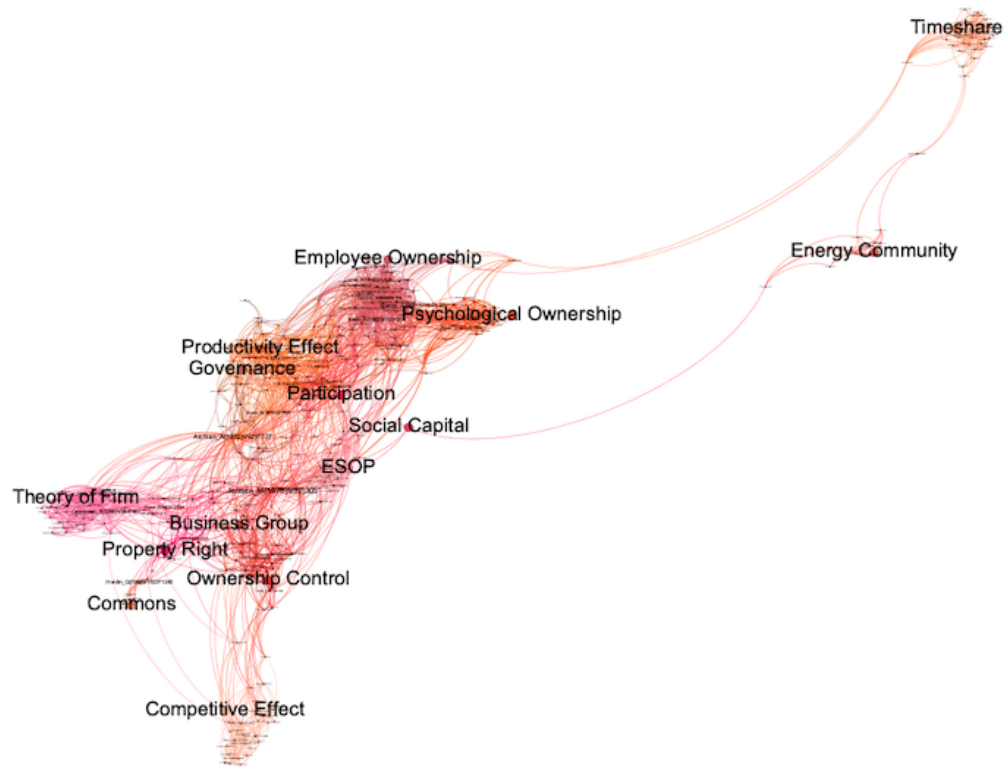
The descriptive statistics show that FO is an older and smaller literature than the work on SE. Considering only the top ranked publications, publishing journals and authors, fewer disciplines contribute to FO literature, but they study several different aspects (i.e., economy and finance which examine the theory of the firm, the theory of the commons and the ownership structure of worker cooperatives). SE includes several disciplines, but most focus on framing the sharing economy (i.e., business, marketing, sociology, tourism management and transport which analyse the characteristics of SE). The next two sections look at the connections between FO and SE.

2.4.3 Community Detection

This section presents the results of the Leiden algorithm of community detection. The algorithm generates communities of nodes in the citation network that represent clusters of publications in a literature, which are highly connected via direct citations. It can be assumed that clusters contribute to the same topic in a literature, although they may have weak links to other topics. The Leiden algorithm is run to detect communities, first, in the two isolated citation networks (FO and SE) and then in the merged network, to detect connections between clusters. Clusters are ranked by summing the number of citations received by the publications included in those communities, and the top 15 are analysed. Clusters are labelled based on the results of the co-wording analysis, which extracts the most frequently occurring terms in the titles and abstracts of the publications in each cluster. These are presented in Table A2 and Table A3 in Annex A.1.

Communities in Fractional Ownership Literature

Figure 2.3 depicts the top 15 clusters in the FO literature. Publications related to employee ownership are the densest cluster and are in close proximity to another dense cluster of publications focused on psychological ownership. This part of the FO literature studies the functioning of employee-owned organisations in relation to perceived feeling of ownership among workers. The workers participate in the governance of the organisation and this direct involvement can have a positive impact on productivity. Therefore, publications on social capital are directly connected to these clusters.



Notes: Top 15 clusters of publications in the citation network of FO literature identified via the Leiden community detection algorithm. Clusters are ranked by summing the number of citations received by the publications included in those communities. Clusters are labelled based on the results of the co-wording analysis, which extracts the most frequently occurring terms in the titles and abstracts of the publications in each cluster.

Figure 2.3: Top 15 clusters of publications in the FO literature

Publications on Employee Stock Ownership Plans (ESOP) are connected to publications that focus on business activity whose ownership control is shared among a group of people. These, in turn, are linked to the cluster studying the competitive effect of this organisational structure in the market. Businesses based on group ownership are linked closely to work on property rights, which relate to the cluster studying the commons. These clusters are linked to publications that focus on the theory of firm, which is another dense cluster in the FO literature.

There are two peripheral clusters in the FO literature: timeshare and energy community (top-right in Figure 2.3). Both are linked to the cluster on social capital and direct involvement in ownership. Timeshare and energy community are examples of fractional ownership where people organise to achieve shared ownership and consumption of a common asset. Timeshare refers to sharing ownership of holiday accommodation among several people. Publications in the energy community cluster focus on local level projects, to manage and take advantage of small-scaled energy production to share the cost and enjoy the benefits of renewable energy.

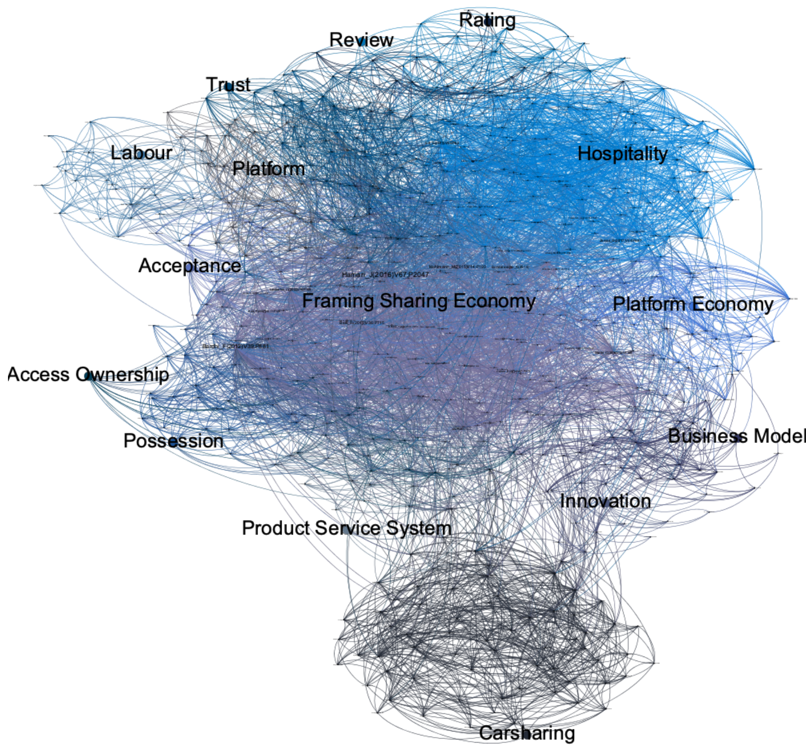
Overall, Figure 2.3 shows that the FO literature concentrates on topics broadly related to the separation of ownership and control in firms. However, it also analyses the role of social capital, implying that social relationships and social structures are pivotal to effective functioning of cooperative and collaborative groups such as energy communities and shared holiday home ownership.

The fact that both examples of fractional ownership (i.e., energy communities and timeshare) are isolated topics in the literature is an important signal in relation to future research avenues that exist and can be developed. Future research in the literature of FO should link to the sharing economy literature in order to investigate the challenges and opportunities for fractional ownership to emerge as a model that increase social benefits and sustainable consumption.

Communities in Sharing Economy Literature

Figure 2.4 depicts the top 15 clusters in the SE literature. The higher number of publications in the SE literature generates clusters that are denser that those in FO literature. The central cluster groups publications contributing to framing the concept of the SE. Around this central cluster are clusters of publications that focus on important topics in the SE literature.

These include work on access ownership which is linked to work on possession. This indicates that the discussion on access-based consumption in the SE literature is linked to studies of consumers' attitudes to ownership, traditionally based on feelings of possession and materialism. Linked closely to the central cluster, is a group of publications dealing with the platform economy which emerges in the SE literature in relation to the diffusion of digital technologies.



Notes: Top 15 clusters of publications in the citation network of SE literature identified via the Leiden community detection algorithm. Clusters are ranked by summing the number of citations received by the publications included in those communities. Clusters are labelled based on the results of the co-wording analysis, which extracts the most frequently occurring terms in the titles and abstracts of the publications in each cluster.

Figure 2.4: Top 15 clusters of publications in the SE literature

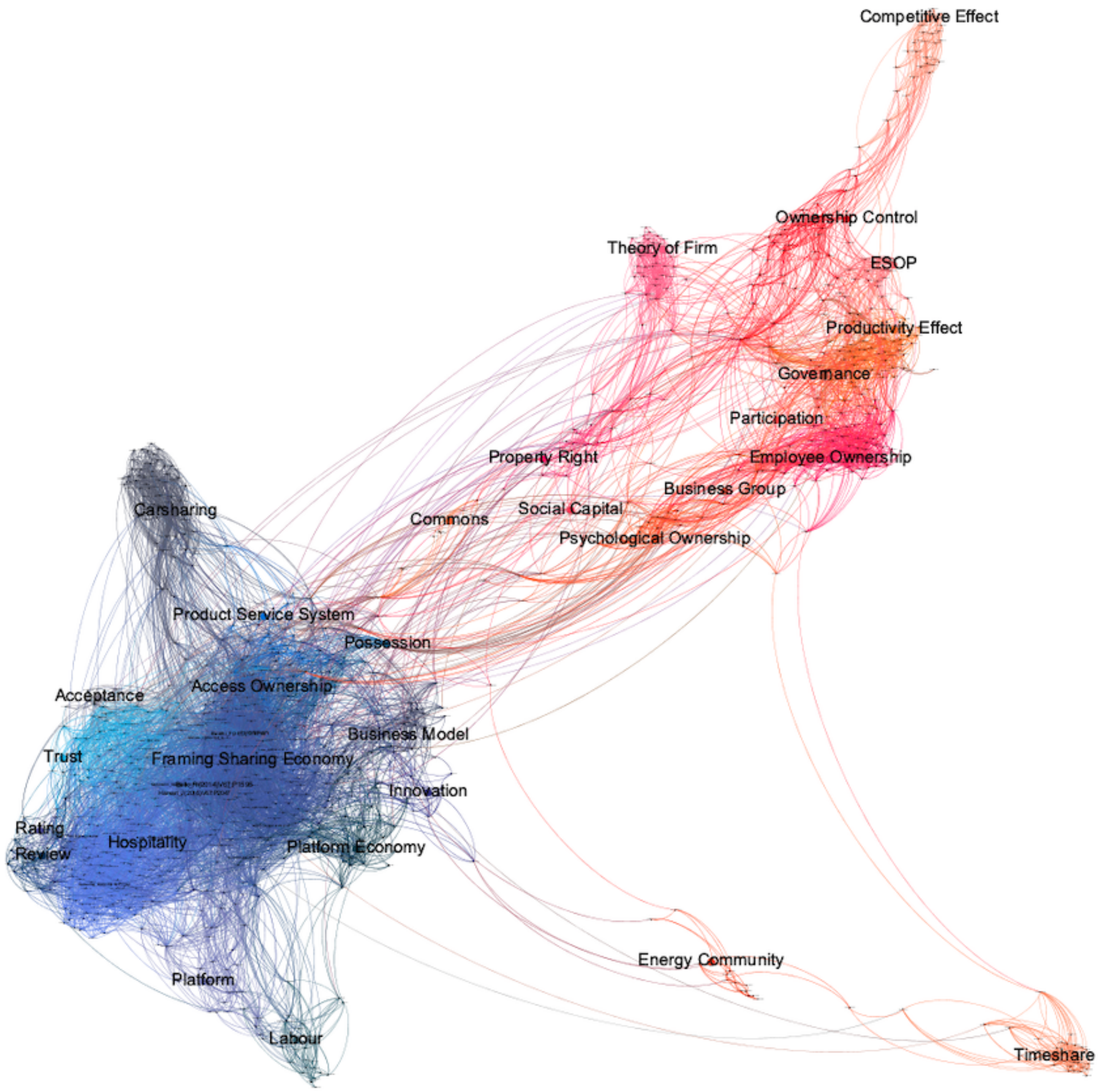
At the top-right of Figure 2.4 we find a cluster of publications analysing the hospitality sector (the second most dense cluster in the SE literature), which is in close proximity to publications related to trust and feedback mechanisms (reviews and ratings). At the top-left are publications dealing with platforms which are linked to the cluster on labour and technology acceptance. This part of the citation network indicates that the SE literature studies specific topics linked to social and economic sectors where digital technologies play a crucial role.

The central cluster in Figure 2.4 links on the bottom-right to publications analysing business models which are connected to the cluster of publications studying innovation. At the bottom of the figure, are publications on car-sharing, which link to the cluster on product-service systems. This indicates that the SE literature deals with innovative business models which contribute to making provision and consumption of products and services more cohesive and sustainable.

In summary, Figure 2.4 shows three main areas in the SE literature: the impact of digital technologies (clusters at the top), access-based consumption (clusters in the centre) and provision of sustainable consumption alternatives (clusters at the bottom).

Linking Communities in Fractional Ownership and Sharing Economy Literatures

Figure 2.5 shows the links among the top 15 clusters in both literatures. Overall, these literatures are separate with a few connected clusters, fundamental to understand the topics contributing to a common conceptual basis between FO and SE. Work on psychological ownership are linked strongly to the SE literature, indicating that the perceived feeling of ownership is an important theoretical element explaining access-based consumption in the SE. It is important, also, to note that clusters of publications relative to social capital, property rights and the commons are connected to the SE clusters possession and product service systems.



Notes: The figure shows the top 15 clusters of publications in both FO and SE literatures that are merged via the Leiden community detection algorithm. Clusters are ranked by summing the number of citations received by the publications included in those communities. Clusters are labelled based on the results of the co-wording analysis, which extracts the most frequently occurring terms in the titles and abstracts of the publications in each cluster.

Figure 2.5: Connections between of top clusters of publications in the FO and SE literature

Figure 2.5 highlights another important connection. This is the link between the clusters of publications studying innovation and energy communities. While previous connections relate mostly to the theoretical conceptualisation linking the SE and FO literatures, this connection sheds lights on real cases of FO linked to the SE literature.

The innovation literature (related to SE) studies energy communities as a form of grassroots innovation, where fractional ownership is a bottom-up process leading local communities to enjoy social and economic benefits of undertaking sustainable common actions.

The cluster of publications dealing with car sharing merits a final observation. In the list of SE keywords (Table 2.1), I included words related to shared mobility (*shared mobility*, *car sharing* and *ride sharing*) since this stream of work studies fractional ownership as sub-model of car sharing. However, the community detection in Figure 2.5 finds no connections between this cluster and the FO literature which suggests that work on car sharing does not analyse ownership in relation to the FO literature, possibly because, as discussed in Section 2.1, car sharing is a form of pseudo-sharing consisting of short-term renting of a car and no community engagement.

2.4.4 Main-Path Analysis

To identify the historical development or knowledge flows in the SE and FO literatures and how they have evolved over time, this section presents and discusses the results of the MPA. The analysis was run separately for both literatures (FO and SE) and then run on the citation network based on merging the two.

This section follows the identification pattern: red nodes FO publications, blue nodes SE publications and green nodes common publications in the FO and SE literatures. In addition, clusters of publications in the main-paths are coloured and labelled based on the results of the community detection analysis. In the main-paths, the arrows represent links between publications: the direction of the arrow indicates that a publication cites the publication the arrow points to. The thickness of arrow connecting two nodes is proportional to their traversal count: the thicker the line, the higher the relevance of that link in the citation network. Nodes are ordered by publication year, from the oldest (bottom) to the newest (top). Nodes are labelled by strings composed of the following bibliographic elements of the publication: first author's surname, first letter of first author's name, year of publication, volume number and first page number.

Main-Paths in Fractional Ownership Literature

The FO main-path in Figure 2.6 starts from Coase's seminal work on the nature of the firm (Coase 1937) and follows through to his study on social costs (Coase 1960) and work on property rights (Demsetz 1967). These papers provide the basis for the theory of the ownership structure of the firm (Jensen & Meckling 1976). The focus on separation and control in firms is the overarching area of research in the first part of the main-path, and is analysed from different perspectives. For example, Myers (1977) analyses the determinants of corporate borrowing in relation to the market value of the firm, and Jensen & Meckling (1979) examines the productivity effect of firms in relation to the structure of the property and contracting rights. These ideas were developed by studying the agency problem (Fama 1980, Fama & Jensen 1983) and analysing how the firm structure affects corporate ownership (Demsetz & Lehn 1985).

The FO literature evolved by considering the value and control of corporations via voting rights (Morck et al. 1988, Mcconnell & Servaes 1990, Coffee 1991), with reference to employee stock ownership plans (ESOP) (Stulz 1988). Corporate governance is central to the historical development of this literature (Shleifer & Vishny 1997) and this topic opens directions for new research on legal protection of investors (La Porta et al. 1997, 1998, 1999). Case studies figure in the historical development of this literature, specifically in relation to the separation of ownership and control in corporations in East Asia (Claessens et al. 2000) and Western Europe (Faccio &

Lang 2002).

Notes: The figure illustrates the local key-route main-path in the citation network of FO literature, considering the first 40 links in the network, ranked by their traversal count. Red nodes represents FO publications and green nodes common publications in the FO and SE literatures. Clusters of publications are coloured and labelled as for the community detection analysis. Arrows represent links between publications: a publication cites the publication the arrow points to. The thicker the line of an arrow, the higher the traversal count of the link. Nodes are ordered by publication year, from the oldest (bottom) to the newest (top). Nodes are labelled by strings composed of: first author's surname, first letter of first author's name, year of publication, volume number and first page number.

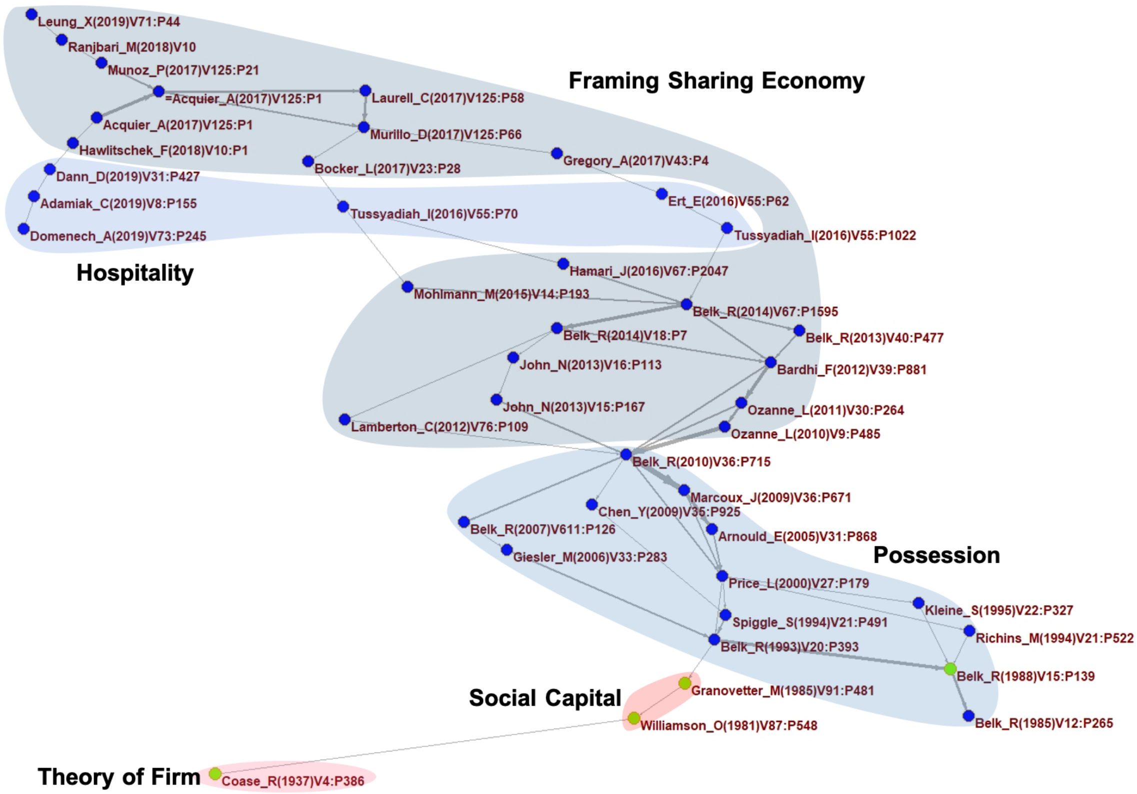
Figure 2.6: Local key-route main-path in the FO literature

Building on the knowledge on ownership control, the FO literature developed by analysing the competitive effect of common ownership in the market. New forms of organisational separation and control are analysed, including blockholdings (Edmans 2014), modern governance mechanisms (Mccahery et al. 2016) and horizontal shareholdings (Elhauge 2016). The literature also studies the impact of institutional investors on market competition (Appel et al. 2016, Fichtner et al. 2017, Posner et al. 2017, Azar et al. 2018). In more recent years, the FO literature has focused on two topics. The first relates to the competitive effect and the market outcome of common-ownership structures (Brito et al. 2018, Rock & Rubinfeld 2018, Patel 2018, Schmalz 2018). The second focuses on large voting power in investments corporations and the impact on the governance and performance of those corporations (Bebchuk & Hirst 2019, Walker 2019, Fisch et al. 2019, Morley 2019).

MPA indicates that the main historical development in the FO literature started with the theory of the firm, to a focus on the separation of control and ownership and corporate finance, including notions related to legislation, antitrust and market competition. The bulk of the main-path includes publications belonging to only two of the top 15 clusters identified in Figure 2.3, which are not connected to the SE clusters (Figure 2.5). This means that FO publications linked to work on SE are not part of the main knowledge flow in the FO literature. However, it should be noted that the initial two nodes in the FO main-path (Coase 1937, 1960) are green nodes, meaning that these publications are common to both literatures.

Main-Paths in Sharing Economy Literature

Figure 2.7 shows the main-path of the SE literature. Similar to the FO literature, Coase's seminal work on the nature of the firm inspired the main knowledge flow in this literature (Coase 1937). It continued by studying transaction costs (Williamson 1981) and the problem of embeddedness in interpersonal relations and institutions (Granovetter 1985). These are green nodes, that is, common to both literatures. In the bottom left part of the main-path, publications on materialism, possession and extended self spurred another initial path in the SE literature (Belk 1985, 1988, Richins 1994, Kleine et al. 1995). These works focus on consumers' attituded to ownership and consumption and provide relevant background to the development of the SE literature.



Notes: The figure illustrates the local key-route main-path in the citation network of SE literature, considering the first 40 links in the network, ranked by their traversal count. Blue nodes represents SE publications and green nodes common publications in the FO and SE literatures. Clusters of publications are coloured and labelled as for the community detection analysis. Arrows represent links between publications: a publication cites the publication the arrow points to. The thicker the line of an arrow, the higher the traversal count of the link. Nodes are ordered by publication year, from the oldest (bottom) to the newest (top). Nodes are labelled by strings composed of: first author's surname, first letter of first author's name, year of publication, volume number and first page number.

Figure 2.7: Local key-route main-path in the SE literature

The two initial paths converge in studies in the SE literature on the theoretical contrast between sharing and gift-giving (Belk & Coon 1993, Spiggle 1994, Price et al. 2000, Arnould & Thompson 2005, Giesler 2006, Belk 2007, Chen 2009, Marcoux 2009). In 2010, Belk (2010) defined the concept of sharing, framed in contrast to gift giving and commodity exchange. While the latter two involve possession and transfers of ownership, sharing involves a feeling of community, cooperation and unity. This publication opens up new directions for SE research by providing a conceptualisation of sharing which led to the cluster of publications on the framing of the sharing economy.

Sharing was studied initially as a form of anti-consumption (Ozanne & Ballantine 2010, Ozanne & Ozanne 2011) that motivates consumers to share rather than to own and enables access-based consumption (Bardhi & Eckhardt 2012). The SE literature developed by studying the extended-self in the digital era (Belk 2013) and analysing sharing practices in the Web 2.0 context (John 2013*a*,*b*) that generate forms of pseudo-sharing (Belk 2014*a*). These SE literature streams converge in the work of Belk (2014*b*), who defined the post-ownership economy as a situation where people identify themselves in relation to what they can access and what they can share. This was another pivotal publication in the SE literature which led to subsequent work on consumers' attitude to sharing practices in the sharing economy.

One branch of this literature studies how trust and reputation affect hospitality and travel behaviours (Tussyadiah & Pesonen 2016, Ert et al. 2016) and public relations (Gregory & Halff 2017). The other focuses on the motivations for participating in the sharing economy (Hamari et al. 2016, Böcker & Meelen 2017) and on factors related to consumer satisfaction (Möhlmann 2015, Tussyadiah 2016). There is a strand of the SE literature which studies promises and paradoxes related to the SE, uncovers some controversies and analyses the tensions between a market and a non-market logic (Acquier et al. 2017, Murillo et al. 2017, Laurell & Sandström 2017).

The most recent SE publications fall into two types. The first includes publications on tourism and hospitality management and consumers' attitudes to participating in sharing practices (Hawlitschek et al. 2018), leading to a specific focus on *AirBnB* (Dann et al. 2019, Adamiak et al. 2019, Domènech et al. 2019). The second includes publications which help to frame and conceptualise the sharing economy with a focus on sustainability and business models (Muñoz & Cohen 2017), and considering the current socio-economic context (Ranjbari et al. 2018, Leung et al. 2019).

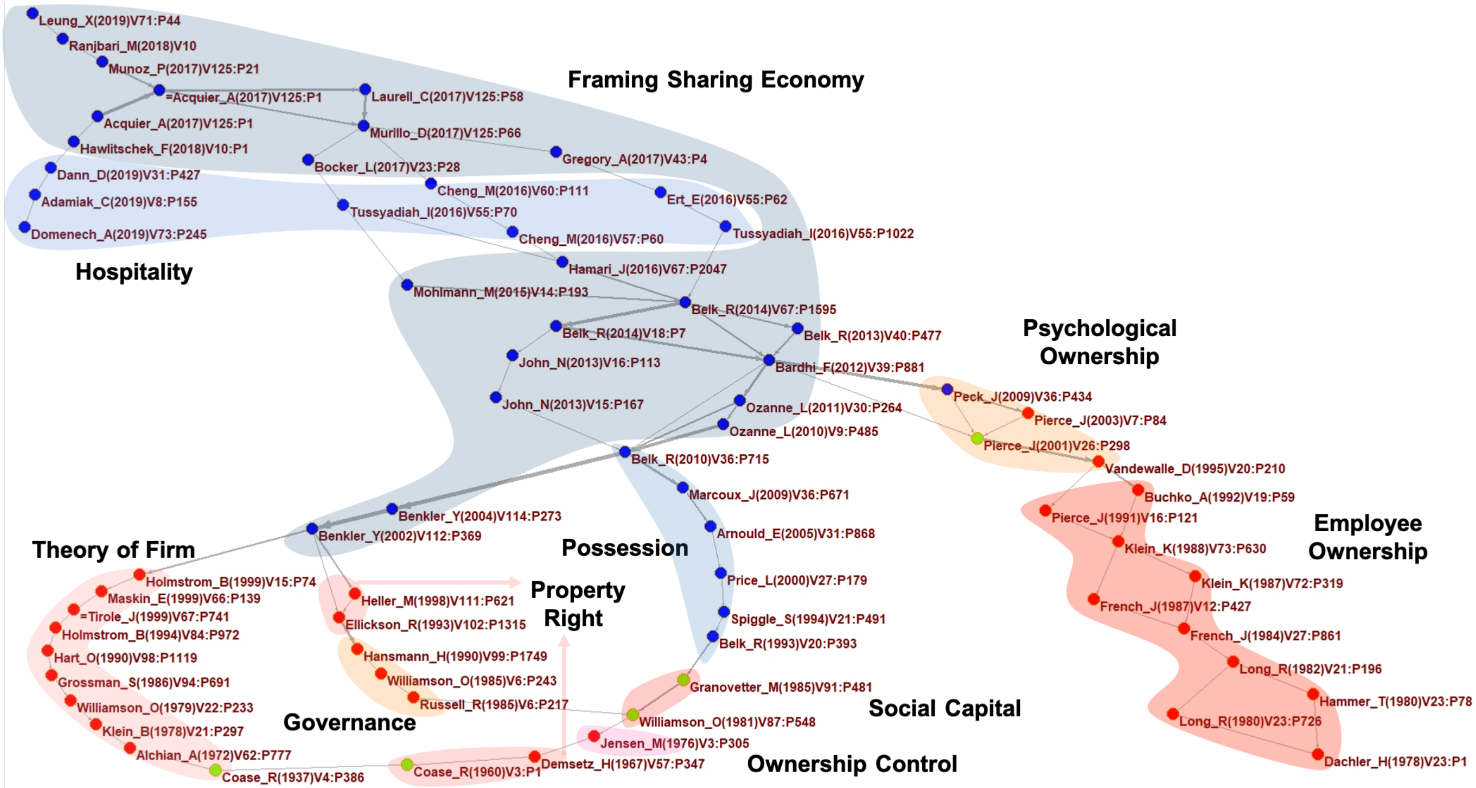
MPA shows that the historical development of the SE literature started with publications related to consumer research which analysed consumers' attitudes to ownership and consumption and was extended by work on the theory of the firm and social capital. These initial concepts contributed to framing the notion of sharing. Following this, the SE literature focused on analysing sharing practices which deviate from the idea of ownership, which is not debated further in the SE main-path.

Linking Main-Paths in Fractional Ownership and Sharing Economy Literatures

Figure 2.8 shows the main-path in the literature based on merging the FO and SE citation networks. The red highlighted publications belong to the FO clusters/literature, and the blue ones to the SE clusters/literature. It can be seen that FO and SE do not overlap, meaning that the publications related to one literature do not appear on the main-path of the other literature. Instead, the literatures are complementary and, more important, the origin of SE literature is linked to the earlier FO publications.

There are three main parts in the FO literature which inspired the SE literature. At the bottom-left of Figure 2.8, are FO publications related to the theory of the firm, property rights, governance and ownership control which are cited by SE publications. At the bottom-right, we can see that the SE literature is connected to FO publications on psychological ownership, which, in their turn, are linked to employee ownership. As in Figure 2.7, SE publications related to possession are linked to publications in the social capital cluster. More recent publications, top-left of the main-path, are the same blue nodes in the SE main-path and belong to the clusters framing the SE and hospitality. This indicates that the more recent SE literature has not been influenced by the FO literature.

I next examine the blue and red nodes linking publications in the FO and SE litera-



Notes: The figure illustrates the local key-route main-path in the citation network that merges both FO and SE literature, considering the first 40 links in the network, ranked by their traversal count. Red nodes represents FO publications, blue nodes SE publications and green nodes common publications in the FO and SE literatures. Clusters of publications are coloured and labelled as for the community detection analysis. Arrows represent links between publications: a publication cites the publication the arrow points to. The thicker the line of an arrow, the higher the traversal count of the link. Nodes are ordered by publication year, from the oldest (bottom) to the newest (top). Nodes are labelled by strings composed of: first author's surname, first letter of first author's name, year of publication, volume number and first page number.

Figure 2.8: Local key-route main-path in the FO and SE literature

tures, to identify the topics linking them. At the bottom-right, the SE publication by Bardhi & Eckhardt (2012) is connected to FO publications on psychological ownership (Peck & Shu 2009, Pierce et al. 2001). Bardhi & Eckhardt argue that access-based consumption generates a temporary perception of ownership in the consumer without the need for actual ownership. This is one of the main driver of access-based consumption in the SE. This connection shows that the main historical development in the SE literature originated from the idea that the sense of perceived ownership motivates consumers to engage in access-based consumption, even though this is a temporary feeling which lasts for only as long as their temporary access.

The bottom-left part of the main-path indicates that the definition of sharing (Belk 2010) is the result of two main streams of research, involving both FO and SE publications, which originates from work on the nature of the firm (Coase 1937). Starting with this initial publications, one path goes through FO publications on property rights, ownership control and transaction costs and ends with problems related to embeddedness in the social structure. The study on social capital connects the FO literature to SE publications on consumers' attitudes to possession, gift and market exchanges, which are the eventual basis of the definition of sharing.

In the second FO literature stream Belk (2010) links backward to the concept of shareable goods, proposed by Benkler (2004), based on a study of transaction cost theory and the motivations to share. Shareable goods are "lumpy" goods, with idle capacity whose access can be granted to others for money. Benkler (2002) links the FO and SE literatures directly by analysing common-based peer production in connection to the topic of property rights. Specifically, he links to the notion of anticommons (Heller 1998) and land property rights (Ellickson 1993). The first link indicates that the sharing economy allows for exclusion with no exclusive use privileges. This determines the paradoxical tragedy of the anticommons leading to underutilised resources, which is one of the dynamics driving the SE. The second link connects to the idea that close-knit groups can choose to coordinate to minimise living costs and achieve more efficient land utilisation.

