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Reducing Environmental Impact through Shared Ownership: A Model of Consumer Behaviour

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Abstract

We propose a simple model to study the conditions under which consumers prefer to purchase a good in coalition rather than individually. To identify those conditions, we study the full parameter space that defines the characteristics and preferences of heterogeneous consumers, the characteristics of the good, and the characteristics of a public service that offers the same services as the good. We find that shared ownership emerges only under niche conditions, for relatively lower income consumers with relatively higher demand. Furthermore, shared ownership is more likely to emerge if the shared good is relatively small and can be purchased in small coalition with lower coordination costs. Results are relevant to design sustainable consumption policies as they show that the diffusion of shared goods reduce the net number of goods in an economy, and therefore their environmental impact. However, we do not find any impact of shared ownership in reducing inequality in accessing goods. We show that policies that reduce the relative price of the shared purchase can accelerate the transition to a more sustainable shared consumption.

Keywords: Shared ownership; Consumer coalitions; Sustainable consumption
JEL: D16; Q57; D81; D85

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1 Introduction

Most households in higher-income countries own a range of domestic appliances, such as vacuum cleaners, washing machines and drills, which are idle most of time (Princen 1999, Peattie 2010, Baudrillard 2016), use a share of the bandwidth of their internet connection, and own cars, which are parked most of the time (Shaheen & Cohen 2013, Frenken & Schor 2017). Could these households coordinate to purchase and consume these goods collaboratively? Shared ownership may reduce inequalities, making expensive goods accessible to more consumers, and is likely to be more sustainable for the environment, reducing the number of goods produced and therefore the material extracted (Albinsson & Perera 2012, Chander & Muthukrishnan 2015, Goedkoop & Devine-Wright 2016). However, coordinating a shared purchase comes with coordination costs.

In this paper, we develop a simple model to investigate under what conditions consumers might shift from individual ownership and consumption of goods to shared ownership and consumption. Sharing is a collective decision which requires the formation of a coalition of consumers.

To study the relation between consumption choice and coalition formation, we extend Pasimeni & Ciarli (2018) Agent-Based Model (ABM) with heterogeneous users who consume a service over a finite amount of time periods (e.g., urban transportation) choosing between three options: a public service (e.g., bus), individual ownership (e.g., individual car) or shared ownership (e.g., shared car). The choice between the three different modes of purchasing the service depends on the consumer's utility, which is a function of consumers characteristics (i.e., income, demand for the service and preferences) and the service characteristics (i.e., cost and supply capacity).

To study under which conditions consumers shifts from individual to shared ownership, we employ a multi-step global sensitivity analysis of the full parameter space of the model defining consumer and product characteristics (e.g., Dosi et al. 2018). We find that shared ownership emerges under a narrow combination of conditions (parameter values). Generally, consumers prefer to use either the public service or, if they have sufficient budget, to purchase their own individual good.

We next study what drives the transition from individual to shared ownership, focusing on the parameter space in which at least some consumers have a preference to share. We find that the small niche of consumers that opt for the shared purchase has a relative higher need for the service and a relatively lower income, which makes the individual good non viable. Shared ownership replaces individual ownership, but does not affect the number of consumers relying on the public service. As a result, 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.

We study two potential policy incentives that may affect the transition to shared ownership: price and capacity of the good. As expected, we find that reducing the relative price of using the shared good relative to using the individual good, can push consumers to share. But 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 increases the coordination costs.

This paper contributes to the literature that studies the role of the sharing economy in enabling environmentally sustainable and more inclusive consumption practices. Some studies find that sharing promotes collaborative consumption of existing products and reduces the need for new products to be manufactured and purchased, thus reducing the environmental impact associated with the extraction of natural resources (Botsman & Roger 2011, Cohen & Muñoz 2016, Fremstad et al. 2018). Other studies argue that sharing enables social inclusion by providing access to goods and services to people who might not afford them otherwise (Belk 2014*b*, Hamari et al. 2016). We make two main contributions to this literature.

First, we shift the analysis from collaborative consumption – the key model of the sharing economy (Botsman & Roger 2010, Belk 2014*b*, Hamari et al. 2016)[1] – to shared ownership and consumption. The sharing economy literature has extensively analysed changes in consumer behaviour from enduring individual ownership of a good to ephemeral and dematerialised consumption of a good accessed temporarily (Bardhi & Eckhardt 2017). But, it overlooks the case of the good being owned by a group of users: shared ownership (Pasimeni 2021). This difference has implications for the distribution of wealth among individuals (Richardson 2015, Martin 2016, Acquier et al. 2017), as most sharing economy practices use business models that are similar to the renting model, also defines as pseudo-sharing (Belk 2014*a*, Eckhardt & Bardhi 2015).