To conclude, MPA shows that the FO literature is important to understand the origins of the SE literature. There are two main FO topics which link to the SE literature. The first concerns psychological ownership and the second one concerns the connection between transaction costs, property rights and social relations. Compared to the FO MPA (Figure 2.6), FO publications on ownership control and competitive effects do not emerge in the combined analysis. This is not surprising since these topics are not relevant to SE. However, this lack of connection is the reason why the recent SE literature does not debate FO: the main knowledge flow in FO is unrelated to the SE.

2.5 Discussion

This paper provides a better understanding of the origins of the SE and sheds light on its relations to FO. Systematic analysis of the citation networks built on the FO and SE academic literatures identifies their common conceptual base.

Compared to work on the SE, the earlier FO literature includes fewer publications. Economy, finance and applied psychology are the main disciplines in the FO literature. The SE literature involves several disciplines such as transport, consumer research, marketing, business and management.

The main historical development of the FO literature shows no links to the SE. In fact, the MPA focuses on the theory of firm, specifically, on organisations where ownership and control is shared among several actors, and on corporate finance. However, there are other clusters of publications in the FO literature that study the role of social capital in firms. In particular, this literature shows that employees' participation in the ownership of an organisation generates a feeling of collective psychological ownership (Pierce & Jussila 2010) that is similar to the sense of community generated when people organise to manage a common good. People engage in common actions and build social relationships to share the values and norms required necessary to create mutual trust and enhance cooperation and collaboration in the group. These social structures are fundamental for effective functioning of practices based on FO.

When analysed independently, the main historical developments in the SE literature show its lack of links to FO. It originated from work on two main topics, which was modified and adapted in line with the evolution of the marketplace in which the SE occurs. The first topic is the theory of the firm, which, by embracing the notions of transaction costs and social capital, leads to the second topic on consumers' attitudes to possession, materialism and ownership.

In contrast to the origins of FO, the theory of the firm and the role of social capital help to explain how the SE operates in the digital space. Here, market exchanges are facilitated by digital platforms, with business models allowing connection between the contracting parties, who may not be proximate and who never interact face-to-face. On the one side, digital platforms reduce the transaction costs involved in accessing a shared good, by eliminating the intermediaries between provider and consumer. On the other side, since the platforms are acting as intermediaries and obtain a marginal profit from these transactions, they can increase their profit by operating at the global level to achieve economies of scale.

The second origin of the main historical development of the SE literature refers to consumer research. This strand of work explains that the SE has generated new forms of consumption behaviour in opposition to possession, thereby downgrading the importance of ownership as the identification of the extended-self. In other words, the SE emphasises the post-ownership model of consumption in which possession is no longer the ultimate goal of the consumer. Instead, consumers are more inclined to favour access-based consumption of goods that are not directly owned.

When the two literatures were merged and analysed together, three topics in the FO literature were shown to be at the roots of the SE literature: psychological ownership, anticommons and group cooperation. As discussed above, in the SE, ownership is not the ultimate desire of consumers. The connection to psychological ownership clarifies this: consumers are motivated towards access-based consumption because it satisfies a need through the use of a shared good, leading to a temporary feeling of ownership (Bardhi & Eckhardt 2012).

The second aspect of FO which inspired the literature on the SE is the characteristic that the shared goods are under-utilised and, hence, shareable (Benkler 2004). Some scholars studying the SE identify shared goods as common goods. The theory of common goods says that utilisation is privileged and there are no rights of exclusion, leading to the tragedy of commons when the common good is overused and, thus, becomes scarce. However, this theory does not hold in the context of the sharing economy, which, instead, is inspired by the tragedy of the anticommons (Heller 1998). It includes rights of exclusion and no effective privileged utilisation and, if exclusion is enforced, the resources become underutilised.

The connection to the tragedy of the anticommons helps to explain two characteristics of the sharing economy. On the one hand, anticommons determines idle capacity of resources, thereby favouring sharing practices. On the other hand, shared goods are privately owned and access to them is granted by their owners. Therefore, the concentration of ownership enables the rights of exclusion, often in relation to goods or services which are fairly essential to consumers, such as accommodation or transport. In the SE, owners that grant access to goods or services have no legal obligations to maintain this provision. They respond to market dynamics and can discontinue provision for any economic, financial or business-driven reasons. Also, consumers have no rights related to continuity of provision. The link to FO shows the difficulty involved in the SE of combining market-driven dynamics with promises of social equity (Richardson 2015, Schor et al. 2016, Acquier et al. 2017, Murillo et al. 2017, Laurell & Sandström 2017).

The third connection between the FO and SE literature is related to the concept of close-knit groups and group ownership (Ellickson 1993). Developed in the context of property rights in land, close-knit groups refer to social entities based on cooperation, power distribution and continuous face-to-face interactions among members. The group is formed to enable collective living on shared land, to increase members' benefits, to minimise their costs and to adapt to changing economic conditions. This strand of work suggests that informal social control could avoid the tragedy of the commons. Within a market economy, the idea of cooperative groups becomes appealing only if it generates higher benefits than those resulting from market dynamics (i.e., reduced costs). However, if the market offers better conditions, the reason for a close-knit group disappears. The SE enables access to goods at very competitive prices, discouraging possible formation of close-knit groups. Collective action and shared ownership in the SE emerge only if the cost of owning a common good is lower than the market cost. For example, people could jointly buy and own a car and share its use, but access to cars provided by car-sharing platforms is cheaper. Also, the legal standards for group ownership often do not exist (e.g., shared car insurance).

2.6 Conclusions

This paper sheds light on fractional ownership to provide a better understanding of the origins of the sharing economy. The analysis of the combined citation networks of the two literatures provides evidence that the sharing economy literature focuses mainly on access-based consumption of goods, which, ultimately are owned individually. This explains the rising ownership polarisation and the difficulties related to the emergence of fractional ownership models in the context of the sharing economy.

Consumer preferences for access rather than ownership, reduce the possibility for fractional ownership where ownership is important if it is shared. Access-based consumption reduces identification of consumers with the shared good, since consumers in the sharing economy are self-interested, lack a sense of community, demonstrate negative reciprocity and do not trust other (Belk 2014*a*). The temporary feeling of ownership perceived by consumers in the sharing economy rejects the positive impact of the collective psychological ownership perceived by participants if the good is owned by the group, which weakens fractional ownership in the sharing economy.

However, combined analysis of the two literatures showed that the sharing economy has resulted in emergence of the topic of energy communities, which is a case of fractional ownership. Publications on innovation in the sharing economy literature define energy communities as forms of grassroots innovation (Seyfang & Smith 2007, Seyfang & Haxeltine 2012). Local energy communities are examples of close-knit groups – often of neighbours – who organise to take responsibility for providing energy at the local level. Driven by the social structure (e.g., shared values and norms, mutual trust, group cooperation and collaboration), the participants in these communities enjoy the social and economic benefit of engaging in sustainable common actions. There are several real experiences of energy communities, and this is a very positive signal suggesting that fractional ownership could be instrumental in alleviating energy poverty (Seyfang et al. 2014, Goedkoop & Devine-Wright 2016, Müller & Welpe 2018). Energy legislation is developing to include regulation of interactions between energy communities and the private sector, to diffuse new climate neutral technologies.

Inspired by the study of energy communities, future research on the sharing economy could be based on fractional ownership models adapted to include self-organising communities to share the purchase, ownership and use of a common asset. More research is needed on mobility in urban areas, where less private car ownership is needed to make city spaces more sustainable (Meelen et al. 2019). Sharing ownership of a car could be a valid alternative for consumers whose budget does not allow purchase of an individual car and who prefer to avoid public transport (or car-sharing schemes) either because they can become congested or because they do not serve all city districts. Communities can have a positive societal impact by increasing access to and ownership of goods or services not affordable individually, thereby alleviating scarcity and reducing poverty. It is important to examine the conditions that might favour the formation of communities and the complex and dynamic interactions among individuals.

Chapter 3

Coalition Formation and the Diffusion of Shared Goods

Abstract

Citizens' engagement and consumers' empowerment are key drivers of the transition to a more sustainable economy. The adoption of decentralised energy systems may improve the efficiency and cost-effectiveness of the generation, transmission and consumption of energy, while reducing emissions, dependence on the (often fossil-based) national grids and energy poverty. However, this adoption, which involves high fixed costs and high capacity, requires the formation of communities of consumers. While several models analyse the diffusion of goods among agents connected within a network, and several models analyse the formation of coalitions, we lack theory and evidence about the coevolution of adoption with coalition formation. This paper addresses this gap by developing a model that combines an evolutionary coalition formation game with a model of diffusion within a regular network. Because coalition formation is a necessary condition for the adoption of a shared good, it is also an obstacle to its complete diffusion. We find that the smaller the neighbourhood that the shared good can serve, the lower is the share of adopters. This is because agents that do not enter the coalition at an early stage remain isolated by being outside the already formed coalition and too distant from agents not yet in a coalition. This geographic constraint also limits the spread of information about the new shared good, hampering the diffusion process before consumers have been able to assess the convenience related to joining a coalition. The paper concludes by discussing some policy implications in relation to increasing adoption of shared goods.

3.1 Introduction

According to both research and policy, citizen engagement and consumer empowerment are key drivers of the transition towards more sustainable economies (Smith et al. 2014, Bauwens et al. 2016, Schot et al. 2016, European Commission 2010, 2015*a*,*b*). According to this view, consumers must be made more aware of the environmental impact of their choices and encouraged to adopt more sustainable goods and lifestyles (Briceno & Stagl 2006, Schweizer-Ries 2008, Hyysalo et al. 2016).

One such sustainable option includes groups of co-located households coordinating to form energy communities to jointly adopt sustainable Decentralised Energy Systems (DES) to generate the energy that they consume (Dóci & Vasileiadou 2015, Van Der Schoor & Scholtens 2015, Bellekom et al. 2016, Goedkoop & Devine-Wright 2016, Koirala et al. 2016, Hasanov & Zuidema 2018). DES are power sources, scaled to household demand, installed physically close to final users and connected to them directly (Hatziargyriou & Meliopoulos 2002, IEA 2002). The adoption of DES in local energy communities would improve the efficiency and cost-effectiveness of the generation, transmission and consumption of energy, while reducing emissions, dependence on the (often fossil-based) national grid and energy poverty (Kirchhoff et al. 2016, IEA 2017, Holstenkamp 2019, Katre & Tozzi 2019).

Despite these benefits, diffusion of DES has proved difficult and, to date, they occupy a niche in the dominant centralised network (Arentsen & Bellekom 2014, Dóci et al. 2015, Strachan et al. 2015). The formation of local energy communities to adopt DES faces a range of challenges. Apart from infrastructures requirements (i.e., energy dispatch), coordination among neighbouring households can be fraught with heterogeneous constraints and preferences (Watson 2004, Sauter & Watson 2007, Groh et al. 2014, Pasimeni 2019). Close local communities are likely to find it easier to coordinate compared to scattered weakly connected communities composed of distant members (Granovetter 1973). However, closer knot communities tend to limit diffusion.

Coordination and the need for DES to be physically located close to users, can hinder diffusion. To design policies to foster the diffusion of DES (Jacobsen et al. 2013, DECC 2014, Oteman et al. 2014, Dóci & Gotchev 2016, Süsser et al. 2017), there is a need to better understand the role of coalition formation in the defined geographical space (Seyfang & Smith 2007, Seyfang 2010, Seyfang & Haxeltine 2012).

This paper proposes a simple model to analyse the diffusion of a shared good, such as DES, in a coalition formed in a geographically delimited neighbourhood. We combine features from coalition formation models with those of network diffusion models. We model coalition formation as an evolutionary game among agents that decide to contribute to a common investment. We model diffusion using elements from both the Bass and the threshold models where agents are located on a regular network.

Users can consume a service (e.g., electricity) by purchasing it from the public provider or by forming a local coalition to purchase a shared good and share its use. Shared goods require the agents to form stable coalitions which satisfy all their members (i.e., none of them prefers to exit or move to a different coalition). Some local residents might decide not to participate in a coalition either because they are better off with the public service or because all coalition members would be better off if they do not join. In order to form a stable coalition, agents iteratively make offers for a contribution which maximises their utility in coalition. At each iteration, all agents assess their utility, which is a function, also, of the contributions of other members, and assess how much of the shared good they will consume (their demand). Before being able to assess the benefit of joining a coalition, agents must be informed of the opportunity to purchase the shared good. Information spreads as informed agents get in touch with non-informed agents, to invite them to join the coalition.

The recursive nature of the model, the heterogeneity of agents and their limited rationality, and the reliance of diffusion on endogenous network formation means that the model has no analytical solution. Therefore, we simulate the model to analyse its properties in terms of diffusion and coalition formation, and to study their co-evolution. In particular, we study the conditions under which coalition formation leads to or hinders diffusion, and how the results change for different properties of the network in which the agents interact.

We find that, because the adoption of a shared good requires the formation of a coalition, the diffusion of the shared good never reaches all of the population. To some extent, this is because some consumers do not find a coalition that increases their utility with respect to purchasing the public service. This depends, in part, on the distribution of preferences across heterogeneous agents. Perhaps of more interest, it depends also on the effect that coalition formation has on reducing the probability of those agents who have yet to join a stable coalition, from doing so. As already mentioned, participating in a coalition depends on the preferences of both the individual consumer and the other members of the coalition.

The number of possible coalitions reduces rapidly if the good can be adopted only by clustered local neighbours (e.g., DES). In this case, the smaller the size of the neighbourhood that can be served by the good, the lower the adoption share since agents that did not enter the coalition early become isolated between already formed coalitions and agents who are not sufficiently proximate to enable a coalition. The geographic location of the shared good and the location of its use constrains diffusion if coalitions are formed before proximate agents are in possession of full information. This happens if an agent who receives information about a shared good joins a large coalition and is constrained from contacting neighbours because they would be too far away from the most distant coalition partner.

The outcomes of the model could be informative for decision-makers in relation to supporting communities to purchase a good with a high investment cost, where belonging to a coalition would reduce the unit cost of the service (e.g. DES).

To the best of our knowledge, there are no other published studies that consider the diffusion of shared goods in combination with the formation of coalitions, and no published evidence showing how the processes of coalition formation and diffusion co-evolve. We build on several strands of work that have analysed these concepts separately: common properties, collective adoption, diffusion in networks and coalition formation. The aim of the present paper is to fill the gap in the knowledge about how these processes co-evolve. To do so, we first abstract theoretical aspects from the case of DES and then use them to develop an agent-based model.

The rest of the paper is organised in four sections. Section 3.2 presents theoretical concepts related to the adoption and use of shared goods. We use these theories to develop the model, which is presented in Section 3.3. Section 3.4 presents the results and Section 3.5 concludes with a discussion of some policy implications related to the diffusion of shared goods adopted by communities.

3.2 Theoretical Background

DES are indivisible, capital-intensive goods with high fixed costs. They produce an amount of energy that is well beyond the needs of the average household. With a few exceptions, they are convenient for use by households only if they are adopted by a group of households. So, we need to study their diffusion as a “collective innovation decision” occurring through “consensus among members of a systems” and where participants “must conform to the system’s decision once it is made” (Rogers 2003, p.28). This is akin to the use of club goods by sharing groups (Buchanan 1965, Lindenberg 1982) and differs from standard models of diffusion that analyse individual choices, including those on low-carbon technologies (Diamond 2009, Schwarz &

Ernst 2009, Weiss et al. 2009, Bollinger & Gillingham 2012, Murakami 2014).

Group adoption has been studied in the case of agricultural technologies, for instance, to analyse farmers' decision' to cooperate to purchase a common irrigation infrastructure (Bardhan 1993*b*,*a*, 2000). These models of governing common-pool resources suggest that local-level community organisations are more efficient and effective than external governance, such as privatisation or nationalisation (Ouchi 1980, Ostrom 1990, Ostrom et al. 1994). This is because autonomous local communities, although formed of self-interested individuals, coordinate via informal relations and agree on shared norms. Shared reciprocity and altruistic behaviours can easily resolve conflicts and ease long-run cooperation in situations of economic and social interdependence.

Similar to other shared goods, such as the irrigation system just discussed, DES are also non-excludable and rival goods (Bowles 2004): the users that share the good can use the energy produced, but the energy consumed by a specific user is not available to the others. Hence, DES, are similar to common-pool resources, which require self-governance, trust, compliance, cooperation and coordination among users to manage their use (Seabright 1997, Dayton-Johnson 2000, Griffiths & Luck 2003).

To achieve coordination, the collective adoption decision must be preceded by formation of a coalition of agents that agree about how much they will contribute to and how much use the will make of the shared good (Olson 1971, Hardin 1982, Oliver & Marwell 1988, Schlager 1995). The literature on game theory has studied extensively the process of coalition formation (Caplow 1956, Gamson 1961, Komorita & Chertkoff 1973, Komorita 1974), in relation to initial conditions and network structure (Dreze & Greenberg 1980, Axelrod et al. 1995, Shehory & Kraus 1998).

In network theory, social interactions are fundamental to understand choices of the players and the profit they gain (Galeotti & Goyal 2009, Elliott et al. 2019, Galeotti et al. 2020). This is even more important when choices and coordination with neighbours will impact the efficiency of equilibrium outcomes and the joint welfare (Elliott & Golub 2019, Fainmesser & Galeotti 2020, Galeotti et al. 2021), particularly when uneven distribution of ownership in network may generate lower aggregate welfare (Galeotti & Ghiglino 2021). Although very different in purpose, the theory of innovation network provides insights on the effectiveness of collaboration to produce (rather than consume) new goods or ideas (e.g., patents), suggesting that forming coalition and joining forces increases overall benefits in terms of knowledge creation and reduced associated risks (Jaffe et al. 1993, Agrawal et al. 2008, Boschma & Frenken 2010).

These models help to understand under which conditions homogeneous rational agents that maximise social and individual welfare, coordinate to form simultaneous one-off coalitions, without intervention from a central planner.

One-stage models of coalition formation are based on two main assumptions (Bloch & Dutta 2011): agents are hyper-rational, meaning that they are aware of how other agents will respond, and are perfectly forward-looking and are able to form a stable coalition since there is an endogenous resolution to the problem of coordination among the agents. These models generally do not consider that organisations, based on coalitions, evolve and transform, which changes the conditions for the agents to remain in the coalition (and, therefore, their assessments). Also, agents are rarely homogeneous and hyper-rational (Simon 1991, Windrum et al. 2009).

Sequential games of coalition formation investigate how non-cooperating agents interact to find a stable equilibrium where all the players end up in a coalition (Bloch 1995, 1996) or remain singletons and gain a payoff equal to zero (Mutuswami & Winter 2002), with a rule of fixed sharing of the surplus among agents. Evolutionary game theory models relax the one-stage model assumptions of homogeneity and rationality and study how organisations change dynamically till they reach a steady state. For example, Axtell (1999, 2002, 2018) models the process of firm formation, showing that self-organised coalitions can achieve a better outcome than if all the players act independently. Firms are non-cooperating agents that contribute an amount of effort to ensure the production of a joint output, whose utility depends on their payoff and on the contribution of the other players that enter the coalition. Agents make proposals about their effort sequentially and to maximise the individual payoffs, and all other players decide whether to form the coalition or not. If not, then the agents must make another offer.

Whether individual or in a coalition, the diffusion of a new good is influenced by social networks (Tarde 1962, Bass 1969, Rogers 1976, Burt 1987, Arthur 1989, Abrahamson & Rosenkopf 1993, 1997). DES are no exception (Nygrén et al. 2015). There is a large literature that studies the diffusion of goods across consumers, modelled as nodes in a social network, linked by social ties. It shows that the speed and rate of diffusion depend on the network structure (Delre et al. 2010, Peres 2014). Three structures are commonly compared (Cowan & Jonard 2004): a regular (or lattice structure) network, a small world network and a random network. In the first, every node has the same number of nearest neighbours. Since this network is locally very dense and has a long average path length, diffusion is slow because information must travel through the whole network in order to reach nodes located at the opposite side of the network. The small world network structure (Watts & Strogatz 1998) is a regular network in which a few random nodes are connected to distant nodes. This structure maintains the same level of clustering as the regular network, but average path length is much shorter, resulting in faster diffusion. In random networks (Erdos & Renyi 1960), nodes are connected to each other randomly. This network has low average path length and low clustering, resulting in fast diffusion, although nodes are not locally connected.

To understand the likelihood that DES will diffuse, we need to combine the above theories to model the joint decision to form a coalition. The group of agents does not exist *ex ante* although their social connections and co-location do exist. We follow the evolutionary game theory literature to model the spontaneous process of coalition formation among heterogeneous agents with limited information and bounded rationality. Because the coalition is formed between agents that are co-located and form social ties, we need, also, to model how the information about the new good spreads through the network. A coalition is a required step to enable purchase of the indivisible good and its shared ownership and use. We model a shared good, such as DES, which is a non-mobile asset and can serve only agents that are co-located. We use insights from the literature on network diffusion to study the constraints on adoption of a coalition by agents in a regular network . Agents can reach out to physically distant, but socially close peers to acquire information about the new good. Unlike the existing research, we model the co-evolution between the processes of coalition formation, network formation and adoption, over time.

3.3 The Model

We build on evolutionary models of firm formation and the best-reply type adjustment dynamics proposed by Axtell (1999, 2002, 2018), which can be categorised as sequential coalition formation games (Bloch 1995, 1996, Mutuswami & Winter 2002).

We model a population of heterogeneous agents that can satisfy their demand for a service by using a public provider or by purchasing a shared good with other agents. The individual cost paid to access the public provider is given exogenously, and the utility of using it depends on the agent's characteristics and preferences. The individual cost of accessing the services provided by the shared good depends, also, on the characteristics and preferences of the other agents in the coalition (and the choices they make based on these characteristics and preferences), and on characteristics of the coalition such as its size. Then the utility of an agent in the coalition depends on how the individual cost and use of the shared good are determined in the uncoordinated process of coalition formation.

When given the opportunity to form a coalition, agents choose between doing so or using public service, through an iterative process in which all agents attempt to maximise their utility. Similar to Mutuswami & Winter (2002), we introduce into the negotiation process, a conditional cost contribution, which represents the monetary contribution that the agents are willing to commit to purchase the shared good. This contribution is a portion of the individual agents' incomes. Therefore, the decision to enter a coalition depends on how much income the agents need to invest (and their preference for income). The decision to enter a coalition depends, also, on how much of the service provided by the shared good the agents will be able to use. As in Axtell (2002), together with the conditional cost contribution, agents communicate their demand for the service.

The utility function in the coalition is an adaptation of the function proposed by Axtell (2002). The use of the good can be shared equally among coalition members, or can be shared in proportion to the agents' contributions or demand. Therefore, beyond the monetary contribution and own access, the utility of each agent in coalition depends also on the monetary contribution that other agents propose to commit, and on their individual demand and the cumulative demand for the service. Since agents respond iteratively to the choices of the other coalition members, the choice to enter each coalition changes over time.

Agents establish a coalition when it is stable, i.e., no agent (inside or outside the coalition) would make a different choice, in the given time step. This means that, for all agents in the coalition, the utility is higher and the individual cost is lower compared to using the public service. Under these conditions, the agents in the coalition adopt the common good jointly and share its use, and contribute to its diffusion. The adoption decision is maintained for the rest of the simulation, implying that adopters cannot form another coalition.

Agents are the nodes in a network whose structure evolves over time as new links are formed and existing links are severed. Changes to the network structure influence both the flow of information and the agents that can join the coalition and, therefore, the choices of other agents (Jackson & Wolinsky 1996, Dutta & Mutuswami 1997, Bala & Goyal 1998, Johnson & Gilles 2000, Jackson & Watts 2002).

We assume that the shared good can provide the service locally to agents that are located in close geographical proximity. This limits the number of coalitions that agents can join: they can form a coalition only with agents that are within a few steps (a few links) (Watts & Strogatz 1998, Amaral et al. 2000). When a coalition is formed, the participating agents cannot join another coalition, which would reduce the network for the remaining agents and affect the conditions under which they choose between potential further coalitions and the public service, in the succeeding time steps.

The model dynamics (i.e., recursive decision making model) and endogenous network formation, make it difficult to find an analytical solution which connects agent behaviour to the macro outcome of the diffusion of the shared good. We use agent-based computer simulations to simulate agents' behaviour and interactions, and we analyse the aggregate result for different conditions and different sequences of stochastic events.

At the start of the simulation, agents are disconnected nodes who have yet to form links to form a regular network. Agents have a maximum of L neighbours with whom they can form links. The model distinguishes between three types of agents: regular, *active* and *initiator*. The sequential coalition formation game starts with m randomly chosen *initiators*, who are the innovators that start the diffusion of the new good (Gersho & Mitra 1975, Rogers 2003). *Initiators* differ with respect to other agents because they: contact neighbours and form links to them to create a network of agents that can be involved in the coalition formation process (action A1); choose the good to buy in the coalition from a basket of available goods (action A2); start the process of coalition formation (action A3).

Regular agents become *active* when they are contacted by an *initiator* (action A1), and a bidirectional link is established between the two.[1] When a link is formed, the *initiator* informs the new now *active* agent about the shared good option to replace the use of the public service. *Active* agents can also become *initiators* and can create new links, thereby continuing the knowledge diffusion process as in the network percolation diffusion model (Mort 1991, David & Foray 1994, Solomon et al. 2000). An *active* agent becomes an *initiator* if its interest in the shared good is above a minimum level which is computed endogenously at each time step. This threshold is defined as *visibility* (Faber et al. 2010) and represents the minimum level of the agent's awareness of the new good. At every time step, a random value, $RND \in [0;1]$, is generated and associated to the *active* agents. An *active* agent becomes an *initiator* when this value is lower than the visibility (W_t). The visibility is computed as:

$$W_t = MAX[W_{t-1}; min[1; Adv + (SC_{t-1})^{\xi}]] \tag{3.1}$$

where Adv is the exogenous level of advertising, as in the Bass model (Bass 1969); SC_{t-1} is the share of agents in the population that have already established a coalition; and ξ is an exogenous parameter reflecting a bandwagon effect (Smallwood &

[1] An *initiator* is always *active*.

Conlisk 1979). Once an *active* agent becomes an *initiator*, it remains an initiator for the remaining time steps. *Visibility* increases with the number of capital goods diffused in the coalition, and increases the number of agents with a chance to become an *initiator*, which increases the likelihood that other agents are involved in coalition formation and adoption. As is common in diffusion models, agents that already belong to the coalition and have adopted the shared good, do not participate in the subsequent coalition formation processes, thereby reducing the number of *initiators* and the likelihood of new agents to be contacted. Therefore, coalition formation and diffusion are two co-evolving processes.

At the start of the simulation, all agents use the service supplied by the general provider at a cost (c_{i1}) which is a function of their demand for the service (d_i) and of the unitary price of the service (p_1):

$$c_{i1} = d_i p_1 \tag{3.2}$$

The cost of the service determines the agent's utility (U_{i1}) related to using the public service, together with its income (e_i) and demand (d_i). As in Axtell (1999, 2002), utility is modelled as a Cobb-Douglas function of the income spent to purchase the service ($e_i - c_{i1}$), and the demand (d_i):

$$U_{i1}(p_1; d_i; e_i; \theta_i) = (e_i - c_{i1})^{\theta_i} (d_i)^{1-\theta_i} \tag{3.3}$$

where θ_i is an agent's preference for income and 1-θ_i its preference for consumption.

As regular agents are informed about the option to purchase the good that provides the same service, at a cost shared with coalition members, they can consider this alternative if they are involved in the formation of a coalition. The *initiators* choose a shared product randomly (action A2). The good is chosen among those available in the market, which differ in cost (I), and capacity (S), i.e., the maximum amount of service supplied, and the unitary price of the service supplied (p_2). A product q is chosen randomly with a probability proportional to its diffusion share, calculated as the number of products q adopted (DS_q) over the total number of products already adopted ($\sum_{q=1}^{Q} DS_q$). At the beginning of the simulation, all products have an equal probability of being chosen. Formally:

$$\Omega_q = \frac{DS_q}{\sum\limits_{q=1}^{Q} DS_q} \tag{3.4}$$

The *initiators* then ask their linked neighbours to join the coalition to contribute to the purchase of the shared good q and share its service (action A3). When purchasing a shared good in coalition, the cost to each agent of accessing the service (c_{i2}) depends on the agent's demand (d_i) and the unitary price of this second option (p_2) compared to the public service options, plus the monetary contribution that the agent would be willing to contribute to purchase the shared good (x_i, $x_i{<}I$, where I is the total cost of the shared good). Formally:

$$c_{i2} = d_i p_2 + x_i \tag{3.5}$$

In the model, x_i is computed endogenously by each coalition member as the value that maximises its utility (U_{i2}) in a given coalition of size N: agents choose x_i to satisfy dU_{i2}/dx=0.

When purchasing a shared good in coalition, agents seek to maximise their utility in coalition, by determining the contribution they must offer to purchase the shared good (x_i), and which they compare to the utility from purchasing the public service. Utility is function of the agent's characteristics and preferences and the decisions of the $N-1$ other participants with respect to how much they are willing to contribute to and use the shared good. Formally, the utility function in coalition has the following Cobb-Douglas structure:

$$\begin{aligned} U_{i2}(p_2; d_i; e_i; \theta_i; \alpha_i; \beta_i; x_i; D_{-i}; X_{-i}) = \\ = (e_i - c_{i2})^{\theta_i}\{(d_i + D_{-i})[\frac{\alpha_i d_i}{d_i + D_{-i}} \\ + (1-\alpha_i)(\frac{\beta_i x_i}{x_i + X_{-i}} + \frac{1-\beta_i}{N})]\}^{1-\theta_i} \end{aligned} \tag{3.6}$$

where d_i is the agent's demand for the service and e_i is the agent's income. θ_i is the agent's preference for income and (1-θ_i is the agent's preference for consumption): a higher θ_i implies a lower propensity to invest in a shared good.

$\alpha_i \in [0;1]$ is the relative importance given to proportional division of use of the good, based on relative demand: for higher values of α_i agents prefer to share the use of the good based on relative demand (if their demand is relative higher, they will be able to use more of the service regardless of how much they have contributed). $\beta_i \in [0;1]$ is the relative importance given by the agent to the proportional division of the use of the good based on relative contribution ($\frac{x_i}{x_i+X_{-i}}$) rather than equal shares ($\frac{1}{N}$, with N the coalition size): for higher values of β_i agents prefer to share the use of the good in proportion to the size of their contributions rather than sharing equally.

X_{-i} and D_{-i} are, respectively, total monetary contribution and total demand of the other $N-1$ coalition members. The coalition's total monetary contribution is X, where X=$\sum x_i$ and X_{-i}=(X-x_i). The coalition's total demand is D, where D=$\sum d_i$ and D_{-i}=(D-d_i). Finally, note that the utility of a single agent purchasing from the public service (Eq. 3.3) can be derived from the utility of the coalition members (Eq. 3.6) when N=1 and D_{-i}=X_{-i}=0.

The utility of the agents that assess the purchase of a shared good and make their offers, depends on the coalition formation process. We assume an iterative process, where all the agents have the chance to assess (and make an offer for) a coalition of increasing size and varying membership. In brief, agents with network ties (*initiators* and *active*) compare the utility of the different coalitions they could join, based on their and other members' offers, and consider the coalition that yields the highest utility and the lowest cost, compared, also, to purchasing the public service. If any of those coalitions maximises the utility of all other members, the deal is sealed and the coalition is formed. Thus, agents adjust their choices in each iteration, in relation to what other agents independently choose to offer. Coalition formation is modelled as a dynamic and time consuming process of interactions among agents, as the value of the coalitions and the neighbourhood evolve over time and agents adapt their choices accordingly.

Let us explain this process in more detail in the context of the model and in a given time step. We do not assume perfect information and foresight: agents have limited time and capacity to compare all possible options, i.e., they do not assess all potential coalitions in a given time step. We model the evaluation procedure as an iterative bargaining process.

First, an *initiator* proposes a coalition to one of its neighbours to which it is already linked (N=2). Next, one of the two randomly chooses one of its neighbours to which it is already linked and invites it to join the coalition (N=3). This procedure continues for an increasing number of participants, making it possible to compare their utility in different coalitions for different investments.

For each coalition of a different size, agents iteratively make offers that maximise their utility. For instance, in a coalition of size N=3, an agent announces the conditional contribution (x_i), and evaluates its utility in this coalition. The conditional contribution of this agent changes the total contribution (X), determining changes to the conditional contribution of the next agents. This iterative process among the three agents continues until their conditional contributions remain unchanged after several announcements. The goal of this iterative process is stability. A coalition is stable if Pareto efficiency is achieved – i.e., no coalition member can improve its utility without making at least one other member worse off. More specifically, in a stable coalition: (i) all members maximise their utility; (ii) no member has an incentive to move to another coalition; and (iii) no other agent would prefer to enter the coalition. Four more conditions must be satisfied to reach stability in coalition. First, the sum of all members' monetary contributions must be at least equal to the investment cost (I) and must not exceed 110% of its value:

$$I \leq x_i + X_{-i} \leq I * 1.1 \tag{3.7}$$

Second, the capacity of the shared good (S) must satisfy the total coalition demand:

$$d_i + D_{-i} \leq S \tag{3.8}$$

Third (and fourth), the utility (cost) for all members in coalition must be higher (lower) than the utility (cost) they would experience as singletons, i.e., purchasing the service from the public provider:

$$U_{i2} > U_{i1} \tag{3.9}$$

$$c_{i2} < c_{i1} \tag{3.10}$$

At the end of the evaluation of the coalition of size N=3, if it is stable, the agents gain higher utility than using the public service. They make a conditional decision and provisionally store this coalition as the optimal one. If the coalition is not stable, they store the public service as optimal conditional decision. In the same time step, as the bargaining process continues, agents evaluate a coalition of size N=4 and other larger sized coalitions. If in a subsequent iteration another coalition yields a higher utility and a lower cost compared to the earlier optimal conditional decision, the decision is updated.

At the end of the evaluation process, all agents announce separately their optimal decisions. If this decision is related to the common investment, they announce the coalition they aim to set up. If all the members of this coalition announce that this option is also their optimal option, then the coalition is established. When a stable coalition is achieved, the coalition is established and the shared good is adopted collectively. We assume that the goods last until the end of the simulated time steps, and agents do not assess other options. Therefore, adopters cannot take part in subsequent coalition formation processes, which reduces the number of future coalition options in their neighbourhood.[2]

3.4 Results

Because the model has no analytical solution, we study its properties through simulations. We run the model for 200 time steps, where each step defines the time needed to form links, form coalitions, bargain, evaluate and make a decision. To control for the effect of random elements in the model on the final results, we run 40 Monte Carlo simulations with different random seeds, and present the averages. The model is implemented on the Laboratory for Simulation Development (LSD) platform (Valente 2008).

To analyse the model, we initialise its parameters to benchmark values, as described in Section 3.4.1. In Section 3.4.2, we study the macro and network properties of the model emerging from the interaction among heterogeneous agents. We focus

[2]A more detailed discussion of the model is provided in Annex A.2. It includes a description of the properties of Eq.3.6 and its parameters, and provides an illustrative numerical example which shows the process of coalition formation and the evaluation stages.

on the dynamics of diffusion and coalition formation. Then, in Section 3.4.3, we analyse the co-evolution of coalition formation and diffusion, and its dependence on the geographic location of the of agents in the network, by studying the parameters that define the neighbourhood size and number of initiators.

3.4.1 Model Initialisation

The model parameters in the benchmark configuration are initialised as in Tables 3.1, 3.2. The model simulates the co-evolution of coalition formation and diffusion of shared goods in a population (P) of 200 agents, distributed in a regular network. In our basic configuration, only 2% of them are *initiators* (m=4), chosen randomly at the beginning of every simulation (t=0). All agents have eight potential neighbours each (L=8), with whom they can form a link.[3]

Parameters		Value
Total population of agents	P	200
Number of $initiators$ at t=0	m*	4
Spatially bounded links in the neighbourhood (geography)	L_i*	8
Income	e_i	μ=1000, σ=250
Demand	d_i	μ=45, σ=10
Preference for income	θ_i	μ=0.5, σ=0.1
Preference for proportional division rule (consumption)	α_i	0.5
Preference for proportional (contribution) & equal share (size) division rule	β_i	0.5
Advertising	Adv	0.01
Bandwagon effect	ξ	0.85

Notes: Parameters of agents' characteristics income (e_i), demand (d_i) and presence for income (θ_i) are initialised based on a normal distribution with given average (μ) and standard deviation (σ). The model is analysed with different initialisation values of parameters with asterisk: m and L_i.

Table 3.1: Model initialisation

Agents are heterogeneous with respect to their income (e_i) and demand (d_i). Income, demand and price (see below) are initialised to respect empirically observable proportions. Agents are heterogeneous, also, with respect to their preference for income (θ_i), with the average agent being indifferent between income and consumption. At

[3]The degrees of separation between agents in a coalition may be larger than 1, because each member could invite its own neighbours.

the outset, each agent is assigned a value for each of the three parameters, drawn randomly from a normal distribution with given average (μ) and standard deviation (σ).

Agents are homogeneous with respect to the two remaining preferences: proportional division rule based on demand (α_i) and proportional division rule based on contribution (β_i).[4] Agent's awareness towards the shared good option increases at each time step by 1% (Adv=1%), meaning that the chances for agents to become *initiators* increase over time. Further, the bandwagon effect related to the share of adopters is almost linear (ξ=0.85).

Initiators can choose among ten different goods (Table 3.2). Each good has a different cost and maximum capacity, which is the maximum quantity of the service they can supply. These values are correlated: the higher the investment cost (I), the higher the maximum capacity (S). We assume increasing returns to scale, so that larger shared goods can provide the same service at a lower unitary price (p_2). We assume that there is a benefit from purchasing the shared good: although it has a fixed cost, the unitary price of its service is at least half of the unitary price of the public service (p_1).

3.4.2 Diffusion in Coalition: Model Properties

In this section, we describe the main model properties: diffusion rate of the shared good, coalition size (and size of the good purchased), network properties and average monetary contribution of the agents in the coalition.

[4]We also analysed the model with heterogeneous α and β; the results differed only marginally. See Table A7 in Annex A.2

Product	Investment (I)	Capacity (S)	Unitary Price (p_2)
q_1	500	200	5.00
q_2	600	250	4.75
q_3	700	300	4.50
q_4	800	350	4.25
q_5	900	400	4.00
q_6	1000	450	3.75
q_7	1100	500	3.50
q_8	1200	550	3.25
q_9	1300	600	3.00
q_{10}	1400	650	2.75
Unitary price of the public service (p_1)			10.00

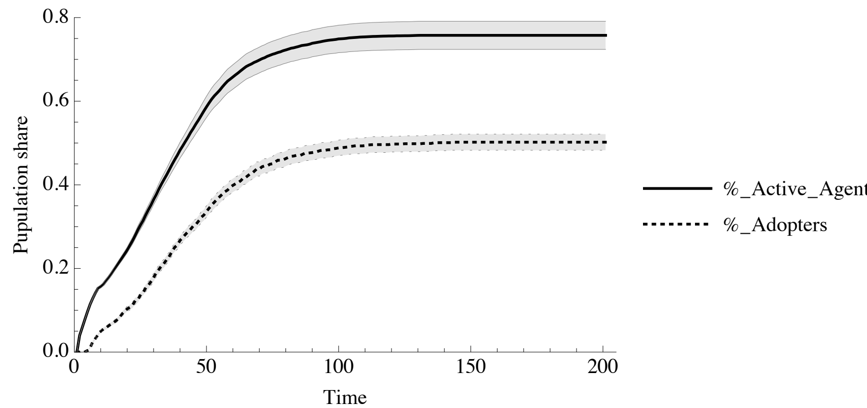
Notes: Ten different products are available to coalitions (q_{1-10}). Products differentiates per investment cost (I), maximum capacity they can supply (S) and unitary price (p_2). From the least to the most expensive, products increase capacity and reduce unitary price, which is always lower than the unitary price of public service (p_1).

Table 3.2: Model initialisation: available products

Diffusion

In our model, only agents that become aware of the new option can enter the coalition; these are the active agents. As already explained, agents become active when they are contacted by initiators that promote the new good in coalition.

Figure 3.1 plots the share of both the active agents in the population and the adopters (i.e., those who enter the coalition). At the outset, only 2% of the population is aware of the option to purchase the good collectively. For our benchmark initialisation, this share increases to around 75%, on average, in about 100 time steps, and then flattens out. This result confirms earlier results that contagion is relatively slow in regular networks (Cowan & Jonard 2004): our agents can reach out to peers to form only a local coalition, i.e., clustering is high. However, the figure shows, also, that around 25% of the population never receives the information and remains isolated. We explore this property of the model in more detail in Section 3.4.3.



Notes: The black line plots the cumulative share of agents in the population that over time have been informed of the option to purchase the shared good in coalition, hence being *active*. The dotted line plots the cumulative share of agents in the population that establish a coalition to buy a shared good. The shaded areas are the respective 95% confidence interval.

Figure 3.1: Cumulative share of active agents and adopter agents

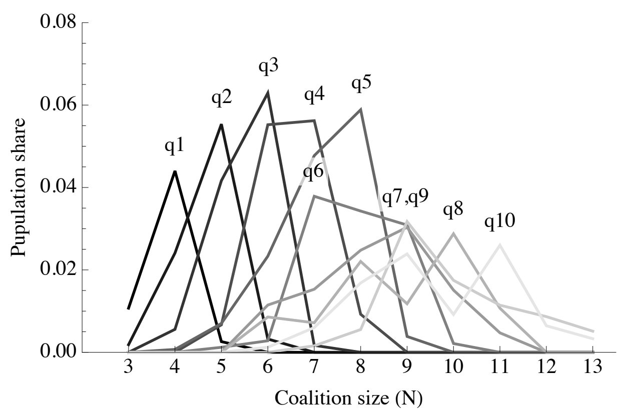
In our model, a good is adopted only if a coalition is formed, so information does not imply adoption. For our benchmark initialisation, the share of adopters reaches about 50% in about 100 periods, on average, and then flattens out. This means around 66% of agents are informed. The cumulative share of adopters follows the characteristic S-shaped curve, although the initial diffusion is fast compared to the observed diffusion curves. Since the early stages of the simulation, sharing the good in coalition brings higher utility for the agents compared to the public service.

In contrast to the standard diffusion model (and some of the figures for individually purchased goods, such as domestic appliances), the rate of diffusion decreases earlier than if 50% of the population adopts the good. This is because, in our model, adoption is conditional on forming a coalition. As we will discuss below, when a coalition is formed, some users that did not take up the offer to join the coalition, will remain isolated and have no other opportunity to join.

Coalition Size and Shared Investment

What is the average size of a coalition to share a good? Coalitions can adopt 10 different goods of varying capacity and cost (with costs reducing with scale). As discussed in the model description, coalitions will tend to choose goods that have been adopted more frequently in the past (Eq.3.4). As the cost of the good increases, either the individual contribution or the number of members needs to increase. As capacity increases, it can accommodate either individuals with higher demand or more individuals with lower demand.

Figure 3.2 plots the distribution of the size of the coalitions for different good sizes, where q_1 is the smallest good and q_{10} is the largest good (Table 3.2). The share on the vertical axis is the share of adopters of the good in the total population.



Notes: Curves plot the distribution of the share of adopters in the population (vertical axis) in relation to the coalition size (horizontal axis). Each curve plots the distribution for different products purchased in coalition. Darker curves represent less expensive and smaller products.

Figure 3.2: Share of adopters per coalition size and product purchased

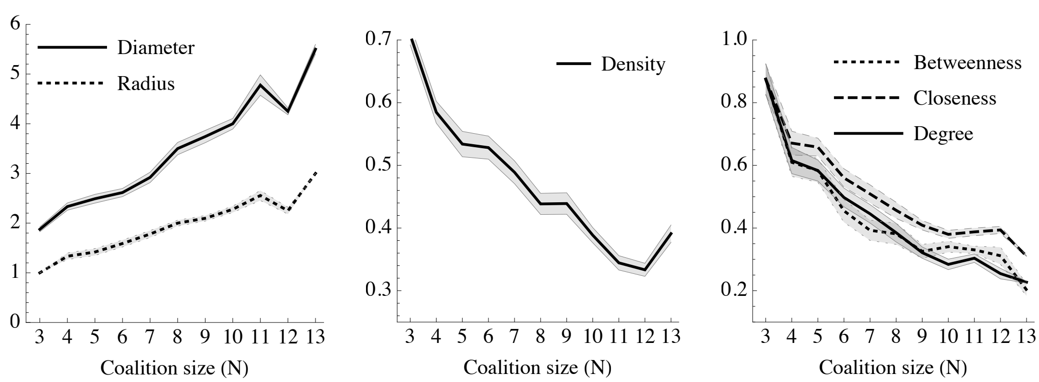
As expected, agents form different coalitions to buy different goods: larger coalitions are established to adopt higher cost and higher capacity goods; smaller coalitions are formed to purchase smaller and cheaper goods. Distributions for small and medium sized goods tend to be concentrated on the mean value of the number of coalition members, suggesting that there is an optimal coalition size for a given good size.

However, the distribution increases with the size of the good, meaning that larger goods are purchased by different types of (different sized) coalitions. This is possible because of the conditions in Eq.3.7 and Eq.3.8.

The result reveals that, through the bargaining process and depending on the randomly distributed features of the agents that meet to form a coalition, several different coalitions are possible. However, while small goods often involve small coalitions, large coalitions may prefer large over smaller goods, despite the fact that coordination requires more time due to the increased opportunities to defect.

Coalition Network Properties

The size of the coalition is due, in part, to its network properties. Figure 3.3 plots standard network metrics in relation to coalition size: radius and diameter (left panel), density (middle panel) and centrality (right panel). Network radius and diameter define the size of coalition network and are measured as the distance between the two most distant nodes. As expected, both measures are positively correlated to coalition size, suggesting that the minimum and maximum absolute shortest paths (or eccentricity) in a coalition increase with size.



Notes: The three panels plot the network properties in relation to the size of the coalition (horizontal axis) formed to purchase shared goods: radius and diameter (left panel), density (middle panel), and centrality (right panel). The shaded areas are the respective 95% confidence interval.

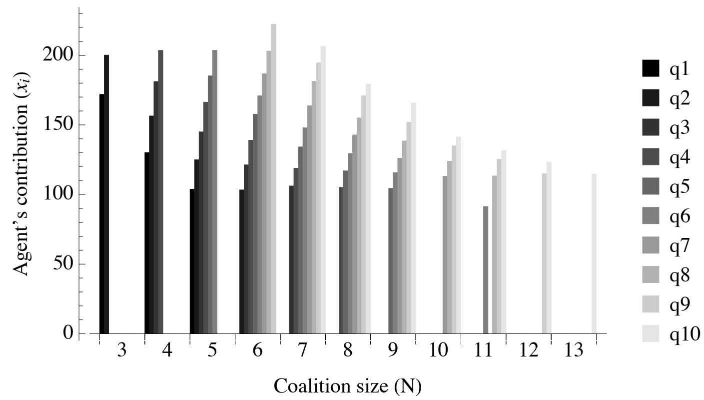
Figure 3.3: Network properties for coalition size

Network density (second panel) is a proxy for structural cohesion (Friedkin 1981), and is measured as the ratio between the number of links over the total possible number of links among the agents in a coalition. The negative correlation between the density and the size of a coalition suggests that smaller coalitions are more cohesive than large ones, i.e., they include a higher share of neighbours. As we discuss in Section 3.4.3, this is a relevant property for the diffusion of shared goods, because, if neighbours in a given neighbourhood do not enter the coalition, they become unable to form other coalitions, because all other agents are too distant.

The connectivity within coalitions is measured by the indicators of network centrality: the number of an agent's links with other agents (Degree); the extent to which agents bridge between other coalition members (Betweenness); and agents' degree of connectedness to all other agents (Closeness). Similar to density, all three connectivity measures are negatively related to coalition size. In order to grow, the coalition must integrate more distant neighbours; some of the closest neighbours do not gain from entering the coalition (under the offered conditions and contributions).

Contribution to Coalitions and Free Riding

Of course, agents in smaller coalitions established to purchase a larger shared good, must also be willing to contribute relatively more. In the model, agents commit a monetary contribution (x_i) to the shared investment that maximises their utility (U_{i2}). Contributions vary with respect to the size of the coalition and the shared good being purchased. Figure 3.4 plots the average agent's individual contribution per coalition size and, within each coalition, per good size. Unsurprisingly, for a given coalition size, the larger the investment cost (I) and capacity (S), the higher the average agent's individual contribution (x_i).

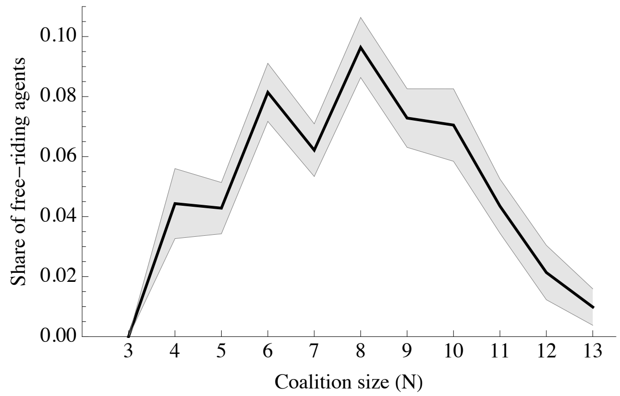


Notes: Chart plots the average agent's monetary contribution x_i (vertical axis) in relation to the size of the coalition N (horizontal axis) and to the product purchased. Darker bars represent less expensive and smaller products.

Figure 3.4: Average agents' contribution in coalition per size and product

However, and more interestingly, the average contribution reduces with the size of the coalition, regardless of the level of the investment cost. This result is in line with the theory of sharing groups that the higher the number of people in the coalition, the lower the individual cost, and the larger the quantity purchased in group, the higher the individual cost (Lindenberg 1982). This happens because, as discussed above, some agents maximise their utility when they buy larger goods in a smaller coalition even though they would be better off with a smaller good. However, because the coalition only includes local members (they compare with a limited set of peers) and members do not have full information, the coalitions becomes sub-optimal (which improves members' utility with respect to the public provider).

These are sub-optimal coalitions also because they leave space for free riders (x_i=0) that are able to benefit from the extra capacity of the good purchased, and pay only the unitary consumption cost (c_{i2}>0), which, by assumption, is lower than the cost of the public service. As the size of the coalition increases, it is possible that the individual contribution becomes less relevant, giving rise to free-riding (Canning 1995, Glance et al. 1997, Huberman & Glance 1996, Shehory & Kraus 1998, Axtell 2000). Figure 3.5 plots the distribution of free riders by coalition size.



Notes: Chart plots the share of free-riders agents (vertical axis) in relation to the size of the coalition size (horizontal axis) they enter. Free-riders do not contribute to the investment (x_i=0) but they pay the unitary consumption cost (c_{i2}>0). The shaded area is the 95% confidence interval.

Figure 3.5: Free-riders per coalition size

In our model, we find a non-linear relation. The share of free-riders increases with coalition size up to a medium sized coalition (N=8), and then decreases for larger coalitions. Small coalitions, on average, purchase small goods, with little extra capacity for free-riders. Large coalitions, on average, purchase large, but expensive shared goods, to which all participants must contribute to cover the investment cost. Therefore, capacity (Eq.3.8) and cost (Eq.3.7) constraints reduce free-riding. In the case of medium sized coalitions, we find the largest variety of goods (Figure 3.2) and more opportunities for free riding.

3.4.3 Co-Evolution of Coalition Formation and Diffusion

Coalition formation and shared adoption occur in agent networks whose structures evolve over time, and where links are formed and severed. Link formation follows a standard diffusion dynamic: as the visibility of the new shared good increases with the number of adopters and with advertisements, it is more likely that agents informed about its existence, will become interested and attempt to form a coalition to purchase the good. Link severance also follows the diffusion of the shared good: as agents enter a coalition and adopt the shared good, they can no longer be contacted by other agents. In this section, we study how adoption and network structure co-evolve, in relation to the coalition formation process.

In each time step t, the neighbours of agent i can have one of the following statuses: link to agent i (f_i), not yet linked (regular) (g_i) or in coalition (h_i). The total number of neighbours is L_i=$\sum f_i$+$\sum g_i$+$\sum h_i = 8$. Given W the total number of *active* agents at time t in the population, we can define the share of linked neighbours for *active* agent (l) as:

$$l = \frac{\sum_{i=1}^{W} \frac{\sum f_i}{L_i}}{W} \tag{3.11}$$

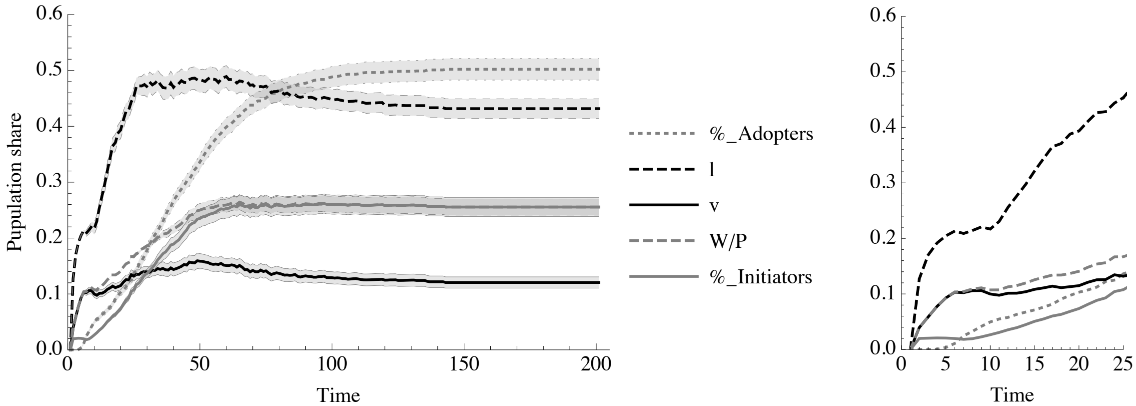
We can define the share of linked and not linked neighbours (i.e., those that can still enter a coalition) in the population P (v) as:

$$v = \frac{\sum_{i=1}^{W} \frac{\sum f_i + \sum g_i}{L_i}}{P} \tag{3.12}$$

As l and v increase, the higher will be the number of coalitions that an agent can join and evaluate, and the higher the likelihood that one of those coalitions may lead to adoption of a shared good.

We analyse the relation between the share of links within *active* agents (l), the share of agents in the whole population that can be potentially involved in the process of coalition formation (v), the share of *active* agents in the whole population (W/P), the share of *initiator* agents and the cumulative share of adopters.

Figure 3.6 plots these five curves over time. During the first few time steps in the simulation, the share of linked agents (l) and the share of agents that potentially can enter the coalition (v) increase at the same pace as the share of *active* agents (W/P). Initiators contact neighbours, some of which become active and contact their neighbours, and so on.



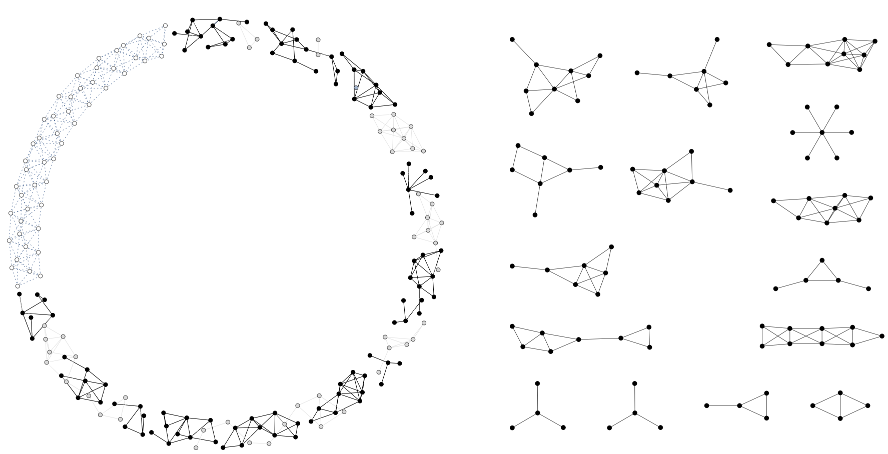
Notes: The curves on the left plot five time series: the cumulative share of adopters in the population (grey dotted line: *%_Adopters*); the share of linked agents for *active* agents (dashed black line: l); the share of linked and not linked agents in the population (black line: v); the share of *active* agents in the population in a given time step (dashed grey line: W/P); and the share of *initiator* agents in the population in a given time step (grey line: *%_Initiators*). The shaded areas are the respective 95% confidence interval. On the right, we zoom on the initial 25 time steps of these five curves.

Figure 3.6: Co-evolution of diffusion and coalition formation

When a coalition is established at an early stage (after 10 time steps, see zoom on the right of Figure 3.6), both series cease to grow because the share of *active* agents stabilises (W/P). At this moment, adopters are no longer available for further coalitions since they break links with neighbours, reducing communication between remaining agents. As soon as information starts to flow again, i.e., when *active* agents become *initiators*, the share of *active* agents increases and the two series start to rise, but with a different slope. l grows faster than v because, while the number of new links increases (f_i), the increasing share of agents in coalition (adopters), reduces the number of neighbours that could be part of new coalitions ($\sum f_i$+$\sum g_i$=L_i-$\sum h_i$). This quickly stabilises around 10%, which also reduces the pace at which new coalitions can form and, therefore, adoption of goods.

When all active agents (W) are enclosed between neighbourhoods with established coalitions, information can no longer flow, because active agents and initiators cannot reach new agents that are not yet linked. This is when all curves reach their steady state, and no more coalitions are formed.

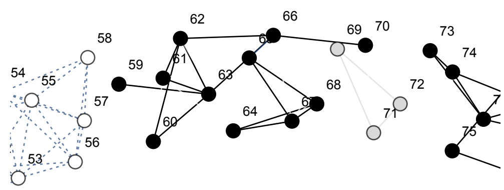
To show this result and better explain the dynamics in Figure 3.6, Figure 3.7 plots the final network configuration (left) and the network structure of all established coalitions (right) for a typical simulation run (with an average share of adopters). The black nodes and edges represent agents belonging to a coalition (h_i). The grey nodes and edges represent linked agents (active, but not part of a coalition) (f_i). The white nodes connected by the dotted edges are neither *initiators* nor *active* (g_i) agents. Agents in the top-left part of the network in Figure 3.7 did not become active, because they were not contacted, hence, they lack information about the shared good. They were not contacted, because their neighbours agreed to form a coalition, before it was necessary to contact a neighbour to do so. As the number of g_i stabilises, so does the diffusion of the shared good.



Notes: Figure shows, on the left, the final network configuration of all agents, and on the right, the network structure of all established coalitions. These are the results of a single simulation, representative in terms of average numbers of adopters as in Figure 3.1. In the networks, black nodes and edges are agents in coalition (h_i), grey nodes and edges are *active* agents, hence informed, that use the public service (f_i), and white nodes connected with dotted edges are neither *initiators* nor *active* (g_i), and do not evaluate coalitions because not informed.

Figure 3.7: Final configuration: network (left) and coalitions (right)

The role of f_i in reducing the pace of diffusion is less obvious. Figure 3.8 zooms in on a section of the network in which three agents (69, 71 and 72) are not involved in any of the closest coalitions (64-65-67-68, 59-60-61-62-63-66-70 and the network including agents 73, 74, 75 and others). 69, 71 and 72 cannot enter an already established coalition among those h_i agents surrounding them, and they are too distant from other agents that are not in a coalition (shared goods such as DES need to be installed and used locally). Therefore, their chances of joining or forming a coalition are substantially reduced, and they are unable to improve their utility with respect to the public provider. This means that, between established coalitions, there are *active* agents that remain isolated in the network.



Notes: This figure zoom on a section of the final network configuration on the left of Figure 3.7. It shows three established coalitions that purchase the shared good (black nodes and edges, h_i: 64-65-67-68, 59-60-61-62-63-66-70 and 73, 74, 75 plus others); three grey isolated nodes (f_i) that buy the public service (69, 71 and 72); and, on the left, white nodes (g_i) that are not *active* and not informed.

Figure 3.8: Isolated agents locked by established coalitions

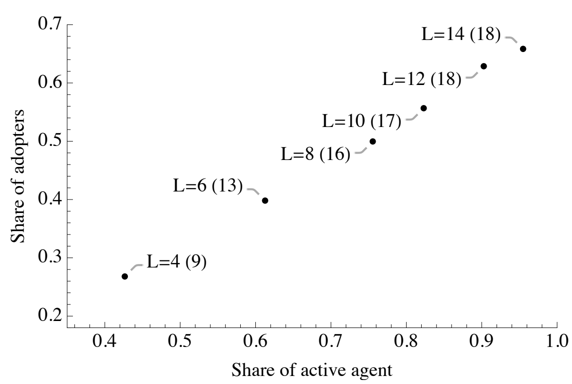
To summarise, in a regular network in which agents can form coalitions only with neighbours (e.g., due to the features of DES) and are not interested in informing peers that are not co-located, the process of coalition formation and adoption stops before reaching the whole population, for two main reasons. First, some agents are never reached because their neighbours agree to enter a coalition before they can assess the options related to expanding it and including these excluded agents. Second, some agents explore the opportunity to enter a coalition and adopt a shared good, but do not find an arrangement where they would be better off than purchasing the service from the public provider. In the meantime, their neighbours form coalitions, and the number of alternative coalitions that they can explore reduces, which reduces the likelihood that they will find a suitable coalition.

This shows how the two processes coevolve: coalitions are necessary to adopt shared goods, therefore, they are pivotal for diffusion. However, diffusion changes the network structure, reducing the pace of and eventually halting the diffusion.

Two conditions are likely to influence this relation between coalition formation and diffusion: the size of the neighbourhood that can form a coalition (and contact new agents), and the number of initiators (randomly distributed throughout the network). We study each in turn.

The Role of Geography

To assess the role of neighbourhood size, we run the model with different initialisations of the parameter L, between 4-14, i.e., the number of closest neighbours that an agent can contact and form links with. Figure 3.9 plots the relation between the share of active agents (cumulative in the entire simulation) and the share of adopters, for different values of L and different values of the number of shared goods purchased (in brackets).

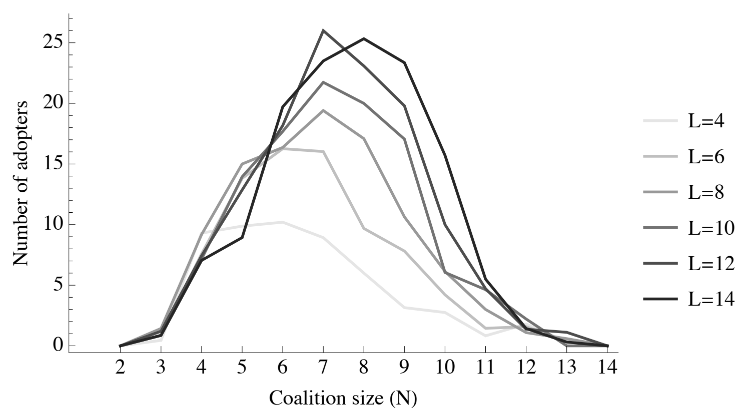


Notes: The plot shows the share of adopters in the population (vertical axis) and the share of cumulative active agents (horizontal axis) under different level of neighbourhood size (L). In brackets we report the number of shared goods purchased in coalition.

Figure 3.9: Share of adopters, active agents and diffusion of shared goods (in brackets) per neighbourhood size.

As already noted, there exist a positive and linear relation between the shares of adopters and *active* agents: the larger the number of active agents, the greater the number of opportunities to create coalitions and adopt the shared good. As L increases, the cumulative share of active agents increases up to about 100% (for $L = 14$). This suggests that, with larger neighbourhoods, on average, no part of the population is excluded from the possibility of forming a coalition and adopting the shared good (as in the top left part of Figure 3.7).

This solves one of the problems that limit the diffusion of shared goods in coalition, the halting of the process of information spread to the entire population. With larger distances for coalition formation agents have more opportunities to form contacts, which increases adoption, but remains well below 100%. To some extent, this is because neighbourhood size does not solve the problem that agents that do not enter the coalitions that are formed around, them remain isolated. In fact, as the size of the neighbourhood increases, so does the average size of the coalitions (Figure 3.10). The increase in the number of closest neighbours leads to larger coalitions, which keep active agents, in between coalitions, too distant from one another to explore a different coalition (the grey nodes in Figure 3.7).



Notes: Curves plot the number of adopters in the population (vertical axis) in relation to the size of coalitions formed to purchase the shared good (horizontal axis), under different neighbourhood size (L). Darker curves represent bigger neighbourhood size.

Figure 3.10: Number of adopters per coalition size for different neighbourhood size

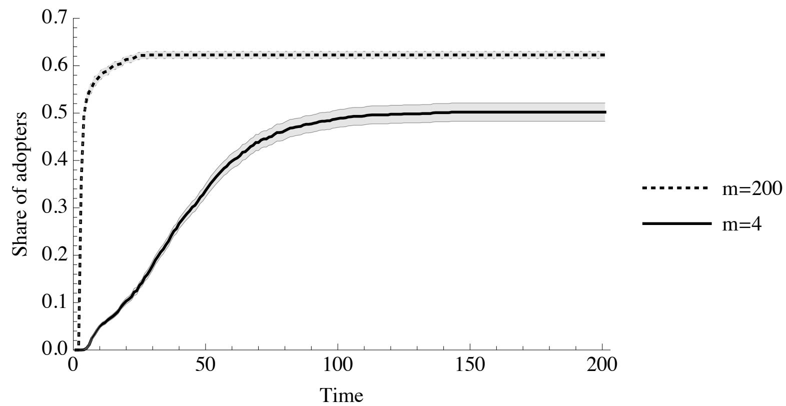
To further test for the role of geography in determining less than full adoption, we relax the assumption that agents are located in a regular network. What would happen if, instead of a decentralised energy system, which requires proximity of its users, the shared good could be adopted by agents located at a distance? We initialise the model with agents located in a random network, where coalitions can be formed with any other (active) agents. As suggested by earlier works, information flows more rapidly, and adoption is faster. After the usual 200 time steps, on average, the final share of adopters increases from 50% of the baseline scenario to 72%, and all the agents in the population are *active*. Although the rate of adoption is higher than observed if the network is regular, adoption does not reach 100%. This suggests that, even were agents able to form coalitions with any other agent, beyond their neighbourhood, not all would find it convenient to invest in a shared good.