Second, we provide a theoretical model to analyse experiences of shared ownership, and study conditions under which they can diffuse. The transportation literature has presented successful cases of "true" sharing (Belk 2017, Dreyer et al. 2017, Czakó et al. 2019), like the Swedish *Göteborgs Bilkoop*. In this scheme, local communities share the ownership of a car, which has allowed low-income consumers to increase their access to flexible transportation. User cooperative is another form of true sharing, like the large car sharing clubs in Switzerland (Truffer 2003, Vaskelainen & Münzel 2018), the food cooperatives in Germany (Vogeler et al. 2021) and Portugal (Moreira & Morell 2020) or the energy communities (Yildiz et al. 2015, Bauwens et al. 2016, Pasimeni 2019). Building on these case studies, our model studies the condition under which they can be successfully implemented in other regions and for other goods and services.

Our model of shared ownership contributes also to the theory of clubs (Buchanan 1965, Lindenberg 1982). Buchanan defines club goods those that cannot be categorised as neither purely public nor purely private. For these 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 extended Buchanan's work by analysing the conditions under which the decision to jointly own a good is preferred to individual ownership. The author focuses on goods that are not affordable for the majority of consumers, who have an opportunity to access them by forming groups (Lindenberg 1982). We contribute to those literatures in two main ways. First, our model combines the models on coalition formation with those on owning and sharing a good in a club by studying under which conditions consumers form coalitions to share ownership. Second, we analyse the conditions under which such coalitions to share a good are likely to emerge.

In sum, we know very little about the drivers of shared ownership and consumption, and this is how this paper makes a unique contribution to the literature on sustainable consumption behaviour, the literature on the sharing economy and on fractional ownership, and the literature on clubs and

[1]The sharing economy consists of users' granting one other temporary access to under-utilised goods (Belk 2007), in exchange for money and without any transfer of ownership (Bardhi & Eckhardt 2012, Frenken & Schor 2017).

sharing groups. We do this by conceptualising the so called "true" sharing through the theory of clubs and building on examples of user cooperatives. Our contribution opens up a research avenue to broaden the concept of sustainable shared consumption (Safarzyńska 2013).

The rest of paper is structured as follows. Section 2 describes the model. Section 3 presents the global sensitivity analysis methodology applied to the full parametric space of the model and identifies the conditions under which stable coalitions emerge. This section also studies the properties of consumer and goods that maximise the number of consumers in coalition and runs the policy analysis. Section 4 discusses the results in the context of urban mobility and concludes the paper.

2 The Model

2.1 Short description

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.

Let us consider individuals who use either the public service (e.g., bus or metro) or a private good (e.g., a car) to satisfy their need (e.g., transport). Over time, consumers have also the option to purchase the same good after forming a stable coalition with other consumers, with whom they have come in contact. In every time period, consumers can choose among one of the three options to access the service: public service, private good individually owned, or shared good. The higher the number of consumers choosing the public service, the higher the congestion related to accessing the service, and the lower the utility from its use. We assume that consumers who rely on the public service make a choice in every time period. Consumers who own a good individually or in a coalition, make a choice every time the good is fully depreciated and cannot provide the service anymore. To purchase a good in coalition, consumers rely on their social network, which evolves over time, changing the conditions under which consumer make their choice.

The model extends Pasimeni & Ciarli (2018) in a number of ways. We relax the constraint on the network proximity of users that can form a coalition: consumers are displayed as a random network to allow analysis of goods that do not require proximity to be shared. We relax the assumption that goods are used indefinitely with no loss in the quality/quantity of service supplied and we introduce a lifetime for the purchased good. We relax the assumption that coalitions last indefinitely. This implies that consumers need to make their consumption choice several times, under different conditions (as other consumers shift between purchasing choices). We relax the assumption that the public service has an infinite supply. The congestion of the public service is a function of the provider's capacity and the overall number of users.[2]

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

2.2 Model details

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 their income, demand for the service and the cost of the service under each option, plus a number of parameters related to the characteristics of the consumers in coalitions and the different purchasing 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

When purchasing the public service, the utility of consumer i ($U_{i,1}$, in Eq.1) depends positively on the consumer's income (e_i) and negatively on the cost of the service ($c_{i,1} = d_i p_1$), 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:

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

where $\theta_i \in [0; 1]$ is the consumer preference for income ($1 - \theta_i$ represents the consumer's preference for consuming the service); the total cost ($c_{i,1}$) 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 (i.e., congestion in Eq.2). 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:

$$K = 1 - \frac{1 - k}{1 + e^{-r(\frac{A_{1,t-1}}{Z} - g)}} \tag{2}$$

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.[3]

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 in Eq.3) which depends on its use (the demand d_i). Consumers can purchase goods of different size (S_2), which we assume are proxies for their maximum capacity, and which also determines their duration. Consumers cannot purchase an individual good if their capacity does not satisfy their demand. Formally, the duration is then simply:

$$L_2 = \frac{S_2}{d_i} \quad \text{with} \quad d_i \leq S_2 \tag{3}$$

[3] See Figure A1 in Annex A where we plots how K varies in relation to changes to its parameters.