The Role of Initiators

To assess the role of initiators on the co-evolution between coalition formation and diffusion, we compare the baseline scenario with only a few initiators (m=4) to the case where all agents are *initiators* (m=200) and are connected to their closest neighbours (L_i=$\sum f_i$=8; $\sum g_i$=$\sum h_i$=0). This is equivalent to studying a complete network, where agents are all informed and evaluate all possible coalitions since the network formed.

Figure 3.11 plots the share of adopters in these two scenarios. In the complete network, adoption is rapid and reaches a rate of 60%. As expected, the share of adopters reaches its steady state after few time steps, suggesting that complete information speeds up the diffusion of a shared good. However, although, by construction, a complete network solves the problem of parts of the network never becoming active, the share of adopters is below the share that would be achieved with larger neighbourhoods (Figure 3.9 at L=14 shows a 66% adoption rate). This is because, although they are informed, several agents remain isolated from the coalition formation process and fail, also, to form a coalition with the few peers in their neighbourhood.

However, as discussed earlier, isolation is only part of the explanation for non complete adoption: on average, a third of agents do not find it convenient to enter a coalition even without geographic constraints.



Notes: Curves plot the share of adopters in the population over time. Black line represents the share of adopters when only 2% of the population being *initiator*: m=4 as in the baseline scenario in Figure 3.1. Dotted line represents the share of adopter in the complete network, that is when all agents are *initiator* at t=0, that is m=200. The shaded areas are the respective 95% confidence interval.

Figure 3.11: Share of adopter in a complete network

3.5 Discussion, Policy Implications and Extensions

Unlike the existing diffusion models, this paper studies the adoption of a shared good, whose adoption requires formation of a group. Therefore, we study the co-evolution between group formation and diffusion. We assume that the good to be adopted is not mobile and needs to be located in close proximity to its users. Thus, users need to form groups among geographically collocated individuals located near to the good. We assume, also, that the service provided by the shared good is a service that users are already purchasing from a public provider, but that the shared good will allow its provision at a lower cost. However, consumers must pay the upfront cost of purchasing the shared good.

We develop an agent-based model where heterogeneous agents are informed about the option to enter a coalition and purchase a shared good with neighbours. As information about the new option diffuses, agents compare the utility they enjoy from purchasing the good from the public provider with the utility from several potential coalitions. To enter a coalition, agents make an offer for their contribution to the shared purchase. All potential members assess their utility with respect to their own offer, their preferences and their demand, and with respect to the offers and demands of other members. Several negotiations may be needed to establish a stable coalition and adopt the shared good.

Drawing on the bodies of work on diffusion and on coalition formation, we study the emergence of shared products such as decentralised energy systems (DES) and provide some novel results. Both coalition formation and diffusion of a shared good depend on network effects: social networks evolve over time, which has an impact on the speed at which information diffuses and the agents' options related to forming a coalition with like-minded partners. Network clustering, density and information flows determine higher adoption in consumer coalitions. Despite the longer negotiation process, consumers prefer larger coalitions to buy expensive goods with higher capacity, since a bigger coalition means that the individual contribution is lower than in a small coalition. However, under equal coalition conditions, the individual contribution increases if higher quantities are purchased collectively. Also, larger coalitions tend to induce free riding up to a certain size after which free riding decreases because the large cost of the investment would be unsustainable.

The model allows us to study the diffusion of a decentralised good, DES, by local communities. The model shows that to promote the diffusion of DES, decision-makers may need to carefully consider the preliminary formation of local groups. For given consumer characteristics, this paper discusses a number of conditions under which the diffusion of DES can easily take off.

First, spreading information is crucial to increase consumer awareness about sustainable options and energy-efficient innovations (Lin 1999, Woolcock & Narayan

2000, Ek & Patrik 2010, McMicheal & Shipworth 2013). Second, DES are more likely to diffuse if consumers are strongly linked and the DES can serve a larger neighbourhood. Third, large-sized DES have a higher adoption probability than smaller DES, with a smaller contribution by consumers and, also, less free riding. However, larger coalitions take longer to form and are more time consuming to coordinate.

Although the adoption of DES (or any other shared good) depends on consumer preferences, there is a risk that parts of the community who see no advantage from early adoption may be unable to adopt at a later stage, because of the difficulty related to finding neighbours who are not already in a coalition (in our model we assume that coalitions are forever and, once they become stable, do not accept additional entrants). Early exclusion can have a negative impact on energy transition. Avoiding isolation and increasing social inclusion may be even more relevant in rural areas where there is greater need to increase access to energy (Kanagawa & Nakata 2007, 2008).

These implications of our model are transferable to other sectors where information and evidence are needed to enable the decision-making process and to respond promptly to a societal challenge. For example, the strict Nearly Zero-Energy Buildings strategy is aimed at improving the energy performance of buildings (European Parliament 2010, European Commission 2013). This ambitious plan requires citizens to take actions and to be actively involved in the renovation of apartments and houses. Some of these buildings are shared and the adoption of new building technologies requires shared decisions. Another example is transport. Currently, the market offers a range of shared options targeting different groups of consumers, based, mainly, on budget constraints and flexibility. However, autonomous vehicles are about to be introduced and they promise to substantially reduce congestion in urban areas, but, initially, will be expensive and not affordable by the average consumer. Under these conditions and subject to proper regulation, group adoption could be promoted as a feasible option to improve the diffusion of shared ownership of a next-generation vehicle (Masoud & Jayakrishnan 2016).

The model has some limitations and, also, could be extended in several ways. Data initialisation was set randomly following a normal distribution, but based on a consistent proportion among the parameters although these were not calibrated based on empirical observation. The model does not allow for the inclusion of additional coalition members: it assumes that stable coalitions do not accept additional members and, also, last for ever. These assumptions could be relaxed in future work.

We assume that the visibility of a product can only increase over time, even if in the real-world products can lose visibility when they become less trendy. Although in our model despite visibility increases, diffusion does not reach the entire population. Allowing visibility to decrease would test whether this implies different outcomes on the diffusion of the shared good. This may be linked also to another extension of the model that considers an endogenous variation of unitary prices depending on agents' demand.

A future complementary analysis to this study can be done by testing the model outcomes to results from simpler benchmark models. For example, one could use stylised existing models of coalition formation and percolation diffusion models to check whether results reflect key features found in this thesis. This exercise has not been done in first instance in this paper because of the research question asks to study the co-evolution of coalition formation and diffusion and how one impacts dynamically the other. Given the relevance of local interaction, agent heterogeneity, non-optimal behaviour, and out of equilibrium dynamics, we opted for an ABM that enables the study of the interaction of inner agents' dynamics leading (or not) to diffusion of shared good in coalitions.

Another possible and relevant extension is related to the impact of different network structures on the co-evolution of coalition formation and diffusion of the common good without local constraints. Finally, the model could be extended to study related dynamics, such as network and coalition formation in international climate agreements (Barrett 1994, Benchekroun & Claude 2007, Tavoni et al. 2011, Balint et al. 2017).

Chapter 4

Do Consumers Shift from Private to Shared Ownership?

Abstract

We propose a simple model to study the conditions under which consumers may prefer to purchase and own a shared good in coalition, rather than owning the good individually. We study the whole parameter value space that defines the characteristics and preferences of heterogeneous consumers and the characteristics of the good, and the characteristics of a public service which offers the same services as the good. We find that shared ownership emerges in relatively low income and high demand populations, with a higher preference for consumption. We find, also, that coalitions tend to emerge if the good required to consume the service is relatively small; too large goods require a large coalition where consensus becomes more difficult and coordination costs are higher. We find that the sharing option is chosen solely by consumers who once owned the good individually, and that this does not affect the share of users that use the public service. The result of sharing is that the overall number of goods purchased and used reduces, producing environmental benefits. Policies that reduce the relative price of the shared purchase should accelerate transition to this more sustainable option, but is more efficient for goods that can be used by a relatively smaller coalitions where coordination is easier.

4.1 Introduction

Most households in high-income countries own a range of domestic appliances, such as vacuum cleaners, washing machines and drills, which, most of time, are idle. These households invariably have internet connections and routers and use only a share of the bandwidth, for limited amount of time. They may also own a car, which, most of the time is parked. So could these households coordinate to purchase and consume these goods collaboratively, in line with a sharing economy where the same good is used by multiple users? Shared ownership can enhance convenience by making expensive goods accessible to more consumers, and is likely to be more sustainable by reducing the number of goods produced and increasing their use.

Take the example of passenger cars. In Europe, the number of passenger cars has increased from one to every three persons in 1990 to one to every two persons in 2018 (Eurostat 2020). For some users, cars offer a fast and comfortable option for moving around cities where public transport is either very crowded (e.g., during peak hours) or does not cover all areas adequately. However, cars generate traffic congestion and increase demand for parking slots, putting pressure on urban spaces. Cars used by a single owner can remain parked (i.e., idle) for many hours. Sharing purchase and use of a passenger car could increase both individual and societal welfare: users who share a car face lower ownership and maintenance costs and reduce the demand for cars and, therefore, the number of cars produced, which, in turn reduces pollution and demand for parking spaces and increases urban sustainability. However, coordinating a shared purchase involves some transaction costs (such as, negotiating time and free-riding), which not all users may be willing to pay.

In this paper, we ask under what conditions might consumers shift from individual consumption and ownership of goods, which often are under-utilised, to a consumption model based on shared consumption and shared ownership. This model differs substantially from the more established sharing economy model, which focuses mainly on shared consumption (Pasimeni 2020). The results of our analysis would allow policies that would increase societal welfare by reducing the transaction costs related to shared ownership, or increasing the costs related to single ownership, by internalising the negative externalities of excess production.

We propose an Agent-Based Model (ABM) where heterogeneous users consume a service in each time period (e.g., urban transportation) and can choose between three different purchase modes: a public service (e.g., bus), individual ownership (e.g., individual car) or shared ownership (e.g., shared car). Shared ownership is an alternative to individual ownership and consumption, and which allows users to enjoy the benefits from the shared costs related to access to a shared good rather than use of a public service. We study the formation of sharing groups that allow participants to jointly own and use a good, in which both consumption and costs are shared.

The choice between the three different modes of purchasing the service depends on the consumer's utility, which is a function of consumers characteristics (such as income, demand for the service and preferences) and the service characteristics, such as its cost and supply capacity. The cost differs for the three purchase modes. The cost of the public service is given by its unit cost (e.g., the cost of a bus ticket). Individual owners face the cost of the investment in the good that delivers the service (which also depends on its size and duration) and the unit running costs (e.g., petrol). Users purchasing the good in coalition pay a share of this investment cost and the unitary running costs.

The three options differ also with respect to their capacity to satisfy consumer demand. Public service capacity depends on how many other consumers are using the same service in the same time period. In the model, this means that the utility of using the public service reduces as congestion increases. Individual owners can satisfy their demand in full using their purchased good. In a coalition, the consumer's utility depends on the size of the coalition, the contributions of the other users in the coalition and their use of the good. If we include negotiation time and the likelihood of free-riding, in our model, these are the transaction costs that consumers in coalition face. We ignore any additional costs related, perhaps, to the technology to enable the sharing such as a platform or insurance.

A shared purchase is a collective decision and first, requires, the formation of a coalition of consumers. This depends on the network of social contacts among users. To study a collective purchase compared to the public service and an individual purchase, we extend the model presented in Pasimeni & Ciarli (2018), which simulates the co-evolution of coalition formation and diffusion of the shared good purchased by a local community, for example, a decentralised energy infrastructure.

We extend Pasimeni & Ciarli (2018) model in several ways. We relax a number of assumptions in order to study the conditions under which consumers choose between individual and shared ownership, in the presence of a public service alternative. We remove the constraint on the number of other users they can contact to form the coalition: consumers are displayed as a random network to allow analysis of the conditions under which goods (e.g., a car) are mobile. As already mentioned, in this version of the model the individual consumer can buy the same good. We exclude the assumption that goods can be used indefinitely, with no loss in the quality/quantity of service supplied. We introduce a lifetime for the purchased good: it depreciates at a rate that is related to their size and use. This implies that consumers need to make their choices several times during the simulation, under different conditions (as other consumers shift between purchasing choices). This implies also that we remove the assumption that coalitions have infinite lives: rather, they break up once the good purchased is fully depreciated. We also exclude the assumption that the public service has an infinite supply: as the number of users increases, the utility of each consumer reduces non linearly. The congestion is a function of the provider's capacity and the overall number of users.

To study the consumer and product characteristics that influence the consumer's decision to shift from individual consumption and ownership of a good to shared consumption and ownership we proceed in four steps.

First, we iteratively analyse the full parameter space of the model, as proposed in Dosi et al. (2018), to identify the conditions under which shared purchase emerges as an option that maximises the utility of some consumers, and is adopted by at least one group. Because ABMs include complex interactions among several parameters, sensitivity analysis of one or two parameters considered critical a-priori, could miss the impact of the remaining parameters – either alone or in interaction with the other parameters. A full exploration of the parameter space (i.e., a global sensitivity analysis), allows identification of all relevant parameters. Since this requires a number of combinations of parameter values, which would require too long a study, we use a design of experiment (DoE), which includes a set of sample parameter value points which are representative of the model behaviour, within the whole parameter space.

To reduce the dimensionality of the model, we first conduct a preliminary screening of the parameters using the Elementary Effects (EE) method (Morris 1991, Campolongo et al. 2007) to identify the parameters most relevant to model output. We then apply the Near Orthogonal Latin Hypercube (NOLH) DoE to optimise the number of model sampling points to be observed for the selected parameters (Cioppa & Lucas 2007). Based on these observed points, we use the Kirging meta-model to study the parameter space (Rasmussen & Williams 2006), in which the number of consumers opting for shared purchase is maximised. Finally, we run a global sensitivity analysis using the Sobol decomposition to evaluate the individual and interaction effects of the model parameters on the variance of the model output (Saltelli et al. 2000, Saltelli & Annoni 2010).

We find that under most parameterisations, shared purchase is a very unlikely option: in our model framework, under most conditions, consumers prefer either to use the public service or, if they have the available budget, to purchase their own individual good. Only a small customer niche opts for shared purchase.

In the second step, we 'zoom-in' on this small parameter space where a non-zero number of consumers consistently opt for shared ownership across simulations, to analyse which parameters (consumer and product characteristics) are most relevant for the uptake of this option. We run a second global sensitivity analysis on this smaller space and more granular sampling. We find that shared purchase is considered an option among a population of consumers with a relative high need for the service (high demand and preference for consumption) and a relatively low income, which reduces the utility of purchasing the good individually.

Third, we study the transition from individual ownership to shared ownership: which consumers drive it and to what extent it leads to a more sustainable model of consumption by reducing the inefficient individual purchase of goods. We narrow the focus even further to identify the model configuration that produces the highest share of consumers opting for the shared purchase. We find that shared purchase replaces individual consumption, but does not affect the number of consumers relying on the public service. The sharing alternative is preferred by consumers who are able to establish small sharing groups to share the purchase of a good that is not too expensive and has low-medium capacity of supply. The transition from individual to shared ownership significantly reduces the cumulative number of goods sold in the economy, enabling a more sustainable model of consumption.

Fourth, based on this ideal world in which a significant proportion of consumers shift from individual to shared ownership, we study two potential policy incentives based on the unit price of the service/good and the size and cost of the good that can be purchased in coalition or individually. We find that reducing the relative price of using the shared good relative to using the individual good, can push consumers to share. The capacity and cost of the good also are critical. Consumers groups are unlikely to emerge in the case of very large goods since this would involve very large coalitions, which would be difficult to coordinate. However, the likelihood of a group purchasing the good increases with goods that have low-medium capacity and average cost.

Literature

This paper examines the case of consumers who autonomously decide and organise to purchase and use a good collectively, whose ownership is also shared by these consumers (described as fractional ownership (Pasimeni 2020)). Shared ownership builds on the theory of clubs in economics (Buchanan 1965) and sociology (Lindenberg 1982). Buchanan (1965) defines club goods as those types of goods that cannot be categorised as either purely public or purely private. For these types of goods, cost-sharing is possible through clubs, and club formation depends on "the extension of ownership-consumption rights over differing numbers of persons" (Buchanan 1965, p.1). Lindenberg (1982) extended Buchanan's work by analysing the conditions under which the decision to jointly own a good is preferred to individual ownership. He focuses on goods that are not affordable for the majority of consumers, but who may have an opportunity to access them by forming groups to share their purchase and use (Lindenberg 1982).

These forms of sharing practices are rooted in the literature on the governance of common pool resources (Hardin 1982, Ostrom 1990, Ostrom et al. 1994, Bowles 2004). The work on shared ownership focuses on use of intermediate goods/capital. For example, Bardhan (1993*a*,*b*, 2000) studies the case of the agricultural infrastructure as a common asset managed by small farmers who, individually, would be unable to accumulate or buy this infrastructure. The sharing of assets has been studied, also, in the context of firm organisation. Shareholders are relevant in the ownership structure of many corporations since shared ownership permits a more flexible and adaptable management, reduces individual risk and provides more assets than would individual ownership (Jensen & Meckling 1976, Demsetz 1983). A more recent example relates to a small-scale, decentralised energy infrastructure, owned by neighbouring communities that benefit from cost sharing of an arrangement which could help reduce the environmental impact of the national electricity system (Pasimeni 2019).

Work on the shared ownership of final goods is more limited and studies specific co-ownership (Hastings et al. 2006, Quigley 2015) or fractional ownership (Lawson 2010, Shaheen & Cohen 2013) experiences. Examples of ownership shared among people who coordinate in order to buy and use a luxury good jointly, include house sharing in crowded spaces (Hastings et al. 2006) and fractional ownership of an aircraft (Yang et al. 2008).

Shared ownership has not been widely discussed in the sharing economy literature which tends to focus on cases of the same good being used by multiple users (shared consumption) and overlooks the case of the good also being owned by a group of users. The sharing economy model consists of users' granting one other temporary access to underutilised goods, in exchange for money, without any transfer of ownership (Bardhi & Eckhardt 2012, Frenken & Schor 2017, Pasimeni 2020). These practices are in line with the definition of sharing as "the act and process of distributing what is ours to others for their use as well as the act and process of receiving something from others for our use" (Belk 2007, p.127).

An understanding of the sharing economy is important for analysing changes in consumer behaviour (Botsman & Roger 2010, Belk 2014*b*, Hamari et al. 2016) from enduring ownership of a good to ephemeral and dematerialised consumption of a good accessed temporarily (Bardhi & Eckhardt 2017). In the sharing economy, ownership of the shared good ultimately remains private, owned either by an individual (e.g., apartments or drills) or an organisations (e.g., fleets of shared cars or bicycles). This has strong implications for the distribution of wealth among individuals (Richardson 2015) since most cases regarded as belonging to the sharing economy have business models that are similar to the renting model, but where the notion of community is absent (described also as pseudo-sharing (Belk 2014*b*,*a*, Eckhardt & Bardhi 2015)).

Pseudo-sharing is common in the transport sector, where car leasing models have been proposed, but are regarded as fractional ownership in the context of the sharing economy. For instance, in 2014, Audi launched its *Audi Unite* programme in Stockholm, which allowed a group of maximum five people to share ownership of a car for up to two years. The project ended in 2017 because of the very high competitive Stockholm market where *Car2Go* and *Sunfleet* had a bigger share. In 2016, Ford introduced its *Ford Credit Link* lease-sharing programme in Austin, Texas, which gave the option for groups of between three and six people to share the car leasing costs, for two years. The project lasted for only a few months because no one signed up for it. In 2017, Nissan launched a similar programme, called *Nissan Intelligent Get & Go Micra* based on the idea of small groups of people with compatible travel needs coming together via a phone app. The group allows to lease a car for a maximum of one year and to pay their costs based on consumption. However, the programme disappeared from Nissan's website and no further news on it have been published.[1]

The failure of these projects launched by major automobile manufacturers suggests that, in the transport sector, fractional ownership in the form of car leasing is not appealing to consumers. However, the literature on car sharing studies other forms of sharing such as the so called "true sharing" (Belk 2017, Dreyer et al. 2017, Czakó et al. 2019), which is similar to the Swedish example of *Göteborgs Bilkoop*, which

[1]Online magazines provided updates on these programs: insidercarnews.com and nordic9.com on *Audi Unite*, businesswire.com and theverge.com on *Ford Credit Link*, and rcimobility.com and marshall.co.uk on *Nissan Intelligent Get & Go Micra*. Access: 28 October 2020.

has had some success. In this scheme, local communities organise to share car ownership, and the benefits derived from sharing the cost is an incentive for low-income consumers to participate to increase their access and allow more efficient and sustainable use of cars.

However, we know very little about why some shared purchase models are more successful than others. This paper studies the consumer and product conditions which lead some consumers to choose the shared purchase option. We do this by conceptualising so called “true sharing” through the theory of clubs. Consumers organise autonomously to establish clubs to jointly purchase and use a shared good. This option is considered an alternative to individual ownership and consumption in the presence of a public service. In our model, ultimate ownership of the shared good belongs to club members who share it. This broadens the concept of shared consumption related to the sharing economy, by considering shared goods owned by a group of consumers. We focus on users’ attitudes to shared ownership and consumption, where consumption behaviour is influenced by the type of goods available in the market. This allows us to analyse the market conditions which make shared ownership more attractive than individual ownership.

The paper is structured as follows. Section 4.2 describes the ABM. Section 4.3 presents the global sensitivity analysis methodology applied to the full parametric space of the model and analyses the results of the agent-based simulations. Section 4.4 discusses the results in the context of urban mobility and concludes the paper.

4.2 The Model

We model the consumption choices of heterogeneous consumers, to satisfy their demand for a good provided by a public service, by purchasing an individual good or by purchasing the good in a coalition. In the first period, consumers are allocated to the first two options. For example, we consider individuals who use either public transport (e.g., bus or metro) or buy a car in order to satisfy travel needs. The higher the number of consumers choosing the public service, the higher the congestion related to the service, and the lower the utility from its use.

Over time, consumers have the option, also, to purchase the same good within a coalition with other consumers. The shared purchase requires a stable group (or coalition) to be established, which in turn, requires consumers to have a network of contacts with other agents over the simulation periods. We assume that consumers who rely on the public service can make a different choice in every time period. Consumers who own a good individually or in a coalition, can revise their choices once the good is fully depreciated. Moving to a shared purchase requires time. The formation of coalitions depends on each consumer's social network, which evolves over time. Because consumers revise their choice every time period, in each time period, the choice conditions also change.

In each time period, consumers $i \in [1, M]$ choose among the three possible options to satisfy their demand, depending on which option yields the highest utility: $Max\,(U_{i,j})$, where $j = 1, 2, 3$ are, respectively, the public service, individual purchase and purchase in coalition. Consumer utility depends on consumer income, demand for the service and the cost of the service under each option, plus a number of other parameters related to the characteristics of the consumers and the different purchasing options. In turn, utility and cost depend on several features that differ across the three options. We describe the three utility functions in turn. To simplify the notation, time is introduced only if the time period differs from t.

Public service

For the first option, the public service ($U_{i,1}$), the utility of consumer i depends positively on the consumer's income (e_i) and negatively on the cost of the service ($c_{i,1}$), while demand for the service (d_i) affects utility both negatively (by increasing the cost of the service) and positively (by increasing demand satisfaction). Formally, this is computed as in Eq.4.1.

$$U_{i,1} = [e_i - d_i p_1]^{\theta_i} (d_i * K)^{1-\theta_i} \tag{4.1}$$

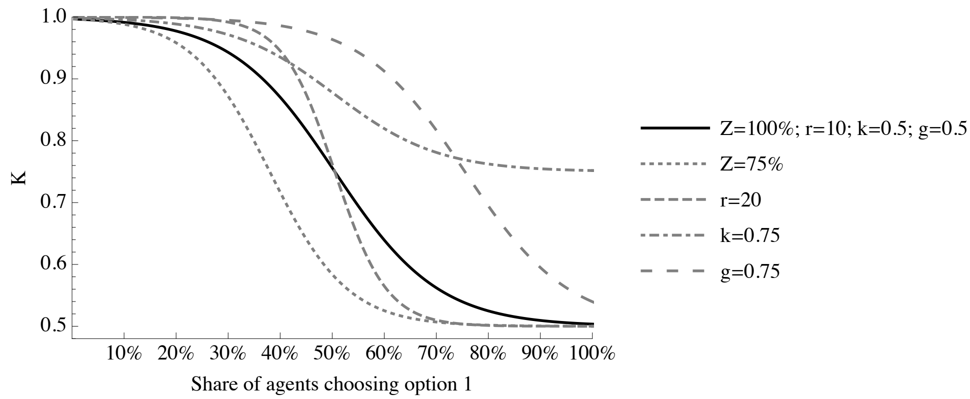
where $\theta_i \in [0;1]$ is the consumer preference for income ($1 - \theta_i$ which represents the consumer's preference for consuming the service); the total cost ($c_{i,1} = d_i p_1$) depends on the unit price of the public service (p_1).

$K \in [0;1]$ represents the loss in utility experienced by the consumer as the number of consumers using the public service increases: the congestion. It is modelled as a decreasing logistic function of the number of users in t-1 ($A_{1,t-1}$), where the carrying capacity is the capacity of the general provider, measured as a share of the population of agents in the model (Z). Formally, congestion is computed as in Eq.4.2:

$$K = 1 - \frac{1-k}{1 + e^{-r(\frac{A_{1,t-1}}{Z} - g)}} \tag{4.2}$$

where k is the lowest value that K can reach; r is an exogenous parameter that measures the rate at which the utility decreases for an increasing number of consumers; and g is a parameter that determines the flex point of the logistic curve. Figure 4.1 plots how K varies in relation to changes to its parameters.

In this model we refer to congestion as the reduced likelihood to get access to a good (that has limited capacity) in a specific point in time, not the congestion that its use can determine (e.g., traffic in the case of cars). This is because the model may refer



Notes: The black line represents the benchmark with values of all parameters set as follow: Z=100% indicates that the capacity of the public service can satisfy the entire population; r=10 is the utility decrease rate; k=0.5 is the value that K assumes with full congestion; and g=0.5 indicates that the flex point is at 50% of the full capacity. Dotted lines plot K by varying one parameter at a time, keeping others at their benchmark value. At Z=75%, K reaches its minimum (k=0.5) earlier then the benchmark; at r=20 the decrease is sharper then the benchmark; at k=0.75, the curve moves higher in the graph; at g=0.75, the flex point moves to the right compared to the benchmark.

Figure 4.1: Logistic function K for different parameter values

to different products, some of which create more congestion (e.g., traffic in the case of transport) than others (e.g., access to an internet provider router). Congestion in use is a very interesting extension of the model, which requires to make the utility of each option dependent on the adoption of the other options. Again, making the example of transport the use of a car affect also public transport, and vice versa. This requires adding substantial complexity and again would need to refer to specific cases to calibrate the model (e.g., cities). We do hope that our model will be adapted to study those specific cases.

Individual purchase

Consumers who purchase a good individually, pay its total cost (I_2). We assume that the purchased good lasts for a finite period (L_2), which depends on its use, that is, the demand (d_i). Consumers can purchase goods of different size (S_2), which we assume proxies for maximum capacity, which, in turn, determines the good's duration. For simplicity, we assume that consumers cannot purchase an individual good if their capacity does not satisfy their demand. Formally:

$$L_2 = \frac{S_2}{d_i} \quad \text{with} \quad d_i \leq S_2 \tag{4.3}$$

The utility of consumer i whose demand is satisfied by purchasing an individual good ($U_{i,2}$), depends positively on the individual's income (e_i) and negatively on the overall costs ($c_{i,2}$) related to purchasing the good (I_2) and the costs related to its use (p_2). As before, demand (d_i) affects utility both negatively (by increasing the cost of the service) and positively (by increasing demand satisfaction). Formally, consumer's utility is calculated as in Eq.4.4:

$$U_{i,2} = [e_i - (d_i p_2 + \frac{I_2}{L_2})]^{\theta_i} (d_i)^{1-\theta_i} \tag{4.4}$$

where, as above, $\theta_i \in [0; 1]$ is the consumer's preference for income ($1 - \theta_i$ is the consumer preference for consuming the service). With respect to Eq.4.1 there is no congestion (the consumer has exclusive access to the good), and the cost depends on both use of the service and its price ($d_i p_2$) and on the cost related to producing the good (I_2). We assume that the overall cost of the good is split equally over its duration ($\frac{I_2}{L_2}$).

Purchase in coalition

Similarly to the two previous cases, the utility of consumer i, whose demand is satisfied by the purchase of the good in coalition with other consumers ($U_{i,3}$), depends positively on the consumers' income (e_i) and negatively on the cost ($c_{i,3}$) paid to purchase the good (I_3) and the cost of its use (p_3), while demand (d_i) affects consumers' utility both negatively (by increasing the cost of the service) and positively (by increasing demand satisfaction).

In contrast to individual purchase, the cost of the good is shared. As in Pasimeni & Ciarli (2018), an agent that considers joining a coalition must offer a monetary contribution $x_i < I_3$ towards the purchase of a good of size S_3, which costs I_3. Hence, the total cost that must be considered by the consumers to make the decision to purchase in coalition is $c_{i3} = d_i p_3 + x_i$. With respect to the use of the shared good, the utility of a consumer who purchases the good in a coalition depends on: the total demand of all the agents in the coalition $(d_i + D_{-i})$, whether use is shared proportionally to demand ($\frac{d_i}{d_i+D_{-i}}$), to monetary contribution ($\frac{x_i}{x_i+X_{-i}}$) or is shared equally, irrespective of demand or contribution ($\frac{1}{N}$). Formally, the utility of purchase in a coalition is computed as in Eq.4.5.

$$U_{i3} = [e_i - (d_i p_3 + x_i)]^{\theta_i}\{(d_i + D_{-i})[\frac{\alpha_i d_i}{d_i + D_{-i}} + (1-\alpha_i)(\frac{\beta_i x_i}{x_i + X_{-i}} + \frac{1-\beta_i}{N})]\}^{1-\theta_i} \quad (4.5)$$

where as above, $\theta_i \in [0;1]$ is the consumer's preference for income ($1 - \theta_i$ is the consumer preference for consuming the service, irrespective of how it is shared); $\alpha_i \in [0;1]$ is a parameter that measures the importance given by the consumer to the proportional division rule based on the relative demand; $\beta_i \in [0;1]$ is a parameter that measures the importance given by a consumer to the combined effect of the proportional division rule based on the relative contribution (β_i) and the equal share division rule based on group size (1-β_i); $N \leq M$ is the size of the coalition; $X_{-i} = X - x_i$ is the total monetary contribution of the other group members $l \neq i$, and X the total monetary contribution of the group; $D_{-i} = D - d_i$ is the total demand of the other group members $l \neq i$, and D is the total demand of the whole group for the service.

Purchasing and consuming a good in coalition is subject to a number of constraints. Given that S_3 is the maximum capacity of the shared good, the total group demand cannot be higher than this value:

$$\sum d_i \leq S_3 \tag{4.6}$$

Similar to goods purchased individually, the shared good lasts for a finite period, and it is assumed that the duration period, L_3, depends on its utilisation. At the limit, if the coalition's total demand equals the size of the good, the good can be used for one period only:

$$L_3 = \frac{S_3}{\sum d_i} \tag{4.7}$$

The overall cost of the shared good, I_3, is split equally across the duration period. Hence, the sum of the monetary contributions of all participants in each period needs to be at least equal to its cost in one period. We assume, also, that the total contribution of all participants should not exceed 110% of its value since this would indicate the possibility to purchase a larger sized good.

$$\frac{I_3}{L_3} \leq \sum x_i \leq \frac{I_3}{L_3} * 1.1 \tag{4.8}$$

To assess their utility, consumers purchasing in a coalition need to decide also how much they contribute to the shared good: $x_i < I_3$ (Eq.4.5), which will affect their utility, and that of the other group members. We model group formation as an iterative process occurring during each time step. Consumers compare the utility accrued from joining one or more coalitions (more on this below) of increasing size, and with respect to U_1 and U_2. They first assess coalitions of two agents, computing the individual monetary contribution (x_i) that they are willing to commit for the joint purchase. x_i is computed as the value that maximises the individual utility in Eq.4.5, that is, the value satisfying the follow condition: dU_{i3}/dx=0.

Once they compute their optimal contribution (taking account also the contributions of the other agents in the coalition), each consumer, in turn, announces the amount they are willing to contribute. All consumers joining a coalition repeat the negotiation. With each iteration, the total contribution of all other members (X_{-i}) changes, implying that agents continuously adapt their choices in relation to what the other coalition members announced previously. Once the group of size 2 has been evaluated (both participants have made their Pareto optimal offer), one of the two consumers asks a consumer in its network to join the coalition and to evaluate a shared purchase. The negotiation takes place among three members, until they all reach their Pareto optimal offer (x_i) with respect to other members' offers (X_{-i}). This is followed by another negotiation with four agents, and so on, subject to the constraints in Eq.4.6 and Eq.4.8.

Once all potential coalitions are explored, the consumers make their choices comparing among all the (different size) coalitions explored and the other two options, public service and individual purchase. Each consumer communicates its (highest utility) choice. If the best alternative for all consumers in a potential coalition of a given size is to form such coalition, they purchase the shared good and engage in shared ownership and shared consumption until the good fully depreciates. Until that time, these coalition consumers make no further consumption decisions.

We assume that in the first time steps there is no purchase by the coalition: consumers can only buy the public service or purchase the good individually. This is because in the model we endogenise formation of social networks which could lead consumers to contact peers and form a coalition. At the beginning of the simulation, we assume that all consumers are isolated nodes. We also assume a random number of socially capable consumers (which we label *innovators*) who can contact other randomly chosen consumers and form bidirectional links with them. We assume that each proposing agent forms only one link during each time period, but that each consumer can be contacted by several consumers. Once agents are contacted and made aware of the possibility of forming a coalition, they become proponents with a probability W_t. Following the standard assumption in similar diffusion models (Faber et al. 2010), we assume that this probability increases as more consumers become aware of the sharing opportunities (W_{t-1}), as more consumers join the coalition ($SharingAdopters_{t-1}$) and as a function of external advertising of the sharing opportunities (Adv).[2] Formally:

$$W_t = MAX[W_{t-1}; min[1; Adv + (SharingAdopters_{t-1})^{\xi}]] \quad (4.9)$$

where ξ is an exogenous parameter measuring the bandwagon effect (Smallwood & Conlisk 1979).

We assume that links can be formed only between agents who have not purchased either individually or in a group, that is, those purchasing the service directly from the general provider. In other words, consumers who already own the good will not be interested in entering a coalition. However, since purchased goods last for a limited period of time, consumers owning a good, individually or in a coalition, may be contacted about its replacement at the end of its duration. During the time needed to decide about purchasing individually or in a coalition, consumers use the public service. Therefore, the network structure of connected agents evolves continuously: new contacts are formed and other links are broken if agents decide to purchase. Hence, every time step is characterised by a different network of consumers who must evaluate the three options.

Equivalence between the three purchasing options

To enable comparison, the utility of the three purchasing options ($U_{i,j}$), where $j = 1, 2, 3$, are equivalent under certain conditions. For instance, in Eq.4.5, D_{-i}=0, X_{-i}=0

[2] W_t can only increase during the simulation run because there are no other goods that could compete, hence changing visibility.

and N=1, then the second term in the Equation is equivalent to Eq.4.1 and Eq.4.4 with the exception that the congestion term K is a property of the public service. If consumers decide to not make any purchase and to rely on the public service, they pay only the unitary price, p_1, implying that x_i=0. If agents purchase individually, x_i=I_2/L_2 since the agent's individual monetary contribution in the second option corresponds to the total cost of the good, divided by its duration period.

The model is implemented in C++ using the Laboratory for Simulation Development (LSD) platform(Valente 2008), which also embeds the EE and NOLH sampling procedure.[3]

4.3 Results

4.3.1 Model Analysis

The aim of this paper is to use the above simple model to understand the conditions that prompt consumers choosing among the three options to satisfy their demand, to choose the more sustainable and equitable option of sharing purchase and use of the good, rather than purchasing the same good individually (when a public service, also, is available). To do this, we invert the usual procedure - studying the role of a few predetermined parameters and analysing the sensitivity to other parameters – and start by analysing the model's global properties (Ciarli 2012). This allows identification of the most crucial parameters and the conditions which might prompt some consumers to choose the shared ownership option, that is, the extensive margin. We next study in more depth, this reduced parameter space and the effect, in this reduced space, of the most relevant parameters for increasing the number of

[3] See https://github.com/marcov64/Lsd for additional information. The code is available upon request.

consumers that opt for shared ownership, that is, the intensive margin. We also examine the policies that may nudge the consumer to shift from individual to shared ownership and consumption. We briefly describe this procedure in the four stages below.

In the first stage, we run the global sensitivity analysis over the entire parametric space of the model (Section 4.3.3) which allows us to define the conditions (consumer and product characteristics) which prompt at least two consumers to purchase in a coalition. This analysis is conducted in four steps.

First, we identify the parameters most relevant for determining the consumer's choice among the three options, using the EE sensitivity analysis method (Morris 1991, Campolongo et al. 2007, Ruano et al. 2012). The EE screening method is applied in sensitivity analysis to detect non influential model parameters that can be excluded from subsequent sensitivity methods to increase computational efficiency. A number of model configurations are generated following the One-At-a-Time (OAT) sampling approach. Different levels are assigned to each parameter, that is, different initialisation values are applied at regular intervals between the minimum and maximum values. Individual parameter levels change, one at a time, keeping the values of the other parameters fixed. This operation is repeated for all parameters and all levels, to generate several model configurations with different parametric initialisation (or trajectories). The relative difference in the output of interest (in our case the number of consumers choosing each of the three options) generated by different random levels for each parameter, determines the EE. To assess which parameters do not influence output, two measures are computed: the mean (*mu.star*) of all the EE for each parameter, across the different levels, which measures the average impact of each parameter, and considering that the same change in different parts of the parameter space might have a different impact on the output; and the standard deviations (*sigma*) of all the EE, which measures the sum of all the interactions between one particular parameter and all the other parameters, which provides a measure of the non-linear and indirect effects of each parameter. Low values for both *mu.star* and *sigma* suggest that the parameter has a less strong effect on the model output.

Second, we analyse the direct and interactive impact of the most influential parameters (identified by the EE method) across the whole space. Ideally, all combinations, for all parameters within a reasonable range, which makes sense empirically, should be studied. However, in models with more than one parameter, the number of combinations to be tested increases exponentially and the time involved would be unreasonable. DoE is used to define those points in this multidimensional space that are statistically representative of the full parameter space and allow accurate estimation of the impact of each parameter on the model. We use the NOLH DoE, widely adopted to explore high dimensional simulations where there is a high level of uncertainty about the responses to the parameters (Cioppa & Lucas 2007).

NOLH DoE enables optimisation of the number of sampling points in the parametric space adhering to the random, hypercube and orthogonal sampling criteria. Let us consider a model with two parameters, each with minimum and maximum values that define their range. Let us assume that, for each parameter, we test four values within this range. This generates a 4x4 matrix with four equally spaced levels per parameter. We select four cells in the matrix, ensuring that each column and each row are selected only once (hypercube sampling) and that each quadrant of the matrix is selected only once (orthogonal sampling). The selected cells are the model sampling points and provide the initial values of the two parameters. For a higher dimensionality, the same procedure is conducted on a multidimensional hyper-plane. We apply the NOLH DoE to define a model configurations based on different initialisation values of the most influential model parameters detected by the EE method.

Third, we estimate the output response to each parameter individually and in combination, using the Kriging meta-modelling method (Rasmussen & Williams 2006, Salle & Yıldızoğlu 2014). This is an interpolation model, based on a Bayesian framework, estimated based on observations of the original model defined by NOLH DoE, and provides the best linear unbiased prediction of the intermediate values. We use the Kriging meta-model to predict the model outcome for unobserved points in the parametric space, based on interpolation of the neighbourhood and the observed points. To predict the model response at a specific point in the parametric space, the meta-model takes account of the linear combination of the closest observed points and their spatial information. The Kriging meta-model estimates the importance of each model parameter on the variation in the model output.

In the fourth step, the Kriging estimates are combined with the Sobol decomposition to enable a global sensitivity analysis of all the parameters in the meta-model (Saltelli et al. 2000, Saltelli & Annoni 2010). The Sobol decomposition is a variance-based sensitivity analysis that measures each parameter's direct and interaction effects on the variance of a given output of the model, where the parameters assume all the values defined in their space between the minimum and the maximum. Sobol sensitivity analysis does not explain parameter variability, but does estimate how much a parameter affects the variance in the model output. We calculate the first-order (or main effect) index, that is, the individual effect of each parameter on the model output variance. We also calculate the total-order (or interaction) index, which measures the effect of a parameter on the variance in the model outcome, taking account of its interactions with all the other model parameters. The sum of the total-order indexes may be higher than 1 since mutual interactions are calculated twice in both parameters.

The global sensitivity analysis allows the ranking of the parameters that have the greatest influence on the variance in the model output. The most influential are mapped graphically based on the meta-model 3D response surfaces, to enable identification of the model output global maxima and minima. An application of these techniques is proposed in Dosi et al. (2018), on which we draw in our methodological discussion.

In the second stage, based on the results of the global sensitivity analysis, we restrict the parameter range to values which induce at least some consumers to opt for the shared purchase (Section 4.3.4). We then perform a second global sensitivity analysis (NOLH, Kriging meta-model and Sobol decomposition) on this much smaller space, to more precisely analyse (detect finer changes in the parameters) which consumers and which characteristics might induce a larger number of consumers to purchase a good in a coalition.

In the third stage, we analyse the configuration that maximises shared consumption to study the transition to shared purchase when this option is introduced (Section 4.3.5). We study the consumer characteristics related to the three consumption options.

In the fourth stage, this configuration is then used to assess two possible policy interventions and their impact on the diffusion of the shared purchase (Section 4.3.6). We examine the effect of the unitary price of consuming the service under the three different purchasing options (which might change as a result of taxes or subsidies) and the capacity and investment cost of the good to be purchased individually or in a coalition.

4.3.2 Model Initialisation

We initialise the model with 200 heterogeneous consumers, who each have the possibility to forge a maximum of 20 bidirectional random links with other consumers (Table 4.1). Consumers differ with respect to their demand (d_i), income (e_i) and preferences for income/consumption (θ_i), and proportional division of consumption of a shared good in relation to the demand and contributions of the consumers in the coalition (α_i and β_i respectively).

Parameter	Symbol	Benchmark	Initialisation Min.	Initialisation Max.	OAT EE	NOLH Kriging
	(a)	(b)	(c)	(d)	(e)	(f)
Product features						
Capacity	S=S_2=S_3	600	200	1000	✓	✓
Investment	I=I_2=I_3	1300	600	2000	✓	
Price	p=p_1=p_2=p_3	1.5	1	2	✓	
Consumer features						
Demand	d_{delta}	30	10	50	✓	
	d_{mean}	50	30	80	✓	✓
Income	e_{delta}	450	100	800	✓	
	e_{mean}	900	600	1200	✓	✓
Preference for income	θ_{delta}	0.25	0.05	0.49	✓	✓
	θ_{mean}	0.5	0.25	0.75	✓	✓
Preference for demand division rule	α_{delta}	0.25	0.05	0.49	✓	
	α_{mean}	0.5	0.25	0.75	✓	✓
Preference for contribution division rule	β_{delta}	0.25	0.05	0.49	✓	
	β_{mean}	0.5	0.25	0.75	✓	✓
Public service features						
Lowest value of K	k	0.5	0.5	0.75	✓	
Steepness	r	10	10	20	✓	
Sigmoid midpoint	g	0.5	0.25	0.75	✓	
General provider capacity	Z	0.75	0.5	1	✓	
Network features						
Share Innovators		0.1				
Advertising	Adv	0.01				
Bandwagon effect	ξ	0.6				
Simulation settings						
Total population of agents		200				
Max random links per agent		20				
Model configuration					180	512+50
Simulation Runs		50				
Simulation Steps		960				
Final steps analysed		240				

Notes: Parameters are initialised based on a uniform distribution between the minimum (c) and the maximum (d) value. The benchmark (b) value is the average values between the two. Columns (e) and (f) indicate which parameters are considered in the Elementary Effect (EE) and Kriging methods, respectively.

Table 4.1: Model initialisation

To initialise these consumer features, we define values for the population average (*mean*) and for the distance between the minimum and maximum values (*delta*), and then assign a random value to each consumer based on a uniform distribution between the minimum and the maximum values. Formally, for each feature f_i, where $f_i = d_i, e_i, \theta_i, \alpha_i, \beta_i$, are the population averages (f_{mean}), and (f_{delta}) is the maximum distance between the minimum and maximum values, a consumer is assigned a value $f_i \in$ UNIFORM (f_{min} ; f_{max}), where f_{min} = (f_{mean} - $\frac{f_{delta}}{2}$) and f_{max} = (f_{mean} + $\frac{f_{delta}}{2}$). This allows us to distinguish whether consumer choice is influenced by features that differ based on the means (*mean*) or within (*delta*) populations.

The remaining model parameters define the characteristics of the good that could be purchased to access the service privately, and the characteristics of the public service. We assume that the same good can be purchased individually or by a group. The good features considered are capacity (S=S_2=S_3) and investment cost (I=I_2=I_3). As noted above, the quality of the public service depends on the number of users and on its maximum capacity (Z), that is, the share of consumers in the population it can cater for in one period, and the parameters that define the logistic curve which models the relation between number of users and reduced service quality due to congestion: k, r, and g. With respect to the unit price for consuming the service, we assume that the three options do not differ (p=p_1=p_2=p_3).

In this version of the model, we consider fixed unitary prices for the three options, because the computation of unitary prices to use the goods depends on the market of interest. Back to the transport examples, public transport is often public, and prices do not change with demand; the cost of using a car depends on the demand for oil, that only partly depends on cars use; the cost of he shared car, depends on the cost pf the platform. Furthermore, the demand curve can be rather flat, as the choice of transport will often depend on other parameters, such as location, access to travel routes, and household composition. These market mechanisms are not obvious to explore and need a separate model (or separate models for different markets). We do however analyse the impact of different price structures on the model results.

All the above parameters are presented in Table 4.1 and are studied in the global sensitivity analysis.

We assume that 10% of the consumers are *innovators*, that is, consumers that at t=0 are aware of the possibility of a sharing option and can contact other consumers to form a coalition. The rate at the information spreads to allow other consumers to form a coalition depends on parameters Adv and ξ (Eq.4.9). Pasimeni & Ciarli (2018) show that the faster the information flows, the faster and greater the adoption of goods in coalitions. Since in this paper we focus on the features of the consumers and the good, we set these parameters to values that allow fast information flow among agents and, over the course of the simulation time steps, will allow all consumers to opt for shared purchase and shared consumption should this be their preferred option.

To analyse the sharing option as a potential new alternative for individual consumers, in an economy where consumer choice has stabilised around the public service and a private good, we run a number (360) of time steps with only these two alternatives: public service and individual purchase. We then consider this time step as $t = 0$ and run the model with all three options for 600 time-steps. We assign parameter values to the benchmark initialisation whose relation is commensurate with the characteristics of an average consumer in a high income country (Table 4.1). Therefore, we assume that each time-step in the simulation is one month and that the model simulates 50 years of potential transition from individual to shared purchase.

For each parameter value combination, we run 50 simulations with a different pseudo-random seed, in order to control for the effect of the model's stochastic elements. The configuration represents the average of these simulation runs and the final 240 time-steps, where we know that, regardless of the model configuration, on average, 99% of all the agents in the model have evaluated coalition purchase at least once.

We average over time steps to avoid the results being driven by what happens in a specific period.

Table 4.1 reports the benchmark (b), minimum (c) and maximum (d) values for all the model parameters defining the space (or range) in which they are initialised. Below, we describe the DoE in more detail.

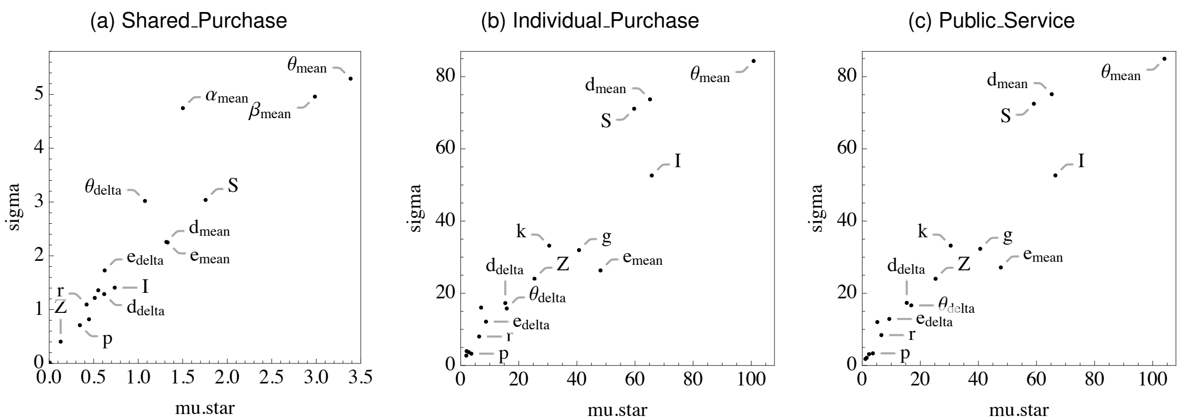
4.3.3 Global Sensitivity Analysis

The objective of the global sensitivity analysis is to investigate the conditions, across the entire parameter space defining the consumer, product and public service features, that induce some consumers to opt for the shared purchase rather than individual purchase or public service. The main output variables are total number of consumers purchasing in a coalition (*Shared_Purchase*), purchasing individually (*Individual_Purchase*) or purchasing the public service (*Public_Service*).

As discussed in Section 4.3.1, we select the main parameters using the EE method. We include in the analysis all parameters ticked in Table 4.1 column (e). EE results in seven main parameters on which we run the NOLH – (these are ticked in Table 4.1 column (f)). To run both EE and Kriging methods, the OAT (e) and NOLH (f) sampling procedures generate several model parameter value combinations. The OAT generates 180 combinations and the NOLH DoE generates 512 points in the parametric space, plus an additional 50 for external validation (see Annex A.3, which also reports the Kriging meta-model estimates).

Elementary Effects (EE)

Figure 4.2 plots the EE for all the parameters, on the number of agents deciding to opt for the shared purchase (a), the individual purchase (b) or the public service (c). The vertical axis plots *sigma*, which are the non-linear and non-additive effects of each parameter and provide an estimate of the interaction effects with the other parameters. The horizontal axis plots *mu.star* the overall effect of each parameter.



Notes: The three graphs plot the overall effects ($mu.star$, horizontal axis) and non-linear and non-additive effects ($sigma$, vertical axis) of all parameters measuring consumer features, product features and public service features (Table 4.1, col. (e) on the number of consumers that choose the shared purchases (a), individual purchase (b) and the public service (c).

Figure 4.2: Elementary effects of the model parameters

The results of the EE analysis suggest that, in the case of consumer features, the population preferences average values have a strong impact on the number of consumers opting for shared purchase. These include θ_{mean}, α_{mean} and β_{mean}. The next most influential consumer features (population average) are income (e_{mean}) and demand (d_{mean}). The level of heterogeneity across consumer features ($delta$) has a negligible effect on the choice among the three purchasing options, with the exception of the preference for income/consumption, θ_{delta}. Among the product features parameters, only good capacity (S) has a relevant impact on the number of agents choosing the sharing option.

In the cases of individual purchase and the public service, again the most relevant parameters are consumer features (population mean: demand (d_{mean}), income (e_{mean}) and preference for income (θ_{mean})), but not the preferences for the sharing rules, which do not apply in these two cases.

Among product features, good capacity is relevant (S). Also, in contrast to shared purchase, in the case of individual purchase and the public service, the cost of the good (I) is relevant since, in this case the consumer pays the entire cost of either option. The shared purchase option is affected less by the cost of the good since the individual contribution to the purchase (x_i) reduces as the size of the group (N) increases. However, the higher the number of agents in the sharing group, the higher the total demand ($\sum d_i$), implying the need for a good with high capacity (S). If this condition is not satisfied (Eq.4.6), the shared purchase is not viable, which explains why the good capacity parameter has a strong overall effect on the sharing purchase option. S is also relevant for the decision to purchase the good individually since it affects good duration and the fractional cost to be paid (Eq.4.3): the higher the capacity, the longer the duration and the lower the cost per period.

The parameters for the public service features are also relevant for the choice between public service or individual consumption: these include maximum capacity (Z), the lowest value for congestion (k) and the value when the congestion curve is at half of its maximum (g). When the capacity of the public service can satisfy the demand of a high number of consumers, the level of congestion related to accessing the service is low. As congestion increases or comes at an earlier point in time (g), this affects consumer utility and explains the overall effect on the consumer decision (Eq.4.1 and Eq.4.2).

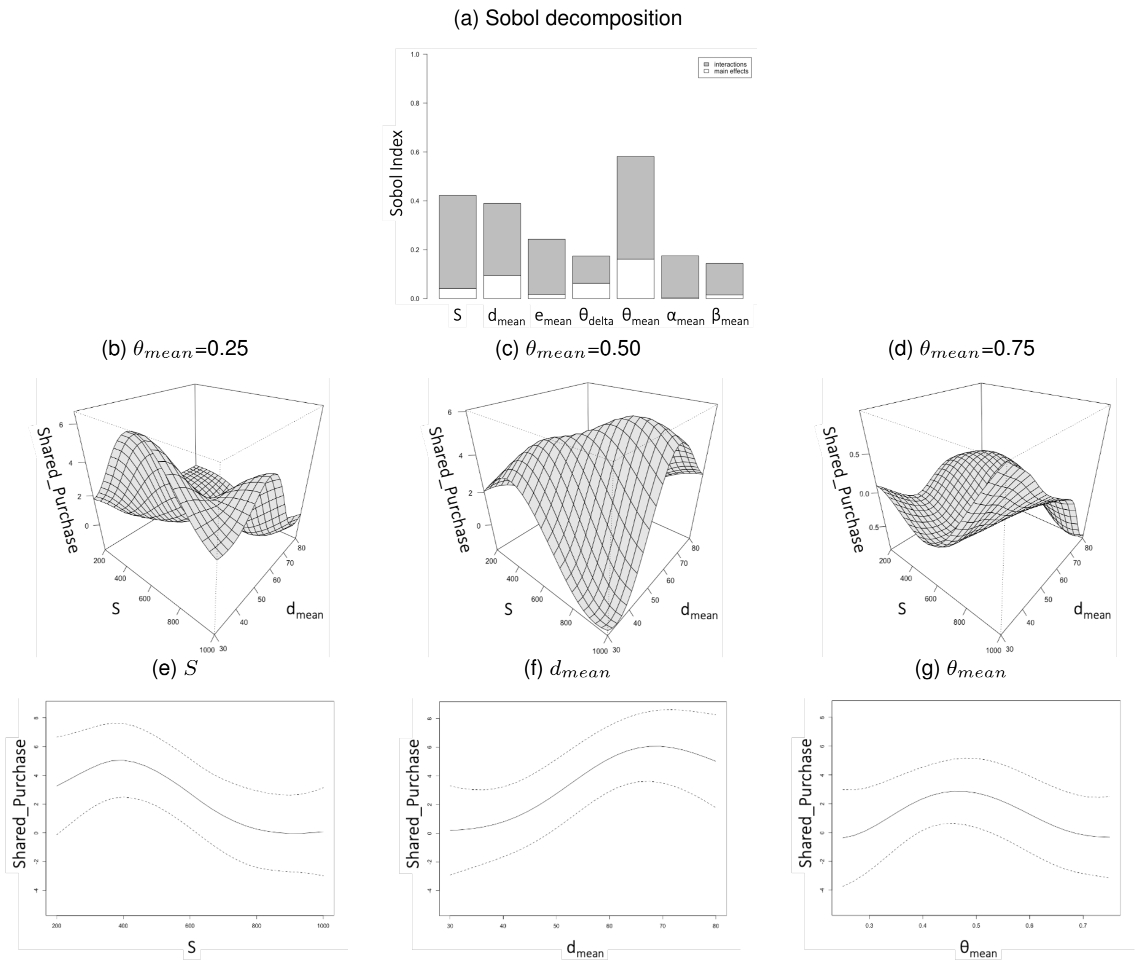
Note that the size of the parameter effects differs substantially between the shared purchase and the other two options (Figure 4.2). All of the parameters have a lower effect on the sharing option because the maximum number of consumers choosing this option, among the 180 model configurations generated by the OAT sampling procedure, is 11 (over 200) which already suggests this option is chosen by a small number of consumers.

Kriging meta-modelling

This section presents the results of the Kriging meta-modelling based on NOLH DoE for the model parameters that have the strongest overall effects on the shared purchase option, as estimated by the EE method. To ensure a manageable computation time to run the Kriging meta-modelling, we arbitrarily assume that the most influential parameters are $mu.star > 1$ and $sigma > 2$ (see Table 4.1 column (f)). We chose to exclude the other parameters because they are all clustered at very low values of both $mu.star$ and $sigma$, which imply non-relevant impact on the model output. The parameters are initialised (according to the NOLH DoE) at values between the respective Min and Max in Table 4.1 columns (c) and (d). The remaining parameters are initialised based on the average benchmark value, column (b).

Figure 4.3 plots the outcome of the sensitivity analysis to assess the impact of the selected model parameters on the number of agents opting for the shared purchase. The Sobol decomposition (bar chart (a) at the top of the figure) indicates that the average value of the preference for income (θ_{mean}) is the most important value and accounts for about 60% of the variance in the number of agents undertaking the shared purchase (considering that the sum of the parameter variance might be higher than 1 due to double counting the mutual interactions among parameters). The next two most important parameters are good capacity (S) and the average value of population demand (d_{mean}).

However, it should be noted that the interaction effect (grey) is always larger than the main effect (white), meaning that the impact of these three parameters on the model output depends on the value of the other parameters. That is, for example, the consumer's preference for income (θ_{mean}) drives the consumer's choice in relation to the shared purchase option, conditional on the value of the other six parameters. This suggests that despite model simplicity, consumer choice is the result of a complex interaction among consumer features (and the capacity of the good available in the market).



Notes: Charts plot the results from the sensitivity analysis on the seven parameters that have largest influence on the number of consumers that opt for the shared consumption (Figure 4.2). (a) We plot the Sobol decomposition analysis, which provides estimates of the direct and interactive impact of each parameter: each bar plots the Sobol index, the extent to which the parameter explains the output variance, directly (part in white), and conditional to interaction with other six parameters (grey). In the middle row, we plot the 3D response surfaces, generated through the Kriging meta-model interpolation, for S and d_{mean} at different levels of θ_{mean}, where the vertical axis measures the total number of consumers that opt for the shared purchase: (b) θ_{mean}=0.25, (c) θ_{mean}=0.50 and (d) θ_{mean}=0.75. In the bottom row, we plot the direct impact of the three most important parameters on the total number of consumers that opt for the shared purchase, and 95% confidence intervals: (e) S, (f) d_{mean} and (g) θ_{mean}.

Figure 4.3: Global sensitivity analysis of the impact of model parameters on the number of consumers in shared ownership

The remaining two preference parameters (α_{mean} and β_{mean}) are less relevant and have no direct impact on the choice to purchase a shared good. This depends on the model construction: α_{mean} and β_{mean} relevance are weighted by 1-θ and are related to consumer demand and consumer income and, also, to how much the individual manages to consume and contribute under a given sharing rule. The population variation in the preference for income/consumption (θ_{delta}) is less relevant for determining the consumer choice to enter a coalition to buy a good. This suggests that the level of heterogeneity in the preference for income in the population does not greatly affect the decision to share the purchase of a good. Surprisingly, the population income (e_{mean}) has only a very small impact and only in relation to the other parameters, not directly.

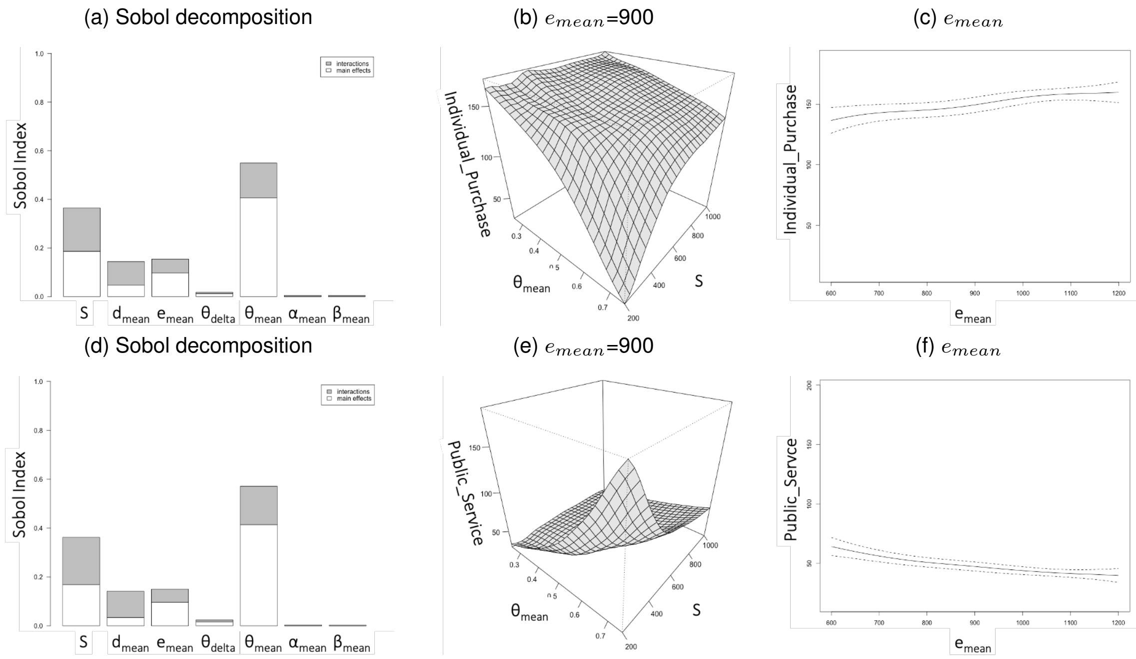
The other charts show the impact of the three main parameters on the average number of consumers (from a population of 200) that opt for the shared consumption. The charts in the centre of Figure 4.3 plot the 3D response surface for S and d_{mean}, with the most relevant parameter (θ_{mean}) at its minimum θ_{mean}=0.25 (b), average θ_{mean}=0.50 (c) and maximum, θ_{mean}=0.75 (d) values and all other parameters are at their benchmark value. The charts at the bottom of Figure 4.3 plot the direct impact of the three parameters on the number of consumers in the shared purchase: S (e), d_{mean} (f) and θ_{mean} (g), with all other parameters are at benchmark value.

Overall, these results suggest that, on average, across the whole parameter space represented by the seven parameters with the strongest impact (on shared purchase), only a niche group of consumers chooses the shared purchase option: the maximum value in the meta-model response is about 6 (out of 200) agents. This is an indication of the small likelihood of a shared consumption models being chosen by the population of consumers.

Cœteris paribus, those few consumers that choose shared purchase tend to be in the population with a medium-low average preference for income (or average-higher preference for consumption) (chart (g)) and higher demand (chart (f)), which is satisfied by a relatively small sized good that is large enough to satisfy more than one consumer for at least a period (chart (e)). However, it should be noted that the number of consumers opting for the shared purchase is not significantly different from zero, for varying income preference values.

How do these three relevant features interact? If we consider a good where the population has a medium preference, on average, for consumption (i.e., they care equally about consuming and about their savings, chart (c)), we observe the largest number of sharing consumers if demand is relatively high and consumers can buy a medium sized good. This relation does not hold for the maximum and minimum levels of consumer preference for income. In the first case (chart (d)), we observe no consumers forming a coalition to purchase the good, irrespective of level of demand or good size. In the second case (chart (b)), the relation is less linear: we observe coalitions only for very low levels of demand and good size. As demand reduces, the good size leading to formation of a coalition becomes smaller than the average. A reduced preference for income gives more importance to the second part of the utility function (Eq.4.5), which is related positively to the total demand of the whole coalition ($D = d_i + D_{-i}$). A small coalition established by consumers with overall low demand makes it feasible to share the purchase of a small good.

Figure 4.4 plots the results of the sensitivity analysis for the same seven parameters, for the number of consumers that choose the other two options: individual purchase (upper set of charts) and the public service (lower set of charts). As Figure 4.2 shows, θ_{mean}, S, e_{mean} and d_{mean} are among the most relevant parameters for determining the number of consumers that chose those two options (charts (a) and (d)).



Notes: The three charts on the top plot the results from the sensitivity analysis on the impact of model parameters on the number of consumers that opt for the individual purchase. The three on the bottom relates to the number of consumers that opt for the public service. (a) and (d) plot the Sobol decomposition analysis. Each bar plots the Sobol index: in white the direct impact of each parameter and in grey the impact considering interaction with other parameters. (b) and (e) plot the 3D response surface for θ_{mean} and S, when e_{mean}=900. (c) and (f) plot the direct impact of e_{mean} on the total number of average consumers that opt for the individual purchase (c) and for the public service (f), and 95% confidence intervals.

Figure 4.4: Global sensitivity analysis for individual purchase (top) and public service (bottom)

As in the case of shared purchase, the parameters that explain most of the variance in the choice are the average value of the consumer preference for income (θ_{mean}, accounting for about 60% of the variance) and the capacity of the shared good (S, accounting for about 40% of the variance). In contrast to the results for shared purchase, the direct effect of the parameters (coloured white on the bar) is higher than the effect due to interaction with other parameters (grey colour). This is because, in these individual choices, the use of the service does not depend on the number of consumers in the coalition, which make the utility from consuming conditional on the size of the good, the individual demand and the preference for the sharing rule. It should be noted, also, that consumer heterogeneity with respect to preference for income (θ_{delta}) is not relevant for determining these two consumption options.

The other parameters that have a relatively high impact on the decision to purchase individually or use the public service are the average values of population income (e_{mean}) and demand (d_{mean}). The impact of income is mainly direct, while the impact of demand is mainly conditional on other parameters. This is because consumer utility can only be positively related to income (in Eqs.4.1, 4.4 and 4.5, e_i appears only on the left side of the utility function), whereas consumer demand can affect utility by both reducing income (θ_i, $c_i = d_i p$) and increasing use of the service ($1-\theta_i$). Therefore, the interaction with the other model parameters is more important. Goods with high average consumer demand increase the cost of using the service and require higher income consumers to increase the utility of consuming.

The two remaining preferences (α_{mean} and β_{mean}), by construction, have no impact because the utility functions of the two consumption options analysed in Figure 4.4 do not depend on these two parameters which determine the sharing rules (see Eq.4.1 and Eq.4.4).

The other two charts focus on the impact of the three main parameters on the average number of consumers (from a population of 200) that opt for individual consumption (top) or public service (bottom). The charts in the middle of the figure, (b) and (e) in Figure 4.4, plot the 3D response surface for the two most relevant parameters, θ_{mean} and S, when the third most relevant parameter is at its benchmark value (e_{mean}=900) and all the other parameters are also at their benchmark values. The charts on the right plot the direct impact of e_{mean} ((c) and (f)).

Overall, for all combinations of the model parameters, most consumers opt for individual purchase or the public service. The impact of the most important parameters on the two individual consumption choices is symmetrical. The population of consumers with a high preference for income (θ_{mean}) is likely to rely on the public service, especially in the case of a small capacity good (S). However, the number of consumer that purchase the good individually increases linearly with both the preference for consumption (1-θ_{mean}) and the good size (S).

What this global sensitivity analysis shows is that the interplay among model parameters makes the purchasing decision dynamic. However, consumers autonomously find the system equilibrium which guarantee the maximum individual utility.

Agents willing to share the purchase of the good in a coalition have high demand. It might be expected that the shared good would be linked to high capacity to satisfy the needs of a larger group of consumers and increase the benefits of cost-sharing. However, large coalitions are more difficult to coordinate and require a lengthy negotiation process, and, also, there is a higher likelihood that some consumers might drop out as the offers change, changing the conditions for the other consumers. In other words, the complexity involved in coordinating a large group, which in our model is represented by the ”tatonnement” process, may rule out the sharing option if only large sized goods are available in the economy. Moreover, the larger the size of the group and the larger its total demand for the good, the lower will be the duration of the good (Eq.4.7). This means that the coalition will have a shorter duration, which might persuade the consumer to choose a different consumption option when the good needs to be replaced; at that time, the conditions will have changed and coalition may not be the solution yielding the highest utility for at least one member. As duration reduces, the monetary contributions of group members required to make the shared purchase increase (Eq.4.8). This reduces consumer utility from a cost-sharing in coalition, which might prompt choice of a different consumption alternative. If new consumers are invited to join the coalition to increase the cost-sharing, the interplay between total demand and product capacity becomes crucial, as just discussed. Shared goods with lower capacity can satisfy a smaller group with relatively lower total demand.

In the case of individual purchase and in the context of Eq.4.3 and Eq.4.4, large capacity increases good duration and reduces the cost to be paid in each time period. In the case of a low capacity good, the convenience of purchasing it individually for the same cost decreases and agents who do not choose shared purchase, will decide to rely on the service offered by the general provider. Overall, the impact of product capacity on consumer utility depends on consumer demand. Consumers with high demand use the good more frequently, with a high rate of depreciation, which reduces its duration and, consequently, increases the overall cost of this option. If income is not high enough to offset the higher expenditure, the consumer will opt for the public service. The public service option has no investment costs: consumers pay only for their use of the service, which, potentially, makes this option the lowest cost and highest utility choice. However, as more and more people choose this option, congestion increases, making all the consumers of the public service worse off and determining a consumption shift to another option guaranteeing a better outcome.

The interplay among these model parameters demonstrates the complexity of the decision process leading to shared purchase. Agents negotiate in order to find the best trade-off among all these conditions, and this negotiation is decisive for formation of a coalition. We know that coordinating a large group is more complicated than in the case of a small group, and that a larger choice set increases decision complexity. In our model, the evaluation of shared consumption in groups whose size increases incrementally, becomes increasingly more complex, suggesting that a non optimising, faster routine could lead to more sharers.

4.3.4 Exploring the Niche of Sharing Consumers

One of the main results of the global sensitivity analysis presented in the previous section, is that, according to the Kriging meta-model estimates, across all possible configurations of our stylised economy, at most, only a small group of consumers will opt for shared purchase, for given values of θ_{mean}, S and d_{mean}. Figure 4.3 suggests, also, that the interaction among the model parameters is important for determining the number of consumers that choose the shared purchase, but is less relevant for consumers that access the service individually. We find, also, that in a population of consumers with low-medium income/consumption preferences, the shared purchase increases with relatively high levels of average demand and lower levels of product capacity.

It should be noted that because this Kriging meta-model estimation is based on the results from a broad range of parameters, and because, under most parameterisations, no consumers opt for the shared purchase, the average estimated share is low. In other words, across this broad range, the shared purchase niches are outliers and occur in rather limited parts of the parameter space.

To investigate the conditions where shared purchase may be successfully adopted by a significant ratio of the population, we analyse in detail the results of the 562 simulation runs of the NOLH DoE to select smaller sections of the parameter space where the sharing consumer ratio is consistently higher. We rank the observed points by the number of consumers choosing shared purchase and select the top three configurations, which reach values between 22 and 28.[4]

We define the range of the seven relevant parameters using the minimum and maximum values across these three configurations. As before, the other parameters are

[4]These values differ from the global maxima in the 3D response surface, 6 out of 200. This is because the Kriging meta-model makes an interpolation between the observed points, which, in most of cases, is zero (Figure 4.3).

set at their benchmark values. For each of the seven parameters, Table 4.2 reports: the average value (b) and the range between the minimum (c) and the maximum (d) values tested in this smaller niche; and the benchmark (e) and range (f, g) tested in the global sensitivity analysis in Table 4.1).

Parameter	Symbol	Benchmark Niche	Initialisation Niche		Benchmark original NOLH (Tab.4.1)	Initialisation original NOLH (Tab.4.1)	
			Min	Max		Min	Max
	(a)	(b)	(c)	(d)	(e)	(f)	(g)
Product features							
Capacity	S=S_2=S_3	460	260	660	600	200	1000
Investment	I=I_2=I_3	1300			1300		
Price	p=p_1=p_2=p_3	1.5			1.5		
Consumer features							
Demand	d_{delta}	30			30		
	d_{mean}	61	55	67	50	30	80
Income	e_{delta}	450			450		
	e_{mean}	850	710	990	900	600	1200
Preference for income	θ_{delta}	0.125	0.05	0.20	0.25	0.05	0.49
	θ_{mean}	0.34	0.25	0.43	0.5	0.25	0.75
Preference for demand	α_{delta}	0.25			0.25		
division rule	α_{mean}	0.55	0.35	0.75	0.5	0.25	0.75
Preference for contribution	β_{delta}	0.25			0.25		
division rule	β_{mean}	0.645	0.61	0.68	0.5	0.25	0.75
Public service features							
Lowest value of K	k	0.5			0.5		
Steepness	r	10			10		
Sigmoid midpoint	g	0.5			0.5		
General provider capacity	Z	0.75			0.75		

Notes: Parameters in the niche parametric space are initialised based on a uniform distribution between the minimum (c) and the maximum (d) value. The benchmark (b) value is the average values between the two. Columns (e), (f) and (g) report the initialisation values for the benchmark, minimum and maximum of the global sensitivity, as initialised in Table 4.1. Considering the range for each parameter, the NOLH-DoE identifies new 512+50 model configurations that are the observed points needed to estimate the Kriging meta-model.

Table 4.2: NOLH initialisation in a smaller parametric space

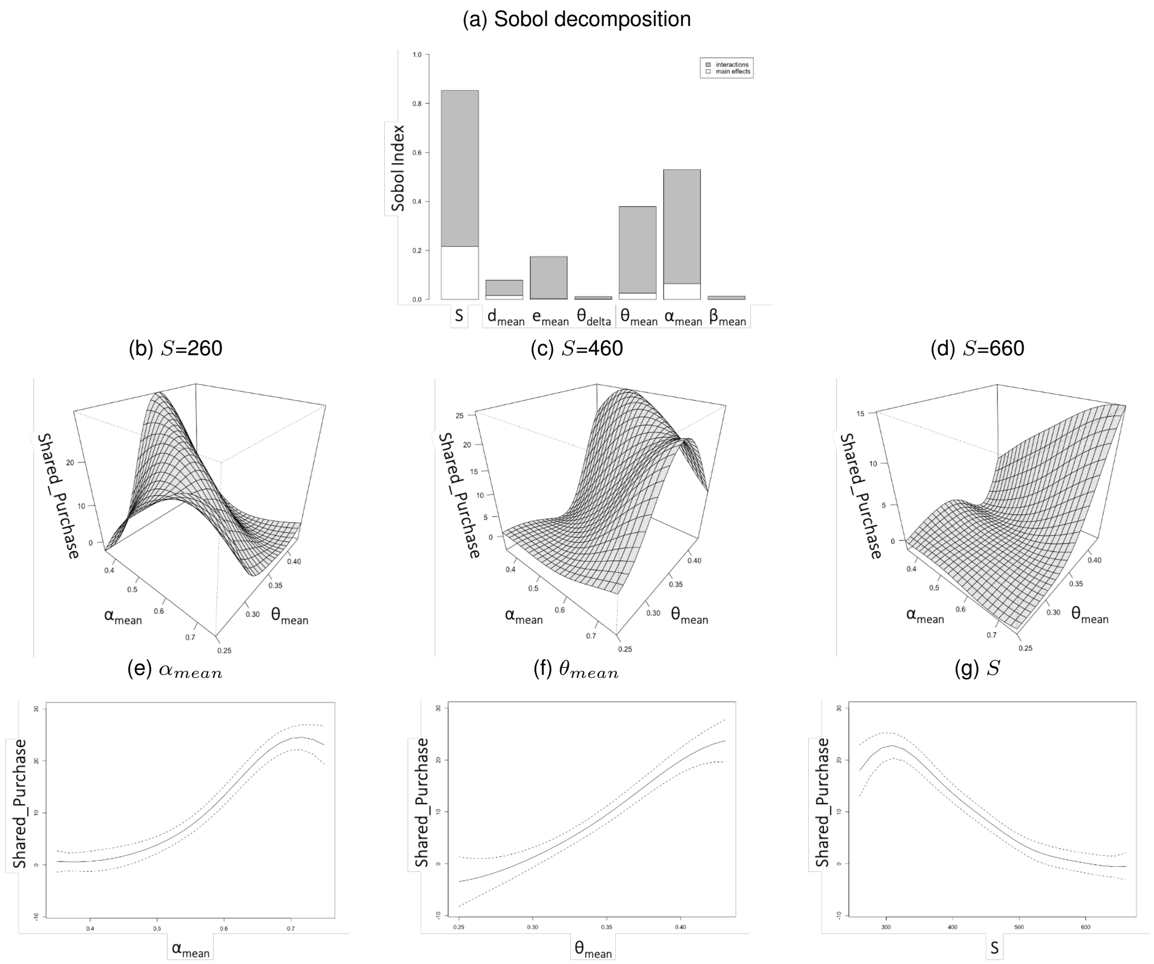
First, we note that the average for S, d_{mean} and θ_{mean} are extremely close to the values that maximise the number of shared purchasers in Figure 4.3 (charts e, f, g). In the case of S, d_{mean}, these coincide with the values for which the number of shared purchasers is significantly different from zero. Second, although we refer to a niche, the range of these parameter values is quite broad and covers quite distinct types of consumers and goods.

The values of the parameters that define this smaller space suggest an economy in which: the capacity of the good has relatively low-medium values (between 260 and 660 compared to the average and maximum in the global analysis, respectively, 600 and 1000); consumers have relatively medium-high demand (between 55 and 67, compared to the minimum and average in the global analysis, respectively, 30 and 50), but low-medium income (between 710 and 990, compared to the average and maximum in the global analysis, respectively, 900 and 1200); consumers have low-medium preference for income (between 0.25 and 0.43, compared to the average and maximum in the global analysis, respectively, 0.5 and 0.75); and a higher preference for the demand and contribution sharing rules (averaging respectively 0.55 and 0.645, compared to 0.5 in the global analysis). All the other parameters remain unchanged.

In other words, the global sensitivity analysis shows that shared purchase is considered an option for the population of consumers with relatively high need for the service (high demand and high preference for consumption), which increases the value of purchasing the good and, especially, if the public service is already congested, but a relatively low income which does not allow them to make an individual purchase. Consumers with tighter budgets, but higher demand are more willing to coordinate over shared purchase. These consumers also prefer to form smaller coalitions and to purchase relatively smaller goods.

To investigate in more detail, the conditions in this smaller parametric space, which might prompt more consumers to opt for the shared purchase, we performed a second global sensitivity analysis, with sampling points, again, identified via NOLH DoE using the minimum and maximum values of the parameters reported in Table 4.2, columns (c) and (d).

Figure 4.5 plots the outcome of this sensitivity analysis assessing the impact of the selected model parameters on the number of agents opting for the shared purchase in this smaller parameter space.



Notes: Charts plot the results from the sensitivity analysis on the seven parameters, in the smaller parametric space. (a) We plot the Sobol decomposition analysis, which provides estimates of the direct and interactive impact of each parameter: each bar plots the Sobol index, the extent to which the parameter explains the output variance, directly (part in white), and conditional to interaction with other six parameters (grey). In the middle row, we plot the 3D response surfaces for α_{mean} and θ_{mean} at different levels of S, where the vertical axis measures the total number of consumers that opt for the shared purchase: (b) S=260, (c) S=460 and (d) S=660. In the bottom row, we plot the direct impact of the three most important parameters on the total number of consumers that opt for the shared purchase, and 95% confidence intervals: (e) α_{mean}, (f) θ_{mean} and (g) S.

Figure 4.5: Global sensitivity analysis and response surfaces in a smaller parametric space of sharing consumers

The Sobol decomposition (bar chart (a) at the top of the figure), indicates that product capacity (S) is now the parameter which has the biggest influence on the decision to opt for shared purchase, accounting for more that 80% of the variance in the number of agents choosing that option. This is almost the double the number identified in the entire parameter space (Figure 4.3), which suggests that, under certain demand and income conditions, good size is crucial since it conditions the size and duration of the coalition. The second most relevant parameter is the average value of the consumer preference for the demand division rule (α_{mean}), that is, the importance assigned by agents to the amount of the shared good to be used by other group members, relative to their own demand (rather than to their contribution). Compared to the analysis of the entire parameter space (Figure 4.3), this becomes twice as relevant, suggesting, again, that the parameters defining coalition become crucial under the demand and income conditions that might induce consumers to share. The preference for income/consumption (θ), is also relevant, at a similar level as in the global sensitivity analysis. Also, in this smaller parameter space, the effect of these most influential parameters is, based, mainly on their interaction, rather than being direct.

The bottom set of charts of Figure 4.5 plot the estimated direct impact of the three most relevant parameters when all other are at their benchmark values: α_{mean} (e), θ_{mean} (f) and S (g), and suggest that, in this relatively smaller parameter space, the likelihood of consumers choosing shared purchase is significantly higher than for other configurations of the economy. Under most values of α_{mean}, θ_{mean} and S, the number of shared purchasers is significantly different from zero and can be over 20. The number increases with the consumers' preferences for the demand division rule (α_{mean}) and for income (θ_{mean}), and decreases with the size of the good (S), which can be taken as a good proxy for the size of the eventual coalition. Recall that the positive relation with θ_{mean} is subject to θ_{mean} being below its maximum value of 0.43, that is, for a population that, overall, has an above average preference for consumption (1-$\theta_{mean} > 0.57$).

The middle set of charts in Figure 4.5 plot the 3D response surface for α_{mean} and θ_{mean}, for different levels of S (low S=260 (b), average S=460 (c) and high S=660 (d)), and for the benchmark values for all the other parameters. Chart (a) shows that the impact of the parameters on the model outputs, depends largely on the interactions with other parameters. However, the direct effect of S accounts for about 20% of the variance in the number of agents in the shared purchase, which explains the different peaks moving from chart (d) to chart (b): low good capacity increases the shared option (as in chart (g)). However, the effect of α_{mean} and θ_{mean} needs to be analysed in relation to the interaction with other parameters, which might call for a different interpretation compared to how we understand their direct effect only (charts (e) and (f) respectively).

For a high value of S, chart (d), high levels of both α_{mean} and θ_{mean}, determine the highest number of consumers choosing the shared purchase. For an average value of S, chart (c), the number of sharing consumers increases and reaches a maximum of both low and high values of α_{mean}, while θ_{mean} remains at above average values. The number of consumers opting for the shared purchase increases even further with very low product capacity values (chart (b)), with α_{mean} at its lowest level and θ_{mean} above the average.

α_{mean} is the population's preference for the division rule based on demand, which leverages preference for the division rule based on contributions (β_{mean}, see Eq.4.5). As product capacity decreases, the level of total demand it can satisfy also decreases, meaning that only small coalitions are feasible. In this smaller parameter space, we are dealing with less wealthy consumers with high demand who may not be able to afford individual purchase; high demand depreciates the good faster entailing a higher cost every time period. To achieve greater utility from a coalition, preference for the division rule based on contributions becomes more important, which implies a lower individual contribution for the shared purchase (x_i), thereby reducing

α_{mean}. In the reverse situation of a higher capacity product, able to satisfy the total demand of a bigger coalition, consumers may be willing to contribute more, subject to being able to use the shared good proportionally to their demand. However, in this situation, individual consumption becomes more cost-effective and fewer consumers choose shared purchase.

4.3.5 Transition to Shared Purchase: Dynamics, Impact and Consumer Features

Having studied which consumer preferences and good sizes are likely to increase the number of consumers choosing shared purchase, we next investigate the dynamics of that choice, starting with an economy where either only individual purchase or the public service are available. We also examine in more depth, who are likely to be sharing consumers. Among the 562 parameter combinations sampled using NOLH for the niche group of sharing consumers, we now focus on the model configuration that results in the highest number of consumers choosing shared purchase (on average 42 out of 200). Table 4.3 presents this configuration (column (b)) and, for reference purposes, includes the parameter values of the niche group (columns d-f).

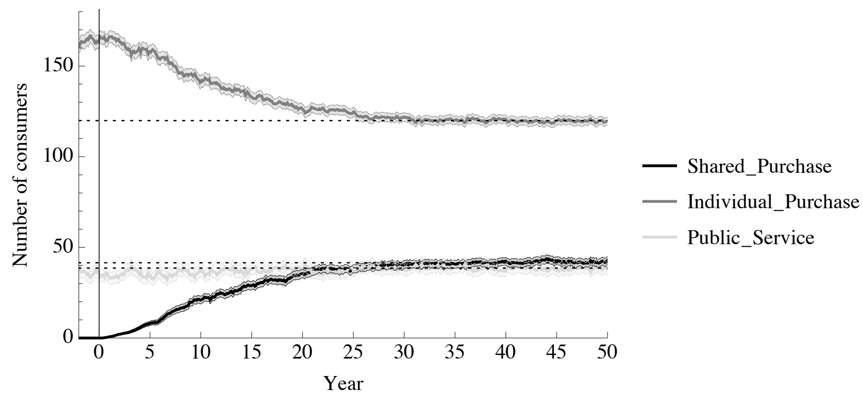
Parameter	Symbol	Initialisation	Policy	Benchmark niche NOLH (Tab.4.2)	Initialisation Min	Max
	(a)	(b)	(c)	(d)	(e)	(f)
Product features						
Capacity	S=S_2=S_3	315.58	✓	460	260	660
Investment	I=I_2=I_3	1300	✓	1300		
Price	p=p_1=p_2=p_3	1.5	✓	1.5		
Consumer features						
Demand	d_{delta}	30		30		
	d_{mean}	64.63		61	55	67
Income	e_{delta}	450		450		
	e_{mean}	931.92		850	710	990
Preference for income	θ_{delta}	0.13		0.125	0.05	0.20
	θ_{mean}	0.40		0.34	0.25	0.43
Preference for demand	α_{delta}	0.25		0.25		
division rule	α_{mean}	0.40		0.55	0.35	0.75
Preference for contribution	β_{delta}	0.25		0.25		
division rule	β_{mean}	0.65		0.645	0.61	0.68
Public service features						
Lowest value of K	k	0.5		0.5		
Steepness	r	10		10		
Sigmoid midpoint	g	0.5		0.5		
General provider capacity	Z	0.75		0.75		

Notes: Column (b) shows the value of each model parameter that maximises the number of agents that opt for the shared purchase. Column (c) indicates the parameters for which we study the effect on the model output as proxy of the impact of policy measures. Columns (d), (e) and (f) report the initialisation values for benchmark, minimum and maximum of the the smaller parametric space, as in Table 4.2.

Table 4.3: Initialisation of the configuration generating the highest ratio of shared purchase

Transition to Shared Purchase

Figure 4.6 summarises the evolution of agents' consumption decisions over 600 time periods, which is equivalent to 50 years. Pre-t=0, the model is initialised with only two options: individual purchase and public service. We run the model for 360 time steps with only these two options available, to allow the model to settle around a long term steady state, *cœteris paribus*. For ease of reading, Figure 4.6 shows only the last 24 time steps (i.e., the final two years) in this initial period with no sharing option.



Notes: The chart shows the transition from individual to shared purchase. During the first 24 time steps ($t < 0$) consumers can choose only from individual purchase or public service. At $t = 0$, and for the remaining 600 time steps (50 years), consumers can also choose the shared purchase. The medium-grey line plots the number of consumers opting for the individual purchase; the black line plots the number of sharing consumers; and the light-grey line plots the number of consumers using the public service. The shaded areas are the respective 95% confidence interval.

Figure 4.6: Number of agents in the three options over time.

Under the current configuration, before the sharing option is introduced, more than 80% of consumers choose individual purchase with the remaining around 20% of consumers satisfying their demand through the public service. If we consider again the mobility example, this is close to recent commuting figures across the UK (except London) (UK Department for Transport 2019).

At t=0, the shared purchase option is made available. As discussed in Section 4.3.2, initially, only 10% of the population (the innovators) is aware of this additional option and able to promote a coalition (they can ask any consumer to join and inform them about the possibility of sharing). In the first 60 time steps, only few consumers choose to replace an individual good with a shared good. As more consumers become aware of the sharing option and are able to form coalitions, the ratio of shared purchase increases and stabilises around its maximum of 20%. Diffusion of the new option follows the well-established S-shaped diffusion curve, and takes a long time under the current parameterisation.

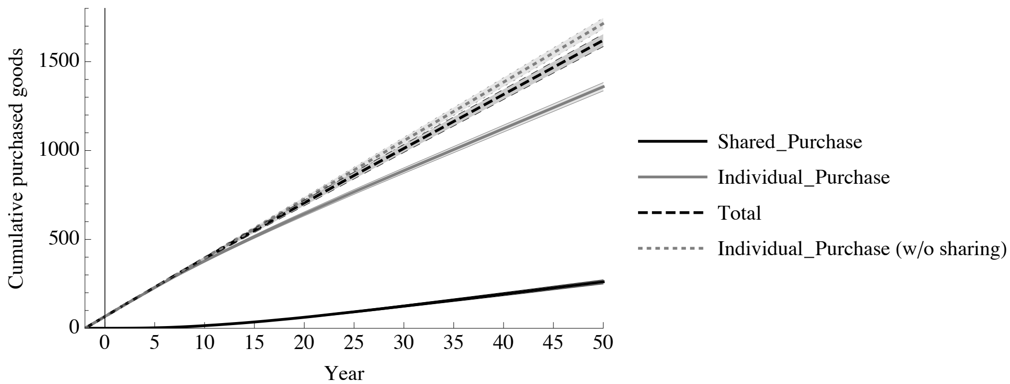
In an economy where, traditionally, consumption choice is based on individual purchase as the only alternative to the public service, the introduction of shared purchase changes consumption decisions, under the conditions defined in Table 4.3. The option of shared purchase is appealing for a portion of the population that used to purchase and consume a good individually and perceives the sharing alternative to be more convenient.

Crucially, the change involves switching from an individual to a shared good and not from the public service to a shared good. The share of agents purchasing individually decreases by around 26%, to about 60%. The share of agents deciding to use the public service remains at about the same level. As a result, shared purchase implies a net reduction in the number of individual purchases, which leads to a reduction in the total number of goods purchased. But by how much?

Goods purchased, either by a group or individually, satisfy agents' needs for a limited time. In the parameterisation in Table 4.3, the capacity of the good is relatively small which would result in a good duration of about 5 years (L_2) in the case of individual purchase and about 2 years (L_3) in the case of group of average size 3 (N). The shorter duration in the latter case, is because use is shared among more than one user and the good depreciates more quickly. After depreciation, the good is replaced by a new individual or shared good.

Given N, L_2 and L_3, we can compute the average number of goods purchased yearly. Before t=0, when approximately 80% of the population uses a good, 32.9 products are purchased annually. This reduces to 23.6 when the ratio of shared purchases reaches its maximum of about 20%. During this period, the consumers in a coalition purchase approximately 6.8 goods per year, reducing by about 2.5 units, the number of goods purchased and consumed each year. This implies that the transition to shared purchase, studied for the case of a specific niche of 200 consumers under specific market conditions (low capacity product), reduces the number of products purchased over 50 years, by more than 120.

Figure 4.7 plots the cumulative number of goods purchased over time, individually (grey solid line), in a coalition (black solid line) and in total (black dashed line), and, also, the number of goods purchased were the shared option not available or if no consumers opt for it (grey dashed line).



Notes: The chart shows the cumulative number of goods purchased in group (black line) and individually (grey line). The sum of the two (black dashed line) is the total goods purchased over time. The grey dotted line plots the cumulative number of purchased good if the sharing option is not available or not chosen. The shaded areas plot the respective 95% confidence intervals.

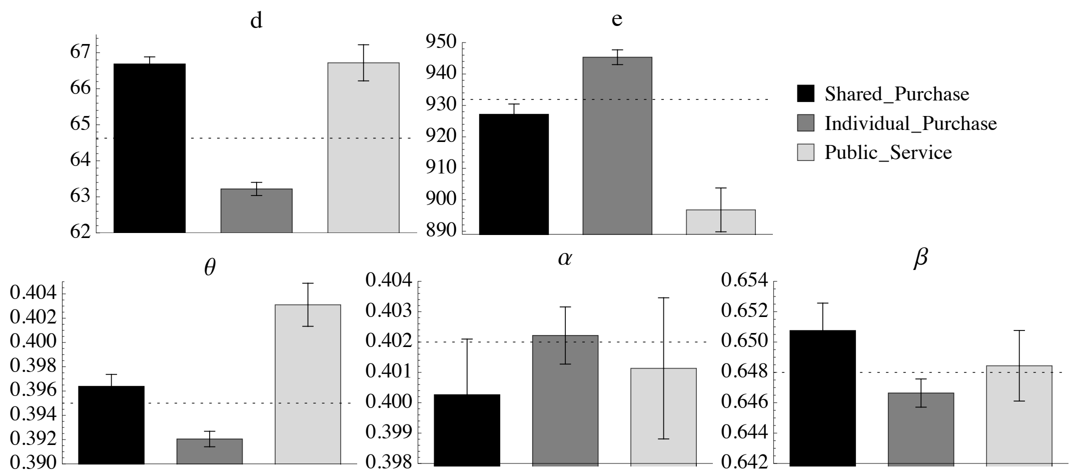
Figure 4.7: Cumulative number of goods purchased and utilised

The results show that, under the configuration that maximises uptake of the shared option, a significantly lower number of goods is produced and used over the 50 years. Annual purchases reduce by 7.4% compared to the number of goods that would be purchased were the shared option not available, or were it not to be adopted. The shared purchase (combined with shared consumption and ownership) leads to an overall reduction in the number of goods purchased, but does not change the number of consumers that have access to the good. It should be noted that the number of goods that are eventually used, depends on both the number of sharing consumers and the time it takes for the transition: a faster transition will lead to a faster reduction in the number of goods produced.

Features of Sharing Consumers

To allow for better targeting of policies to increase shared purchase, we analyse in more detail, which consumers are likely to switch from individual to shared ownership. The sensitivity analysis in Section 4.3.3 shows that the population of consumers with tighter budget constraints and higher demand, is more likely to coordinate for shared purchase. We observe, also, that in this population, consumers prefer smaller coalitions and smaller goods. We now focus on the parameterisation that leads to the highest shared purchase ratio (Table 4.3, column (b)). The results confirm and reinforce the profile of a sharing consumer, based on the sensitivity analysis, and provide some insights into the extent to which these groups of consumers differ.

Figure 4.8 plots the average characteristics of the consumers choosing the three options (shared purchase (black), individual purchase (grey) and public service (light grey) with 95% confidence intervals, and the population mean (dashed line). On average, and compared to the population mean (see Table 4.3, column (b)), agents choosing shared purchase have significantly higher than average demand and lower than average income compared to those choosing individual purchase. Demand of those choosing the shared purchase is not significantly different with respect to consumers that opt for the public service, but their income is significantly higher. Also, the consumers involved in shared ownership have a slightly higher preference for income (θ) – or lower preference for consumption (1-θ), compared to the overall population, but significantly higher preference for income than individual consumers and a lower preference compared to consumers that rely on the public service. Under this specific model configuration, there are no significant differences among consumers with respect to their preferences related to division rules.



Notes: The bar charts show the average characteristics, calculated over the final 240 time periods of the simulation runs, of consumers grouped in relation to their consumption decision: shared purchased (black), individual purchase (grey) and public service (light grey). Top left chart plots consumer demand (d); top right chart plots consumer income (e); at the bottom, in order from left to right, charts plot consumer preference for income (θ), for the division rule based on demand (α) and for the division rule based on contribution (β). Dotted lines represents population means, as in Table 4.3. At the top of each bar we plot the 95% confidence interval.

Figure 4.8: Consumers' features of consumers grouped by their consumption decision

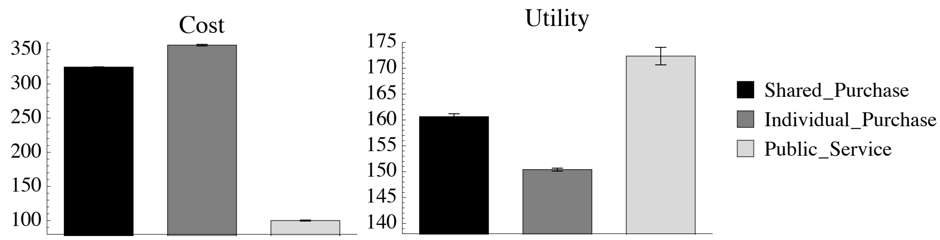
On average, consumers opting for individual purchase have low demand, high income and low preference for income. These are the wealthier consumers that can afford individual purchase to avoid the congestion costs of the public service. The overall cost of the purchase of the good is split evenly over its duration. Because the duration of the good decreases with demand (Eq.4.3), individual purchasers are mainly consumers that use the good infrequently: low demand reduces the cost in each time period. The low level of demand and, therefore, use (for a given contribution to its purchase), may mean that these consumers, also, may find it less convenient to share: the good duration is reduced by the use of other consumers, reducing the benefit to low level users. In the case of good availability of finance, individual purchase is fostered by a lower preference for income and, hence, a higher preference for consumption.

High demand characterises those consumers that choose either shared purchase or the public service. Their higher (but lower than the individual purchaser's) income, allows some of these consumers to buy a shared good, which costs less than purchase of an individual good. Low income makes it impossible to either purchase individually or contribute to a group. The low level of financial resources among this group means that they rely on the public service and have a higher preference for income, compared to the population mean. Their income is the distinct characteristic motivating their choice of the public service.

In a model where consumers only maximise individual utility, shared purchase becomes a third way for those with a preference for an individual good (initial preference), but find it becomes unaffordable. They can increase their utility by joining a coalition. This explains why the transition to shared purchase is driven by individual owners able to choose a less expensive option, while use of the public service remains almost constantly and involves the same share of consumers. Consumers with the highest incomes will pay individually to satisfy their need and will not enter a coalition. Consumers with the lowest level of income cannot afford any kind of purchase and, hence, use the public service.

It is important, also, to recall that, while the utility of consumers opting for the individual purchase and the public service is determined mostly by the direct effect of consumer characteristics (Figure 4.4), in the case of consumers maximising their utility through shared purchase, the interaction among these characteristics that is more important (Figure 4.3). This is because establishing a coalition requires a high level of coordination and the characteristics of the individual consumer interact with those of the others in the coalition.

Consumers opting for the shared purchase face lower costs compared to individual purchasers and experience higher utility. However, since the choice of relying on the public service implies no investment costs, agents choosing this alternative have the lowest overall costs and highest overall utility (Figure 4.9).



Notes: The bar charts show the average consumers' cost (on the left) and utility (on the right), calculated over the final 240 time periods of the simulation runs. In black consumers that chose the shared purchased, in grey the individual purchase and in light grey those choosing the public service. At the top of each bar we indicate the 95% confidence interval.

Figure 4.9: Consumers' cost and utility grouped by their consumption decision

Individual consumers have the lowest utility, but , based on their characteristics (see Figure 4.8), this is the option that maximises their utility. Moving to shared purchase or using the public service would make these consumers worse off. Consumers that rely on the public service experience the highest utility. They pay only for use of the service and congestion does not affect their utility since a total of around 40 consumers (about 20% of the population) still makes its value close to 1 (see Figure 4.1 and Eq.4.1).

4.3.6 Policy Interventions

Assuming a population with consumer characteristics that lead to some consumers switching from individual to shared purchase, as discussed above, we can analyse the product features that could be used by policy to increase the proportion of consumers choosing shared ownership and reduce the number of goods produced and sold. Starting from the model configuration in Table 4.3, we study the effect of varying the service unit price (p_i), and the good sizes (S) and costs (I) that are more likely to involve successful sharing.

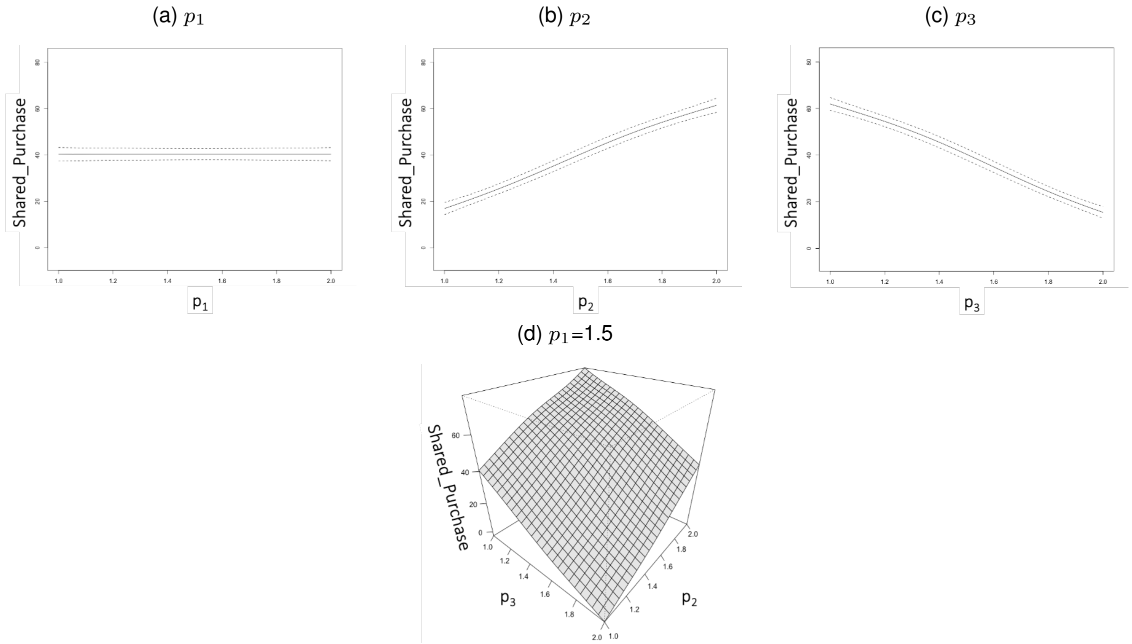
Unit prices

In assuming homogeneous prices, in the foregoing, we have studied whether the same changes to the variable costs have an influence on consumer choice. However, we should also consider the effect policy interventions to regulate these prices (taxes and subsidies), which would introduce price differences among the three options.

We investigate the role of heterogeneous unit prices for the three consumption options. The unit price is the variable cost, in all three options, of accessing the service. In line, again, with the mobility example, if we measure demand in kilometres, p_1 (Eq.4.1) is the cost of a bus ticket covering a given zone, while p_2 (Eq.4.4) and p_3 (Eq.4.5) refer to the variable costs (i.e., fuel, road taxes) of the purchased good. To test the potential impact of policy interventions, we performed a sensitivity analysis on the three prices, for a population whose characteristics lead to a high ratio of shared purchase (Table 4.3). We selected the sampling points via a NOLH DoE where the three unitary prices vary between $\in$[1;2].

Figure 4.10, as expected from a comparison of the three utility equations (4.1, 4.4 and 4.5), shows that the number of sharing consumers increases with the unit price of individual purchase (p_2, chart (b)) and the reduction in the unit price of shared purchase (p_3, chart (c)). The price of the public service (p_1 chart (a)) has no impact on the consumer propensity to share. In other words, in our simple model, a tax that doubles the cost of using a private good, or a subsidy that halves the cost of using a shared good, increases the number of agents choosing the shared purchase by 74% (from about 42 to 73, chart (d)) and reduces the number of individual consumers by around 50%.

The unitary price of buying the service from the public provider has no effect on the number of shared purchases. This confirms that, in our model, the sharing option



Notes: Charts plot the results from the sensitivity analysis on the three unit prices of the three consumption option. On the top we plot the direct impact of the three prices on the total number of consumers that opt for the shared purchase, and 95% confidence intervals: (a) p_1, (b) p_2 and (c) p_3. At the bottom we plot the 3D response surfaces for p_3 and p_2 where p_1=1.5.

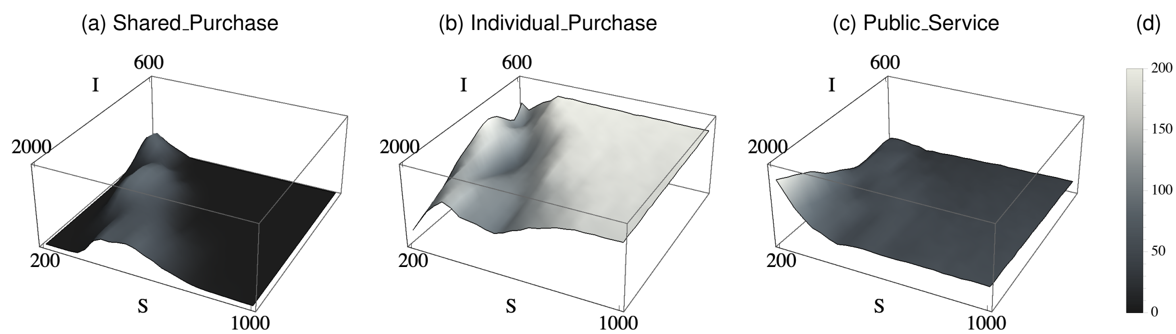
Figure 4.10: Impact of unit prices on the number of consumers in coalition

reduces the use of individual goods without inducing more consumers who use the public service, to purchase in a coalition. The results are similar (results not shown here) for capacity of the general provider (Z). We find that, as the capacity of the public service increases, more consumers use it, which significantly reduces the number of individual purchases, but has no effect on shared purchase.

Good characteristics: Capacity and Cost

Some goods may be more suited to sharing than others. The decision to purchase a good, individually or in group, may depend also on its capacity and cost. We have discussed the important role of size, while cost (I) has been fixed based on the results of the EE procedure (Section 4.3.3). To assess how both of these characteristics influence consumer choice, we run a sensitivity analysis over S and I, for a population with characteristics that lead to a high shared purchase ratio (Table 4.3, column (b)) and under favourable policy conditions where p_1=1.5, p_2=2 and p_3=1. We run a full factorial DoE for sensitivity analysis, where all combinations of good size, $S \in [200; 1000]$, and cost, $I \in [600; 2000]$, are explored, at 25 levels.

Figure 4.11 plots the number of consumers for each of the three consumption options, for different combinations of good capacity and cost. The results are presented on heat charts, where the x-axis measures the capacity of the good and the z-axis its cost, and the number of consumers varies along the y-axis.



Notes: We plot 3D surface for the three consumption alternatives: (a) shared purchase, (b) individual purchase and (c) public service. The x-axis measures the capacity of the good (S) and the z-axis measure the cost of the good (I). The vertical axis plots the number of consumers, between 0 to 200: the higher the surface the higher the number of consumers. Surfaces are also coloured following the black-white scale of the legend (d): black indicates 0 consumers, white 200 consumers.

Figure 4.11: The effect of product's capacity and cost on the three consumption options

The results show that, even in a population of consumers with a likely high proportion of sharing consumers, and under the most favourable policy setting, the number of sharing purchases depends on the characteristics of the good. Large sized goods, regardless of their cost, are purchased exclusively individually (in line with our previous sensitivity analyses, Figure 4.4. Small and expensive goods are not purchased at all: consumers rely on the public service, even if utility is reduced due to congestion.

Shared purchase appeals to consumers in the case of a relatively low capacity good whose cost increases with capacity: the number of shared consumers is maximised when the cost is in the medium range and capacity is low-medium (initialisation in

Table 4.3). Smaller goods are likely to appeal to coalitions and, especially, if these goods cost less. This is because small goods favour the formation of small coalitions, which allow relatively easy coordination of participants' contributions.

The number of sharing consumers increases, also, for increasing good cost as long as the size of the good does not become too large. In other words, as the cost of the good increases, to prompt a coalition requires the size of the good to increase (but at a lower rate), to allow a larger coalition (the highest level of I corresponds to the biggest coalitions size, N=4). As already noted, a larger product capacity requires a bigger consumer coalition, but this is deemed infeasible due to the potential costs of coordination and free riding.

These results are important to inform policy interventions, aimed at promoting shared purchase among consumers for given goods that are particularly polluting. There are some good characteristics that make policy initiatives (such as changing the price) not effective: in the case of goods that might be shared by many consumers, the coordination costs mean that individual purchase is preferred to shared purchase, regardless of the cost of the good or the price of the service. To promote the diffusion of sharing practices related to the purchase of goods, and to reduce the number of goods needed by reducing individual purchases, the best policy option might be to focus on goods with low-medium capacity and medium cost. It may not be effective to nudge people to choose shared purchase of very large products.

4.4 Discussion and Conclusion

In this paper we developed a simple model in which heterogeneous consumers can choose to consume the same service, offered by the public provider or based on purchasing a good. The good can be purchased individually or in coalition with other consumers. In the latter case, cost and use are shared among the consumers in the coalition, and the contribution of each participant is determined based on their preferences, income and demand. The optimal choice for each consumer depends on a number of product and consumer features and preferences – and how they are distributed among the heterogeneous population. The public provider has limited capacity, so the quality of its service depends on the number of its users, but its use entails no additional cost; individual ownership of the good allows large capacity, but at the cost of the price for purchasing the good; shared ownership is positioned in between: the capacity (cost) is larger (higher) than in the case of the public service and is smaller (lower) than in the case of individual purchase of the good.

We use the model to study the conditions under which, in the presence of a public provider, shared purchase of a good is preferred to individual purchase if consumer demand is not satisfied by the public provider. Replacing individual with shared ownership has the potential to increase sustainability of consumption – by reducing the number of goods produced that stand idle and which will need to be recycled – and increases access to the same service for consumers with budget constraints. Examples here include cars for commuting, washing machines, drills for DIY jobs, and holiday accommodation.

In our model, consumer utility and consumer choice depend on the behaviour of the other consumers in the same population, in the current and past periods: this influences the utility of using the public service, and the formation of a coalition to purchase and consume a shared good. These simple interactions generate complex dynamics, which we analysed using an agent-based model and simulating emergent properties for different initial conditions.

Despite the model's simplicity, these interactions are complex. Since we had no prior expectations about the consumer and product features which might influence the distribution of consumer choices in the economy, and which might lead to lower individual consumption. We first studied the full parameter space of the model to identify the product and consumer conditions inducing choice of the sharing option by at least one group of consumers. We identified the parameters with the strongest impact on the number of consumers choosing shared purchase. These include mainly consumers features, such as average preference in the population for income and the sharing rules, demand and income, and size of the good that can be purchased (which also determines the size and duration of the coalition). We ran a global sensitivity analysis to study the impact of all potential combinations of those parameters.

Our exploration of the whole parameter space showed that shared purchase emerges in a relatively low income and high demand population, with somewhat higher preferences for consumption (compared to saving). We found, also, that coalitions emerge in the case of a medium or small good; a too large good requires a large coalition, which makes it difficult to find agreement and incurs higher coordination costs.

Next, to explore the consumer and product features that maximise uptake of shared ownership as opposed to individual ownership, we ran a second sensitivity analysis on this smaller population, defined by a smaller range of the parameters. The results confirmed the above individual and product features. We found, also, that consumers that decide to purchase a good in a group, give careful consideration to the division rules among participants, based on consumption and monetary contributions. We found some interesting trade offs between the consumption and sharing preferences: consumers in coalitions need to satisfy a relatively high demand, so they enter a coalition if the use of the good is decided proportionally to demand and, especially, if they have a higher preference for consumption. We found that those conditions varied for varying sizes of the good purchased.

Overall, we show that, while it is relatively simple to determine the features of consumers that prefer the public service or individual purchase, emergence of the sharing purchase, depends on the interactions among several consumer characteristic for all consumers.

We examined the configuration that maximises the number of sharing users, to study the transition to shared ownership, its impact on the number of goods consumed, and the impact of policies. We found that, in a population where ownership and consumption choices are based on maximising individual utility, shared purchase replaces individual consumption, but does not affect the number of consumers of the public service. The sharing alternative is preferred to individual purchase by consumers who establish sharing groups to share the cost of purchasing a less expensive good of low-medium capacity. Sharing purchase, ownership and consumption of a good reduces inefficient individual utilisation of resources. In fact, under specific population characteristics, shared purchase reduces the overall number of products in the economy, allowing consumers to satisfy their demand, maximise utility and increase access to goods, while enabling a more sustainable model of consumption.

Finally, by exploiting the population configuration that maximises uptake of the shared option, we explored a potential policy instrument, which might influence consumer behaviour and reduce the number of goods purchased, by modifying the price of the different options using taxes and subsidies. Reducing the relative price of using the shared good with respect to the individual good, can push more consumers to share, but the price of the public service does not affect the choice made by sharing consumers. We found that the capacity and cost of the good are critical and our results suggest that policies may not be effective for influencing uptake of shared purchase for all goods. Consumer groups are unlikely to emerge in the case of very large goods since this would require very large coalitions, which would be difficult to coordinate. However, the likelihood of joining a coalition and purchasing a joint good increases with low-medium size of the good, regardless of its cost. In fact, as the cost increases, consumers may find it more convenient to share the purchase.

Note that, to avoid results being driven by sustainability preferences the model does not include consumer preferences related to sustainability. Our results indicate that, even in the absence of sustainability concerns, some consumers might still find sharing a good more attractive and, especially, in the presence of policies that make it more convenient.

To put these findings in context, let us consider the case of shared mobility in an urban context. Individual ownership and use of private cars may not be sustainable and, in many cities, generate negative environmental externalities (Camagni et al. 2002). Catering for all mobility needs by public transport is difficult and, in most cases, public transport provision is inefficient (Murray 2001, McLeod et al. 2017). Buses, trams and subways often do not extend to all urban neighbourhoods and suburbs and are stretched to capacity in periods of high demand such as rush hours. Individual car ownership is among the most frequent options to satisfy travel needs, such as commuting, but is not affordable for everyone (Sheller & Urry 2000, Urry 2006). Car-sharing schemes, already operating in some large cities, are aimed at reducing use of private cars by increasing efficient utilisation of shared cars. However, although these systems allow greater flexibility, they are more similar to public transport, since users pay per use (as in the case of buses or the metro), and access to shared cars may be susceptible to congestion.

The possibility for groups of people to organise themselves in communities and to purchase a car collectively, has several advantages. In addition to reducing the individual cost of satisfying travel needs, compared to the individual ownership, it reduces the number of cars, thereby, increasing the sustainability of the city. However, there may be a need for appropriate policy interventions to promote shared purchase of cars. Regulators could propose incentives or lower tariffs related to shared cars (e.g., parking authorisations, refuelling, insurance, etc.) or could increase the cost of individual ownership and use (e.g., congestion taxes). The promotion of shared ownership and use of cars might persuade users to choose this consumption alternative, while, at the same time, reducing demand for public transport and, thus, congestion. Of course, increasing the capacity of public transport would have an even greater impact on reducing the number of individual cars, but many users may continue to need flexibility with respect to space and time and, especially, those living in areas with less efficient or safe public services.

Nevertheless, our results suggest that tailored policy interventions could be effective for persuading the small consumer niche that would benefit most from shared purchase of a car. That is, consumers with relatively lower incomes and high demand. In many large cities, these characteristics corresponds users in suburban areas with many commuters and reduced access to public transport. Shared purchase could enable consumers in these areas to reduce their transportation costs and increase their transport efficiency. Shared purchase is also more inclusive.

In practical terms, shared purchase of a car would need to be accompanied by specific instruments, which, so far, are not available. It would need appropriate legal conditions to facilitate group purchase, including shared car insurance, and market conditions that would promote shared purchase as a viable option. Shared purchase would open market opportunities for the car manufacturing industry and enable new business models to accompany the rapid transformation already happening in this sector. For example, if the estimates are correct, new autonomous or driverless cars will soon be available in the market, but at prices which will be prohibitive for the average user. These new types of vehicles have the potential to satisfy large demand, to have a positive impact on urban mobility and to enable flexible use. To increase adoption and diffusion of next-generation vehicles, the industry should consider promoting shared purchase.

Chapter 5

Conclusions

5.1 Summary and Key Findings

In this thesis, I studied whether sharing the consumption and ownership of goods could contribute to sustainability. Potentially, shared consumption should be more efficient since the same consumer needs are satisfied by a smaller amount of good, which reduces the environmental impact. Shared ownership of a good can promote more affordable access to essential services, since it offers a cheaper and higher utility consumption option and increased inclusiveness towards ownership. Moreover, efficient model of consumption may also alleviate the pressure on the public sector to provide those essential services.

The literature considers different models of shared consumption and ownership, ranging from public goods to club goods and shared private goods. For example, the sharing economy literature studies shared consumption of goods and highlights more efficient consumption. However, consumption models based on the sharing economy are characterised by individual ownership of a good, which can lead to polarisation and concentration of ownership and accumulation of resources in the hands of a few, and increased inequality. The literature on fractional ownership studies cases of shared consumption and shared ownership among consumers, but focuses on luxury goods that do not provide essential services.

My doctoral research project has examined how the sharing of both consumption and ownership of a good could enable sustainable models of consumption. I investigate whether these models can provide the benefits related to shared consumption, discussed in the sharing economy literature, while reducing the risks of inequality, based on the practices discussed in the fractional ownership literature.

If consumers organise to adopt a shared good and to share both consumption and ownership, sharing can contribute to sustainable consumption. Therefore, it is important to understand the conditions that lead consumers to share. We need, first, to understand how groups of consumers form with the aim of collective adoption of a shared good. We need, also, to understand whether diffusion benefits consumers so that they have an incentive to share.

Consumption and ownership models related to shared goods include alternative options for consumers to satisfy essential needs. For example, energy needs are satisfied by the centralised energy grid, but consumers may organise in a group to adopt a Decentralised Energy System (DES), allowing them to produce and consume independently the energy they need. Consumers can satisfy their travel needs by using public transport or buying and owning a private car. However, they could also choose to organise in a group to share the purchase and use of a car, thereby increasing consumption utility at a lower consumption cost for the same level of demand satisfaction. In addition, the whole population could benefit from the diffusion of shared goods that are sustainable (such as DES which have a high share of renewable energy technologies) or a reduction in the number of individual goods that are used inefficiently (such as private cars which are idle for most of the time).

My interest in studying the impact of shared consumption and ownership on sustainability, drawing on different streams of work on sharing, has highlighted the need to understand how sharing groups are formed. This has led to my three research questions:

- **RQ1: Do fractional ownership and sharing economy differ, and what are their conceptual and theoretical roots?**
- **RQ2: How does the diffusion of a shared good coevolve with the formation of a consumer coalition?**
- **RQ3: Do consumers shift from an individual good to a shared good?**

Chapter 2 addressed RQ1, based on bibliometric analysis of publications on fractional ownership and the sharing economy and how sharing is conceptualised and theorised in both of these literature streams. Shedding lights on the literature on fractional ownership reveals aspects of the literature on sharing economy that suggest reasons why this body of work does not propose models based on shared consumption and ownership. The sharing economy literature is based on the notion that consumers engage in sharing practices motivated by the sense of ownership they feel when they buy individual temporary access to the good, when needed. Goods are owned individually, which gives the owners rights of exclusion over the common resource (i.e., anticommons). Further, consumers do not establish sharing groups to exploit the benefit of cost-sharing because the sharing economy provides them with access to the good at a lower price than if they were purchased by the group.

What is missing from the sharing economy literature is any investigation of the role of shared ownership and the benefits it provides to consumers. The properties of sharing economy and fractional ownership can be derived from the dialogue between these two literature streams. This reveals the conditions that give consumers alternative access to the good, as in the sharing economy, by exploiting the (social and economic) benefits of shared ownership of the good. One example is the discussion in the sharing economy literature of grassroots innovation, which links to discussion of local energy communities in the fractional ownership literature. Sharing communities, such as energy communities, are established to adopt a sustainable good that is not affordable by the average individual consumer. The diffusion of shared goods adopted in a coalition of consumers is the focus of Chapter 3 which addresses RQ2.

I draw on the case of a DES, whose diffusion is desirable because of the environmental (use of renewable energy technologies) and technological (more efficient use and production of energy) benefits. A local energy community is necessary in order to share the cost of ownership of a DES. Shared consumption of its output has the potential to increase consumer utility since users satisfy their energy demands at a lower cost than buying from the centralised energy grid. The Agent Based Model (ABM) simulations show the complex interplay between coalition formation and diffusion of a shared good (such as a DES). Diffusion is conditioned by the preliminary formation of a coalition, which, in turn, affects diffusion since adoption changes the structure of the social network among consumers. Consumers form a coalition to adopt a shared good to satisfy a demand that could be satisfied by the public service. In this case the high price of the shared good is affordable only by purchase in a group. Shared goods that are indivisible and non-movable, must be located close to the final users, and replacement is not possible.

Thus coalition formation is a necessary condition for the adoption of a shared good and, at the same time, is also an obstacle to its complete diffusion. The results show that there can be widespread adoption of a shared good, despite the need to establish a coalition beforehand. The smaller the neighbourhood that the shared good can serve, the lower will be the share of adopters. Agents that do not enter the coalition at an early stage remain isolated, outside the already formed coalition and too distant from agents not yet in a coalition. This geographic constraint limits the spread of information about the new shared good and hampers its diffusion before consumers have been able to assess the convenience related to joining a coalition.

Shared goods can reduce the number of individual goods, which increases sustainability, as in the example of private car ownership and congestion in urban areas. In Chapter 4, I study the reduction in the number of individual goods via models based on both shared consumption and shared ownership. Chapter 4 extends the ABM model proposed in Chapter 3 and addresses RQ3. The model relaxes some of the model assumptions and studies a (shared) good that is movable and affordable individually, but which depreciates and, hence, needs to be replaced. I explored the whole parameter space of the model to identify the conditions under which consumer characteristics and the characteristics of the shared good make sharing a viable alternative to ownership of an individual good, in the presence of a public service.

The transition from consumption models based on individual ownership to models of shared ownership is not rapid. Under the model assumptions, wealthier consumers will continue to purchase goods individually, regardless of the provision of the same service by a public provider or the option to share the purchase with others. At the same time, low-income consumers lack sufficient income to invest in either individual or shared ownership. However, there is a niche of consumers that previously were individual owners of the good (hence, those with sufficient income), that opt for the shared good in order to save money and increase consumption utility. The model findings show that the transition to shared ownership is faster in the presence of policies (taxation) that increase the consumption price of the individual good or (incentives) that lower the consumption price of the shared good. However, policy may be ineffective if it targets goods which do not promote coalition formation, that is, goods with high capacity that require large coalitions which are more difficult to coordinate and manage.

5.2 Contribution to the Literature

This thesis contributes to the literature on the sharing economy by studying how to exploit its positive aspects without increasing inequality. I draw simultaneously on both the sharing economy and the fractional ownership literatures, to establish a conceptual base to investigate sharing practices that are more sustainable. Sharing practices that combine both shared consumption and shared ownership can be more sustainable since the shared good is used more efficiently, which reduces its environmental impact. Also, consumers gain more affordable access to goods that provide essential services which increases inclusiveness and equity of ownership.

This thesis contributes to the literature on diffusion by studying the adoption of goods, driven by a collective adoption decision and not by an individual decision as in the traditional diffusion models. It contributes, also, by showing that the collective adoption decision is subject to the previous formation of a coalition of consumers, not part of a pre-existing group, but which come together with the aim of sharing consumption and ownership. The novelty with respect to existing modelling literature is that I propose an evolutionary ABM to study the diffusion of a shared good in a consumer coalition, by combining elements from innovation diffusion, collective action, coalition formation and network formation theories.

I use a novel global sensitivity analysis method which allows exploration of the whole parameter space of the model and identification of where diffusion in coalition is more frequent. The implementation of these new methodological tools contributes to handle the typical complexity of social systems (Kirman 1992, Arthur 1999) that is modelled in highly parameterised ABM, which are difficult to analyse. That is, the difficulty to analyse simultaneously the combined effect of several parameters on the model outcome. The use of the global sensitivity analysis to determine the parameter space to investigate, allows to better choose the space where the phenomenon under scrutiny may occur and is more relevant. This is what economists call a *niche*, that is conditions under which certain changes may emerge in the society, hence where a favourable combination of factors determine the possibility of the innovation to emerge and prosper.

This is the case of the two specific empirical phenomena that I model in this thesis. DES are energy infrastructures that already exist and can be deployed widely if supported by a favourable policy framework. The latter considers those infrastructures pivotal to the green transition, being instrumental to move from a fossil-fuel based centralised energy system to a decentralised one based on higher share of renewable energy technologies, key elements in DES. This thesis contributes to show that, in a favourable policy and technology context, DES can be diffused via community-ownership, under given conditions. These conditions may be crucial for policy makers to design policies to incentivise adoption.

The second phenomena that I analyse in the thesis is the practice of sharing a smaller good, such as car, but that does not concern car sharing schema running under the sharing economy. In this thesis I contribute to the concept of sharing a single car among a group of consumers (e.g., friends, neighbours or households), which is a long-standing practice in relation to several goods that cannot be afforded by a single user, and whose service can be shared (as they often remain idle). In a regime based on private ownership and public transport, I show that sharing a car can be a suitable option for a *niche* of consumers in the population, which gains extra benefit, such as increased utility and lower travel expenditure. In particular, those owning a car individually in the past are the consumers more inclined to share a car than those using the public transport, and they will do it in small sharing groups. This shows that the decision to share a car is not always a direct substitute of the decision to use public transport. This may be a consequence of the fact that not all individuals have a driving license or have monetary resource to make a purchase, hence they have the public transport as the only viable transportation option.

This thesis also contributes to the growing literature on sustainable consumption, in line to the Agenda for Sustainable Development of the United Nations proposing to do more and better with less. I show that it is possible to satisfy the same consumption needs with less resources keeping (affordable) access to essential goods and services to all, even when, as in the model, consumers are not driven by sustainability concerns nor preferences. The thesis shows that fractional ownership has the potential to lead to higher sustainability. Nevertheless, it is important to understand that these sustainability effects only concern a restricted part of the economy, and therefore have a small impact on emissions. In this context, it is important to consider the rebound effect that reduce the sustainability benefits when savings generated by fractional ownership are spent for more consumption (Binswanger 2001, Sorrell & Dimitropoulos 2008). In fact, consumers that shift to another convenient consumption option (e.g., decentralised energy or shared car) may decide to increase their consumption at the same total cost of the previous option. This would be interesting to test by extending the model to a more dynamic and endogenous change in agents' demand.

5.3 Policy Implications

The findings from this thesis suggest several policy implications about how sharing the consumption and ownership of goods can contribute to sustainability.

Improved understanding of models of shared consumption and ownership

For policy makers and organisations interested in facilitating models of shared consumption and ownership, this thesis should provide a better understanding of the foundations of the sharing economy. Chapter 2 acknowledges and reinforces the sustainability nature of sharing practices and highlights the importance of policies and strategies to promote not just shared consumption, but also shared ownership in line with the principles of cooperation and empowerment. The findings shed light, also, on the existence of a common area where the properties and benefits of shared consumption and shared ownership are combined. Policy makers should focus on this when developing new measures to promote and benefit from the sharing economy. They should aim, also, at reducing the risks of ownership polarisation and inequality through the promotion of social structures intrinsic to collective psychological ownership. Policy frameworks supporting community energy initiatives, such as grassroots innovations for sustainability, are an example of how governments could promote more sustainable and socially fair models of ownership and consumption.

Improve diffusion in consumers' coalitions with higher people coordination

The findings in Chapter 3 show that diffusion of a shared good can be hindered by the problems related to coordination of coalition members. This could result in the stakeholders in the sharing economy to reconsider the role of digital platforms, which, currently, are the main means of mediating transactions between consumers and providers. Platforms could play an important role in facilitating the formation of groups of consumers willing to share both consumption and ownership of essential goods and enabling preliminary matching of consumers' characteristics (e.g., preferences and needs), and connecting the provider of the good to be shared. This would create a space for new business models for service providers and offer consumers additional consumption options, to obtain the maximum benefits from the sharing economy. Policy makers should provide regulatory support (i.e., data gathering and sharing rules) for the development of platforms that meet the coordination needs of sharing groups and allow providers to supply the shared good to be adopted by the group.

Increase affordable access with sharing communities

The results of the agent-based simulations, in Chapters 3 and 4, show that the adoption of a shared good in a coalition could increase affordable access to goods for essential services. This highlights the importance of bottom-up community-led initiatives to diffuse sustainable models of shared consumption and ownership. Therefore, in the context of the transition towards a more sustainable economy, the models developed in this thesis suggest that policy makers should stimulate citizen engagement and consumer empowerment to increase affordable access to goods.

For example, understanding the impact of community-led initiatives for the adoption of shared goods, would support policies related to the development of rural areas, where shared ownership may help to reduce energy use, transport and digital poverty. Supporting the formation of rural communities could provide less advantaged and more vulnerable consumers with access to essential goods and services, in more affordable and sociable ways. Sharing resources, as if they were commons, can reduce the isolation of rural communities and give them the possibility of cheaper and more sustainable consumption solutions.

Assessment of network, consumers and goods' characteristics to improve diffusion

The ABMs developed in this thesis can be used to assess the impact of the network characteristics on the diffusion of not movable and expensive shared goods (Chapter 3), and the effect of the characteristics of consumers and goods on the diffusion of less expensive and movable shared goods (Chapter 4). The findings suggest that, in order to promote sharing initiatives and to diffuse models of shared consumption and ownership, it is important to consider the type of shared good which the community wants to adopt. To support the diffusion of goods, such as DESs, policy makers should remove the barriers to diffusion by focusing on consumers that are proximate and can easily connect to each other. Moreover, the adoption of movable goods, such as shared cars as an alternative to private cars, could be boosted by targeting smaller coalitions of consumers with sufficient budget to invest in a common purchase and that have a high demand for the service. This implies that understanding consumer preferences and characteristics in relation to the shared good that provides the service and which they want to adopt, is pivotal to the implementation of successful policy initiatives.

Insights into the impact of pricing policies

Chapter 4 provides some useful insights into the impact of monetary benefits, such as cheaper prices, related to the consumption of the shared good, on the consumers' utility from sharing. The results show, also, that a tax on the individual consumption of a good can increase the number of shared goods. These findings should help policy makers to assess the costs and benefits of pricing policies. For example, promotion of the shared ownership and consumption of cars or of hand drills may require different policies. Reducing the number of private cars is high on many national and international policy agendas as a way of increasing sustainability in urban areas and improving living conditions. However, the current high diffusion of private cars means that monetary policies to encourage consumption and ownership of shared cars would be expensive. In contrast, policy initiatives to reduce individual ownership of goods, such as hand drills, would be fairly inexpensive, but would not lead to increased sustainability. Therefore, while the latter policy measures would be cheaper, the former are more desirable because they would have a greater effect on sustainability. Policy makers should focus on the diffusion of shared goods with the best cost-benefit ratio.

5.4 Limitations and Future Research

Future research could address some of the limitations of this thesis and analyse other aspects.

Network geography and links

The geography and the connections among consumers need further study. Although I examined both regular (Chapter 3) and random networks (Chapter 4), all agents are homogeneous in term of their geographic constraint, meaning that all agents always have the same number of possible links. To simulate real life social networks, each agent could have a different geography in relation to the numbers of links. Making the formation of the social network endogenous to the different individual links, would allow analysis of the role of hubs in the coevolution between coalition formation and diffusion, for instance. Hubs are network nodes characterised by higher numbers of links. *Are hubs enablers or inhibitors of the diffusion of shared goods in coalitions?* The model could be extended by characterising the type of link associated with each agent. This would allow investigation of the impact of agents' social proximity on the formation of coalitions and diffusion of shared goods. *Does the type of social connection (i.e., the links between relatives, neighbours, friends or strangers) change the willingness to share and collaborate?* Studying both different agents' geography and types of links could provide useful information for policy makers related to ways to boost shared ownership and consumption.

Empirical bases for consumers' characteristics and preferences

The findings from this research show that consumption preferences and the consumer demand for a service have a strong effect on the adoption of a shared good. We know, also, that consumer income affects consumption choices and attitudes to sharing. The model could be extended by adding parameters related to other consumer characteristics. These could be latent variables (i.e., consumer perceptions, attitudes and lifestyles) and socio-demographic characteristics (i.e., consumer age, education level, household composition). *Do socio-demographic characteristics affect consumer connectivity and coordination? How does this in turn affect the diffusion of the shared good in a coalition?* To address these questions, it would be necessary to complete and test the model with empirical data. Future research could identify pilot projects where community-led initiatives are implemented to share common resources. For example, it would be interesting to collect data on local energy communities related to the adoption of a shared good in a coalition. Surveys of consumers' characteristics and preferences could provide empirical information to calibrate the agent-based simulations. Such empirical experiments should be run in various geographical contexts and in relation to various types of shared goods.

Coalitions of coalitions

The ABMs developed in this thesis aim to simulate the collective adoption decision process of a single good that has to be shared (i.e., owned and consumed) by a group of consumers that coalesces beforehand in a stable coalition. This is a narrow example of sharing practice that may occur in small groups of consumers. But these models may be further expanded to study other important phenomena, like the emerging of car sharing cooperative in Switzerland and in Germany. In both countries, car sharing developed in the form of small users' cooperatives that owned one or more cars were membership allowed the use the shared cars. Over time, small cooperatives have joined together assets and members, growing to the point of having big national car sharing cooperatives. Therefore, an important extension to this model of coalition formation and adoption and diffusion of shared goods would be (i) to allow coalition formation co-owning multiple items of the same good, and (ii) to allow the formation of coalitions of existing coalitions. The first extension would enable coalition members to purchase more than one good in order to satisfy a higher demand, under the condition that this option will make all participants better off. Once a number of coalitions are established, the second extension could be modelled by reopening the options to the group to allow for the entry of new members, including entire coalitions. This would make the model even more dynamic and realistic, accommodating several more options of sharing.

Policy Scenarios

Another direction for future research would be to study the contribution to policy of the adoption and diffusion of a shared good in a coalition. In recent years, policy initiatives have been proposed to support the formation of local communities since these boost citizens' engagement and consumers' empowerment and contribute to the energy transition. It would be interesting to define future energy scenarios and to set specific targets for the contribution of communities to the adoption of renewable energy technologies. *To what extent does the diffusion in a coalition contribute to energy targets?* Future research could analyse whether and how the diffusion of shared goods in coalitions would contribute to those scenarios/targets, and whether nudges (to change agents' consumption preferences) or pricing schemes, could contribute to faster achievement of those objectives.

Legal Standards for Shared Goods

Transfer of the ownership of goods is legally regulated by transactions in the market. Individual adoption is determined by the consumer that buys the good from a provider that sells the good and transfers the ownership. In the sharing economy, although there is no transfer of ownership, the market regulates consumers' access to goods that providers make available for a short time for a rental payment. *What is the legal standard to sell and purchase shared goods in consumers' coalition?* Therefore, future research could study the legal standards that support the diffusion of shared goods characterised by both shared consumption and ownership. This is important because, unlike individual purchase and the sharing economy, which involve exchanges with individual consumers, shared goods need to be purchased and owned by a group of consumers. Consumers may be more reluctant to join a sharing group if there is no clear basis for regulating the sharing practices.

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Appendix A

Annexes

A.1 Annex to Chapter 2

A.1.1 Data Clean-Up Process

To highlight the issues encountered in the dataset of publication, I will consider the manuscript by Russel Belk published in 2014, entitled “You are what you can access: Sharing and collaborative consumption online” (*Journal of Business Research* vol. 67, p. 1595). Based on this bibliographic information, this publication should be identified uniquely in the network as a node labelled with the string *Belk_R(2014)V67:P1595*. Unfortunately, references to this publication are reported in various ways as shown in Table A1. If raw data are used with no further data harmonisation, the six CR for this publication are represented by four different network nodes, each labelled with a different string. The data cleaning process aimed to harmonise bibliographic information for a given publication in order to obtain a single node labelled uniquely. In the example, all six references are harmonised with the string in the last column of the last raw.

Author	Year	Journal	Vol	Page	String
Belk R.	2014	J BUS RES			Belk_R(2014)
Belk R.	2014	J BUSINESS RES			Belk_R(2014)
Belk R.	2014	J BUSINESS RES	V67		Belk_R(2014)V67
Belk Russell	2014	J BUS RES		P1595	Belk_R(2014)P1595
Belk R	2014	J BUS RES	V67	P1595	Belk_R(2014)V67:P1595
Belk Russell	2014	J BUS RES	V67	P1595	Belk_R(2014)V67:P1595

Table A1: Belk's publication as cited in different ways

A.1.2 False Negative

The historical expansion of the citation network via search communities with false negatives is summarised in Figure A1. Circular nodes represent publications (CP) downloaded using keywords search. Triangular and square nodes (CR) represent works cited by circular nodes. Square nodes are identified as key publications based on the high number of citations. These are transformed to CP, meaning that a further search was run to extract their CR, visualised in the figure as diamond-shaped nodes.

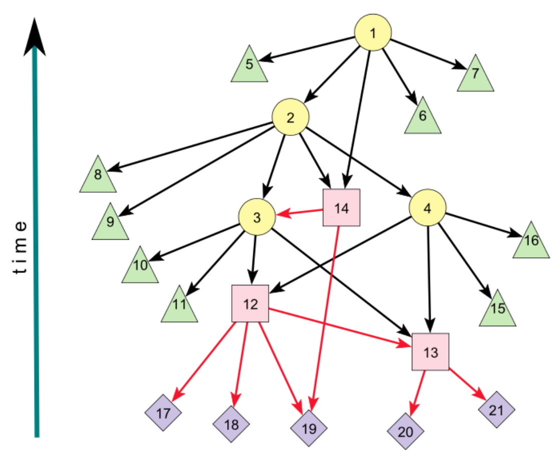

Figure A1: Citation network structure (Batagelj et al. 2017, p.506)

A.1.3 Traversal Counts and Key-Route Main-Path

Figure A2 illustrates three ways to select the main-path in a network based on traversal counts of the links between nodes. The traversal count of the link B-E has the value 4 since there are 4 paths going through this link: B-E-F-H, B-E-G-H, B-E-G-I and B-E-G-J. The local main-path starts from the source nodes (A and B) and goes to the sink nodes (H, I and J), following the links with the highest traversal counts. The global main-path selects the paths with the highest sum of traversal counts. The key-route main-path first selects the links with the highest traversal counts, for example, those with values higher than or equal to 4, then continues towards the source and sink nodes by going through those links with the highest traversal counts.

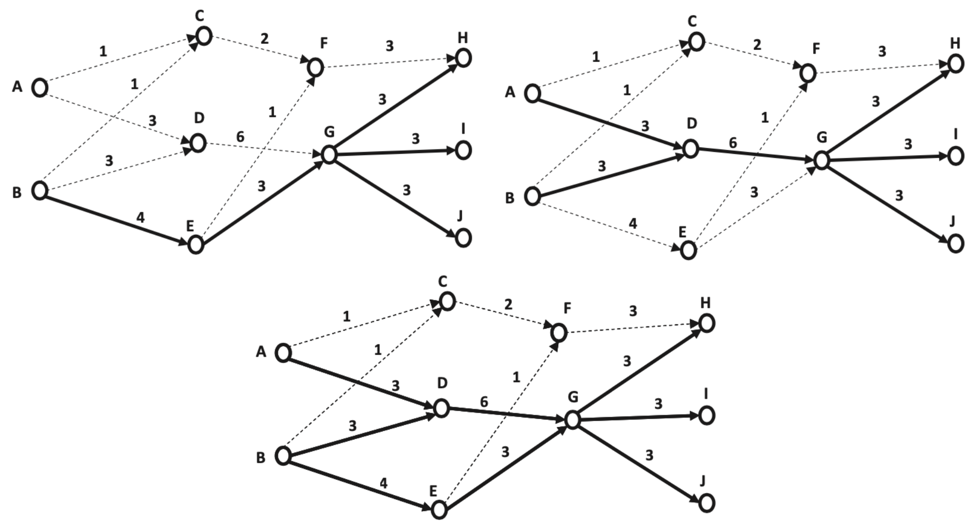

Figure A2: Search Path Count: local (top-left), global (top-right) and key-route (bottom) main-path (Xiao et al. 2014, p.596-597)

A.1.4 Preprint Transformation

Figure A3 illustrates how preprint transformation modifies the network and the links among publications (nodes) citing each other in the same year. This transformation added two preprint publications to the publications that cite each other and were published in the same year. The original publications now cite their own preprint and the preprint version of the other publication.

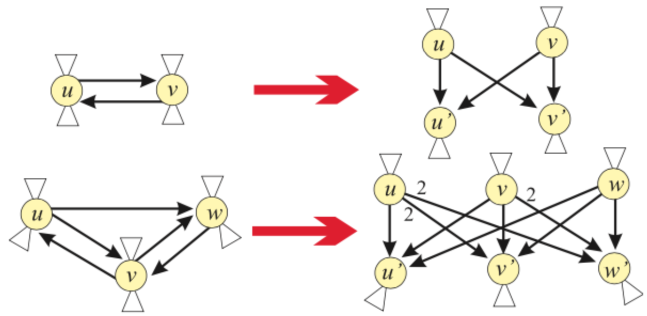

Figure A3: Preprint transformation (Batagelj 2003, p.9)

A.1.5 Labels of Clusters Identified via the Co-Word Analysis

Table A2 and Table A3 present the list of cluster labels identified by the Leiden algorithm. These are based on the top three most frequent terms in publication titles and abstracts. The table reports, in order from left to the right, the label of the cluster, the total number of citations, the number of nodes (or publications) and their ratio for each cluster.

Label	Cit.	Node	Ratio	Top 3 terms per cluster	Occur-rences	Rele-vance
ESOP	246	24	10.25	Employee Stock Ownership Plan	9	1.29
				ESOP	12	1.24
				Firm	13	1.10
Employee Ownership	910	50	18.20	Effect	17	1.31
				Employee Ownership	28	1.16
				Study	16	0.53
Theory of Firm	530	43	12.33	Ownership	27	1.05
				Theory	19	1.05
				Firm	20	0.89
Psychological Ownership	374	28	13.36	Psychological Ownership	16	1.29
				Ownership	16	1.10
				Organisation	16	0.61
Productivity Effect	675	44	15.34	Firm	28	1.40
				Productivity	15	1.21
				Effect	21	1.18
Commons	95	10	9.50	Common	5	1.33
				Resource	5	0.83
				Tragedy	3	0.83
Ownership Control	550	36	15.28	Ownership	17	1.43
				Firm	17	0.91
				Control	11	0.66
Competitive Effect	277	31	8.94	Competitive Effect	5	2.15
				Effect	10	1.25
				Mutual Fund	7	1.19
Timeshare	207	34	6.09	Study	21	1.39
				Timeshare	14	0.98
				Timeshare Industry	14	0.64
Participation	117	16	7.31	Firm	6	1.62
				Evidence	6	1.58
				Financial Participation	6	0.82
Social Capital	58	6	9.67	Firm	3	1.00
				Social Capital	4	1.00
				Trust	3	1.00
Governance	92	14	6.57	Internal Governance	2	3.93
				Market Economy	2	1.98
				Incidence	2	0.96
Business Group	80	11	7.27	Business Group	2	2.69
				Chile	2	2.69
				Evidence	2	2.69
Property Right	175	15	11.67	Resource	8	1.39
				Property	7	1.37
				Property Right	5	0.24
Energy Community	78	15	5.20	Community	11	1.44
				Renewable Energy	9	0.98
				Paper	6	0.58

Table A2: Labels of clusters in FO literature identified via co-word analysis

Label	Cit.	Node	Ratio	Top 3 terms per cluster	Occurrences	Relevance
Framing Sharing Economy	6740	113	59.65	Economy	78	1.71
				Study	56	1.35
				Sharing	41	0.85
Hospitality	3217	94	34.22	Study	64	1.54
				Airbnb	58	1.43
				Accommodation	38	0.58
Carsharing	1547	67	23.09	Car Sharing	23	2.25
				Car	44	1.54
				Carsharing	32	1.23
Possession	593	27	21.96	Consumer	12	1.23
				Article	11	1.07
				Possession	9	0.70
Labour	320	27	11.85	Worker	19	1.27
				Work	19	1.13
				Platform	16	0.60
Trust	995	48	20.73	Trust	40	1.76
				Model	24	1.12
				Study	25	0.99
Acceptance	439	19	23.11	Order	3	2.93
				User Acceptance	4	2.04
				Usage	5	1.68
Platform Economy	670	33	20.30	Platform	23	1.43
				Economy	13	0.78
				Firm	13	0.78
Review	320	20	16.00	Review	16	1.41
				Study	15	1.41
				Mouth	9	0.18
Business Model	465	28	16.61	Business Model	26	1.44
				Literature	15	1.13
				Firm	11	0.44
Product Service System	377	24	15.71	Product Service System	18	1.52
				Pss	15	1.37
				Consumption	15	0.61
Access Ownership	324	18	18.00	Access	11	1.29
				Service	10	1.02
				Ownership	8	0.69
Innovation	218	18	12.11	Article	7	1.22
				Change	10	1.22
				Innovation	9	0.56
Platform	686	33	20.79	Study	19	1.37
				Paper	12	0.82
				Platform	16	0.82
Rating	337	19	17.74	Airbnb	6	1.49
				Rating	7	1.49
				Ebay	6	0.02

Table A3: Labels of clusters in SE literature identified via co-word analysis

A.2 Annex to Chapter 3

A.2.1 Properties of the Utility Function

The utility function related to the shared option (U_{i2}, Eq.3.6) includes two parameters, α_i and β_i, allowing for the linear combination of three elements. The first element, $\frac{d_i}{d_i+D_{-i}}$, is the approximate percentage of the total service, S, provided by the shared good and consumed by agent i in coalition (see Eq.3.8). The second, $\frac{x_i}{x_i+X_{-i}}$, is the approximate percentage of the value I of the shared good, purchased by agent i in coalition through the monetary contribution (x_i, see Eq.3.7). The third element, $\frac{1}{N}$, represents the equal split of the service based on the number of coalition members. Then Eq.3.6 can also be written as:

$$
\begin{aligned}
U_{i2}(e_i; c_{i2}; d_i; D_{-i}; x_i; X_{-i}; N; \theta_i; \alpha_i; \beta_i) = \\
= (e_i - c_{i2})^{\theta_i}\{\alpha_i d_i + x_i \frac{d_i + D_{-i}}{x_i + X_{-i}}(1-\alpha_i)\beta_i \\
+ \frac{d_i + D_{-i}}{N}(1-\alpha_i)(1-\beta_i)\}^{1-\theta_i}
\end{aligned}
\quad \text{(A1)}
$$

Eq.A1 implies that, by neglecting the effect of α and β, the agent's utility function in coalition, along with the money saved from individual income (first part of the equation), depends on the linear combination of (i) the individual demand for the service, (ii) the return from the common purchase (total service produced, $d_i + D_{-i}$, divided by the total cost spent to purchase the shared good, $x_i + X_{-i}$) multiplied by the individual monetary contribution committed in the common purchase, and (iii) the total service produced by the shared good split equally among coalition members.

Figure A4 shows how the parameters of the utility function, *cœeteris paribus*, influence the agent's utility in coalition (U_{i2} vertical axis) and the monetary contribution (x_i horizontal axis), and their relation.

A high level of θ_i indicates that an agent has a higher preference for income (and

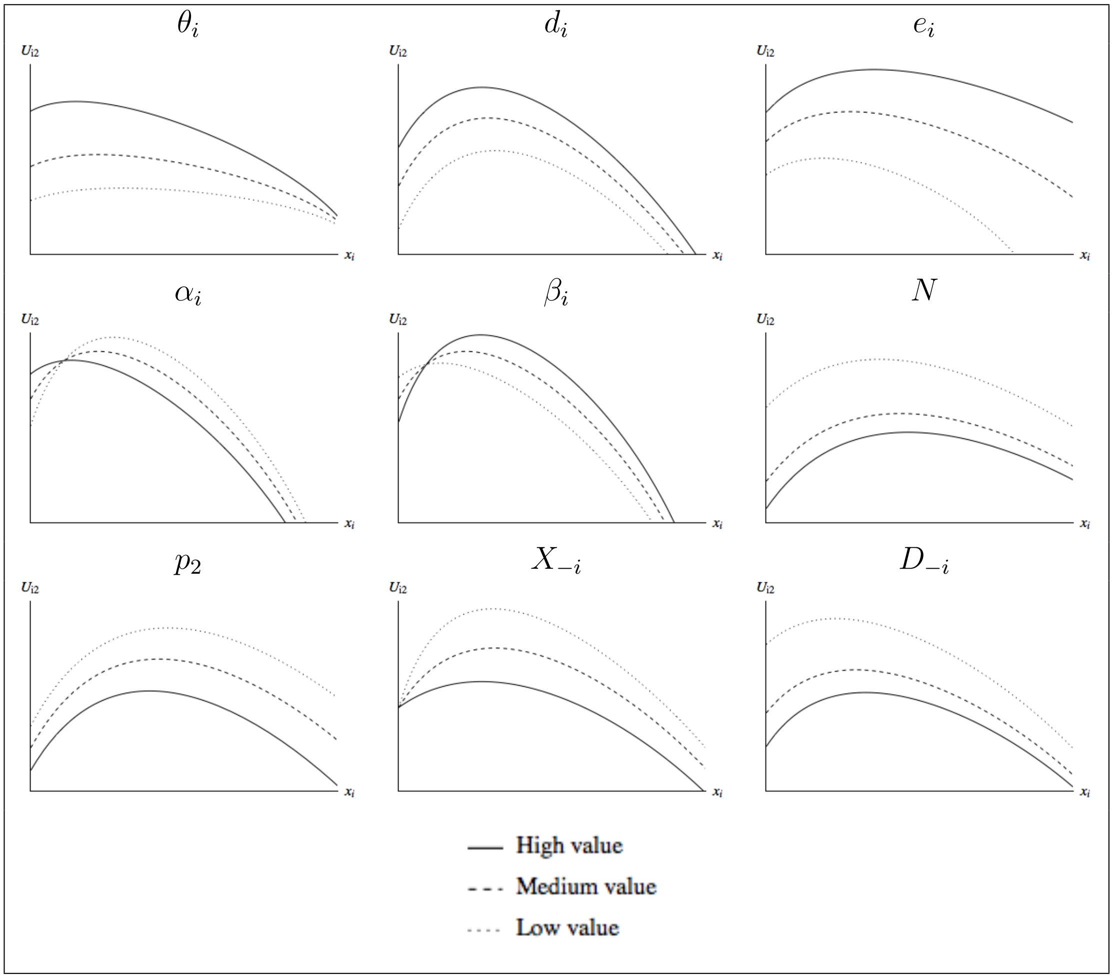

Figure A4: Impact of model variables on monetary contribution and utility in coalition

saving), while a low level of θ_i indicates a higher preference to consume (demand satisfaction). When θ_i=1, the utility depends only on the income saved. In the opposite case, when θ_i=0, agent utility depends only on consumption. When the preference for income is high (high θ_i, and the preference for consumption is low), *cœteris paribus*, an agent in coalition maximises its utility (U_{i2}) by reducing the individual monetary contribution (x_i). When θ_i is lower (hence, a higher preference for consumption), the agents in coalition are willing to contribute more in order to maximise utility.

The relation between d_i and x_i and U_{i2} is similar. A higher demand raises the cost (c_{i2}=$d_i p_2$), reducing the contribution that maximises utility. Instead, agents in the coalition with higher incomes (e_i) are willing to contribute more compared to those with lower incomes. This is because the savings are higher if the income is higher, and utility increases even though the contribution is higher, *cœteris paribus*.

α_i and β_i influence individual utility and contribution in opposite directions. With higher (lower) values of α_i (β_i), utility reaches its maximum at a low level of monetary contribution. This is because α_i measures the importance given by the agent to the proportional division rule based on consumption. The higher the α_i, the higher the importance assigned to the fact that the agent is using only part of the service provided by the shared good. Therefore, as α_i increases, utility decreases. Parameter α_i captures the individual perception of the attitude to sharing; an agent agrees to share use with others, but, at the same time, is reluctant to limit its own consumption.

β_i instead measures the importance given by the individual agent to the proportional division rule based on contribution. A higher value indicates a preference for consuming a portion of own income while owning and using part of the shared good. Also, a higher β_i signals that the agents give lower relevance to the number of coalition members. As a result, individuals with high β_i are willing to contribute more to the common purchase, due to their higher interest in sharing the cost proportionally with others. With respect to coalition size (N), individuals participating in smaller coalitions increase their utility by contributing more than in larger coalitions.

The last three terms are also straightforward. The higher the unit price (p_2) of the service in coalition, the lower the utility. The higher the other members' total contribution (X_{-i}), the lower the individual contribution, and the higher the other members' total demand (D_{-i}), the lower the individual contribution. These latter two characteristics, in combination with other factors in the utility function, might induce members to free-ride.

A.2.2 Example of Coalition Formation

Here, we provide an illustrative example of the co-evolution of coalition formation and diffusion. The initial parameters are set as in Table A4. For simplicity, it is assumed that *initiators* can only choose one product. Agents are heterogeneous only in respect to their demand (d_i), while all the other parameters (e_i, θ_{i1}, α_i and β_i) are set equal for all agents. Each agent has different cost and utility in relation to the public service (Table A5).

Parameters	Value
p_1	10
p_2	5
θ_{i1}	0.5
e_i	1000
α_i	0.5
β_i	0.5
S	175
I	200

Table A4: Illustrative example: initial parameters

Agent	1	2	3	4
d_i	30	55	35	45
c_{i1}	300	550	350	450
U_{i1}	145	157	151	157

Table A5: Illustrative example: agents' parameters

For graphical convenience, the example includes only eight agents, located in a regular lattice. Each has four spatially limited potential links in their own neighbourhood. Panel (a) in Figure A5 shows an *initiator* agent in the population.

At every time step, the *initiator* forges a link with one of its available neighbours that is not yet linked (action A1). The choice is random among the spatially limited links. Bidirectional links are formed. The linked agent becomes *active* and is informed of the opportunity to make the common purchase. In this example, agent-1 contacts agent-2 and they establish a link (panel (b) in Figure A5).

(a) *Initiator* (in black) in regular network structure
(b) Step 1: *initiator* ties link with agent-2
(c) Step 2: *Initiators* tie one link each
(d) Step 3: coalition established and agent-3 isolated

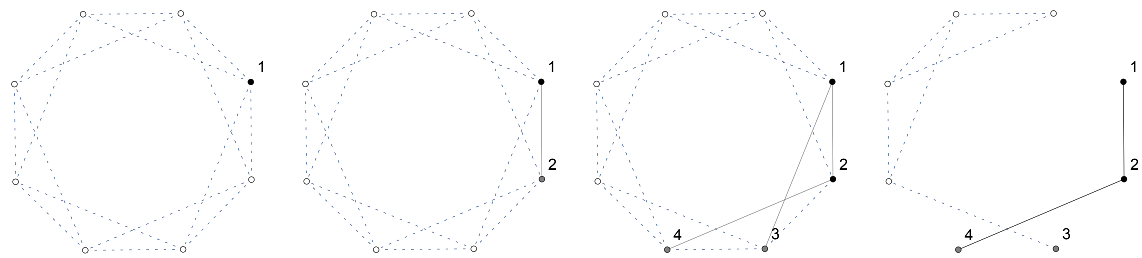

Figure A5: Illustrative example: co-evolution of coalition formation and diffusion

In this moment, agent-1 is the *initiator*, but agent-2 is not. Both agents and all the other agents in the population, satisfy their demand via the public service. Eq.3.2 and Eq.3.3 calculate their individual cost and utility. Only agent-1, the *initiator*, can start the process of coalition formation. Before doing so, a product is chosen (in this example only one product is available) and the relative common purchase is proposed (action A2). The process of coalition formation starts (action A3): agent-1, the *initiator*, contacts the linked agent-2 (panel (b) in Figure A5) and they evaluate the common purchase in coalition (Eq.3.5 and Eq.3.6). The two agents make a conditional decision among the options to invest in coalition or to use the public service. The option that makes an agent better off is stored as optimal. When all coalitions have been evaluated (in the example only coalition (1-2) is available), all agents announce their optimal conditional decision.

Now, assuming that the coalition (1-2) is not established because it does not satisfy all the stability conditions, the two agents can contact more neighbours and forge more links, thereby improving and enlarging their network. However, only *initiators* can do this. At the beginning of each time step, all *active* agents check their level of awareness (Eq.3.1) to become *initiators*. Assuming that agent-2 becomes an *initiator* in this step, the two agents can each contact one additional neighbour (action 1), choose a product (action 2) and start the process of coalition formation (action 3). As shown in panel (c) in Figure A5, agent-1 contacts and forges a link with agent-3 and agent-2 does the same with agent-4. Subsequently, the two *initiators* choose the product they want to purchase with others, and they start the process of coalition formation as explained before.

The coalition formation starts from *initiators*. First agent-1 and later agent-2 begin this process by evaluating coalition size 2 and then, depending on the available links, evaluate bigger coalitions. In this case, the full coalition, size 4, is the largest they can form. Table A6 summarises all possible coalitions that can be formed and evaluated in this network of agents. There are three coalitions with size 2 (1-2, 1-3 and 2-4), two coalitions with size 3 (1-2-3 and 1-2-4) and one coalition with size 4 (1-2-3-4).

		Agent									Agent				
Coalition		1	2	3	4	$\sum x_i \geq I$		$\sum d_i \leq S$			1	2	3	4	
1-2	x_i	101	72			173	x	85	✓	stop					
1-3	x_i	97		89		186	x	65	✓	stop					
2-4	x_i		78		88	166	x	65	✓	stop					
1-2-3	x_i	138	76	127		341	✓	120	✓	continue					decision
	c_{i2}	288	351	302						$c_{i2} < c_{i1}$	✓	✓	✓		
	U_{i2}	163	169	164						$U_{i2} > U_{i1}$	✓	✓	✓		
1-2-4	x_i	142	84		108	334	✓	130	✓	continue					decision
	c_{i2}	292	359		333					$c_{i2} < c_{i1}$	✓	✓		✓	
	U_{i2}	167	173		171					$U_{i2} > U_{i1}$	✓	✓		✓	
1-2-3-4	x_i	161	81	145	113	500	✓	165	✓	continue					stop
	c_{i2}	311	365	320	338					$c_{i2} < c_{i1}$	x	✓	✓	✓	
	U_{i2}	163	169	164	167					$U_{i2} > U_{i1}$	✓	✓	✓	✓	

Table A6: Coalitions evaluated

The three coalitions with size 2 do not satisfy the condition in Eq.3.7, i.e., the total monetary contributions of all participants is not enough to cover the investment cost (I). Consequently, these three coalitions are not formed and they do not provide any optimal conditional decision for the agents involved. Agents stop evaluating these coalitions. The agents then evaluate the two coalitions of size 3. These satisfy both conditions in Eq.3.7 and Eq.3.8, so agents continue the evaluation process and consider their individual cost and utility in coalition (Eq.3.9 and Eq.3.10). All agents in these two groups are better off, therefore, the two coalitions of size 3 are subject to further negotiation in the final decision step. In the full coalition option, i.e., size 4, even though it satisfies both initial conditions, agent-1 does not gain compared to the public service (the cost is higher in coalition). Therefore, agent-1 exits this coalition, which implies that the full coalition is not stable and is not considered further by agents.

The four agents involved in the final decision step have to make their own optimal conditional decision. Agent-1 and agent-2 want to establish coalition (1-2-4) since their utility would be higher than in coalition (1-2-3). On the one hand, agent-3 has coalition (1-2-3) as the only available option to improve individual utility, on the other hand, agent-4 has coalition (1-2-4) as the only available option to improve individual utility. Based on these conditions which the agents announce, coalition (1-2-4) is established. This implies that these three agents have coordinated, agreed on their monetary contributions and can jointly purchase the shared good. The coalition is established, which means that coalition members are out of the game, leaving agent-3 isolated in the network. Figure A5 panel (d) shows how the network structure changes after adoption. The three agents in the established coalition (1-2-4) break their existing already formed links (e.g., link 1-3) and do not take up those potentially available in their neighbourhood (e.g., links 2-3, 3-4, etc.). Agent-3 remains isolated, but being an *active* agent, in the next time steps agent-3 can re-evaluate whether or not to become *initiator* (Eq.3.1). If agent-3 does so, the process continues with the remaining agents in the population.

A.2.3 Check on Agents' Preferences on Division Rules

Here we provide the results of the additional check on the impact of heterogeneity in agents' preferences on the proportional division rule based on consumption (α_i), and the proportional division rule based on contribution, and the equal share division rule based on coalition size (β_i). In the baseline scenario, all agents have the same preferences (α_i=β_i=0.5). We run the model with three different initialisations, in which values are assigned to agents randomly from a normal distribution (Table A7). Under these new conditions, the adoption share increases by about 8% , on average, compared to the baseline case of homogeneous agents where the final adoption share is 50%.

	α_i	β_i	%_Adopters
i)	μ=0.5, σ=0.1	μ=0.5, σ=0	54.0%
ii)	μ=0.5, σ=0	μ=0.5, σ=0.1	53.7%
iii)	μ=0.5, σ=0.1	μ=0.5, σ=0.1	53.9%

Table A7: Adoption share varying α_i and β_i

A.3 Annex to Chapter 4

A.3.1 Kriging Meta-Model

The Kirging meta-model provides linear unbiased predictors for complex, non-linear simulation models, enhancing traditional linear interpolations. Kriging is a spatial interpolation method used to predict unknown points in the parametric space, based on known observations. To predict the model response to a not observed point in the parametric space, the Kirging meta-model uses a correlation function to make an interpolation among the closest observed points, by also considering spatial information related to these points. The NOLH DoE is the best sampling method to select points in the parametric space to be observed via simulation runs. Five different correlation functions are tested, for which the estimation of the Kriging meta-model is validated via both cross in-sample validation (Q^2 predictivity coefficient) and external out-of-sample validation (root mean square error ($RMSE$) measure). Among the correlation functions, we chose the one with a combination of higher Q^2 and lower $RMSE$ values. The Kriging method statistically estimates the coefficients of each model parameter in relation to a specific correlation function. However, the coefficients provide only a rough (inverse) estimate of the importance of the variation in the model output. Therefore, we combined the results of the Kirging meta-model with the Sobol decomposition in order to run the global sensitivity analysis. The effect of each model parameter on the model output, is high if the value of the estimated coefficient is low. Below we report the results of the five alternative correlation functions (Table A8) and the coefficient estimation of the best performing one among these alternatives (Table A9).

Validation	Trend	Matèrn 5/2	Matèrn 3/2	Gaussian	Exponential	Power exp.
Shared Purchase						
Cross Q^2	Constant	0.000	0.409	0.073	0.344	0.380
	Linear	0.167	0.167	0.167	0.348	0.447
External $RMSE$	Constant	2.615	2.673	2.758	2.573	2.634
	Linear	2.710	2.534	2.784	2.462	2.714
Individual Purchase						
Cross Q^2	Constant	0.947	0.953	0.933	0.918	0.956
	Linear	0.959	0.958	0.945	0.932	0.958
External $RMSE$	Constant	7.242	6.826	6.505	8.043	6.464
	Linear	5.680	5.803	8.717	7.506	5.608
Public Service						
Cross Q^2	Constant	0.977	0.970	0.973	0.937	0.966
	Linear	0.979	0.976	0.967	0.949	0.973
External $RMSE$	Constant	3.831	4.430	3.849	7.023	5.482
	Linear	3.557	4.026	4.107	6.314	4.089
Shared Purchase - niche						
Cross Q^2	Constant	0.870	0.848	0.832	0.750	0.813
	Linear	0.852	0.852	0.883	0.753	0.870
External $RMSE$	Constant	3.628	3.436	2.617	3.571	3.234
	Linear	3.351	3.372	2.638	3.499	2.874

Notes: Comparison of alternative correlation functions for the Kriging meta-model: Shared Purchase in Figure 4.3, Individual Purchase and Public Service in Figure 4.4 and Shared Purchase smaller space in Figure 4.5. Higher Q^2 and lower $RMSE$ values are preferred.

Table A8: Comparison of alternative meta-model specifications

	Shared Purchase	Individual Purchase	Public Service	Shared Purchase niche
Trend function	Linear	Linear	Linear	Linear
Intercept	2.038	138.866	60.626	4.033
Correlation function	Power exp.	Power exp.	Matèrn 5/2	Gaussian
Estimated coefficient				
S	0.232	0.225	0.264	0.158
d_{mean}	0.442	0.541	0.614	0.838
e_{mean}	0.701	0.656	0.639	0.511
θ_{delta}	0.816	1.728	2.000	2.000
θ_{mean}	0.320	0.384	0.374	0.332
α_{mean}	0.693	2.000	2.000	0.247
β_{mean}	0.598	2.000	2.000	2.000
Cross validation Q^2	0.447	0.958	0.979	0.883
External validation $RMSE$	2.714	5.608	3.557	2.638
NOLH samples used	512	512	512	512
External validation samples	50	50	50	50

Notes: Kriging meta-model estimation. The value of the estimated coefficient indicates the importance of each parameter on the variation model output: higher coefficient indicates a smaller influence of the parameter on the model output.

Table A9: Kriging meta-model estimation