The utility of consumer i whose demand is satisfied by purchasing an individual good ($U_{i,2}$ in Eq.4), depends positively on the individual's income (e_i) and negatively on the overall costs ($c_{i,2} = d_i p_2$) 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:

$$U_{i,2} = [e_i - (d_i p_2 + \frac{I_2}{L_2})]^{\theta_i}(d)^{1-\theta_i} \quad (4)$$

where $\theta_i \in [0;1]$ is the consumer's preference for income ($1-\theta_i$ is the consumer preference for consuming the service). Comparing to Eq.1 there is no congestion cost, as the consumer has exclusive access to the good. Without any loss of generality we assume that the overall cost of the good is spread proportionally over its lifetime ($\frac{I_2}{L_2}$), implying that two consumers can pay a different cost for the same good, depending on their usage (demand).

Purchase in coalition

The utility of consumer i, whose demand is satisfied by the purchase of the good in coalition ($U_{i,3}$ in Eq.5), depends positively on the consumer's 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). Demand (d_i) affects consumers' utility both negatively (by increasing the cost of the service) and positively (by increasing demand satisfaction).[4]

Differently from the 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 a consumer 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 ($d_i + D_{-i}$), the extent to which the use of the good is shared proportionally to each consumer demand ($\frac{d_i}{d_i+D_{-i}}$), the proportional consumer's contribution to the purchase ($\frac{x_i}{x_i+X_{-i}}$), and the equal share proportion irrespective of demand or contribution ($\frac{1}{N}$). Formally:

$$U_{i3} = [e_i - (d_i p_3 + x_i)]^{\theta_i}\{(d_i + D_{-i})[\frac{\alpha_i d_i}{d_i + D_{-i}} + (1-\alpha_i)(\frac{\beta_i x_i}{x_i + X_{-i}} + \frac{1-\beta_i}{N})]\}^{1-\theta_i} \quad (5)$$

where $\theta_i \in [0;1]$ 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

[4] In Annex A we describe the equivalence between the utility functions of three purchasing options.

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:

$$\sum d_i \leq S_3 \tag{6}$$

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. If the coalition's total demand equals the size of the good, the good can be used for one period only:

$$L_3 = \frac{S_3}{\sum d_i} \tag{7}$$

The overall cost of the shared good, I_3, is spread equally over the lifetime of the good. 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 good.

$$\frac{I_3}{L_3} \leq \sum x_i \leq \frac{I_3}{L_3} * 1.1 \tag{8}$$

To assess their utility, consumers purchasing in a coalition need to decide also how much they contribute to the shared good: $x_i < I_3$. This will affect their utility and the one of the other coalition members. We model coalition formation as an iterative process occurring within a time period. 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.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 to the other coalition member. 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 their network to join the coalition and to evaluate the shared purchase option. 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.6 and Eq.8.

Once all potential coalitions have been explored, all consumers involved in coalition formation in that period make their choice, comparing among all the (different size) coalitions explored and the other two options (public service and individual purchase). Each consumer communicates their optimal choice to the member of the coalitions in which they have been involved. If the best alternative for all consumers who considered a potential coalition 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.

To analyse the emergence of the shared ownership as a new model of consumption, in the first time steps consumers can only buy the public service or the good individually. We endogenise the 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 that in the population there is a limited random number of innovative consumers (which we label *innovators*) who have the capacity to contact other randomly chosen consumers to form bidirectional links with them. We assume that each innovative consumer can form only one link during each time period, but that each consumer can be contacted by several innovative consumers and from more than one tie. Once agents are contacted and made aware of the possibility of forming a coalition to purchase a shared good, 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 opportunity (W_{t-1}), as more consumers join the coalition ($SharingAdopters_{t-1}$) and as a function of external advertising of the sharing opportunities (Adv).[5] Formally:

$$W_t = MAX[W_{t-1}; min[1; Adv + (SharingAdopters_{t-1})^{\xi}]] \tag{9}$$

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

We assume that links can be formed only between consumers who have not purchased either individually or in a group, that is, those purchasing the public service. In other words, consumers who already own the good are not interested in entering a coalition, until their good completely depreciate. During the time needed to decide about purchasing individually or in a coalition, consumers use the public service. The network structure of connected consumers evolves over time: new contacts are formed and older links are broken if agents decide to purchase an individual or shared good.

3 Results

3.1 Model Analysis

To understand the conditions under which shared ownership may emerge (i.e., at least one group of consumers choose the shared option), we invert the usual procedure to analyse models, which consists in calibrating parameters and then analysing the sensitivity of the results to alternative parameterisations. Instead, we first study the full parameter space to identify the parameters that have the strongest impact on the outcome of interest (Ciarli 2012, Lamperti et al. 2018). This allows

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

us to identify the parametric conditions under which at least one group of consumers choose the shared ownership option – the extensive margin. We next study in more depth this reduced parameter space by analysing the effect of the most relevant parameters on the number of consumers that opt for shared ownership – the intensive margin. Third, we examine the policies that may nudge more consumers to shift from individual to shared ownership and consumption. We do this procedure in the four stages described below.

In the first stage, we run the global sensitivity analysis over the entire parametric space of the model (Section 3.3) and define the consumer and product characteristics which prompt at least two consumers to purchase in a coalition. This analysis is conducted in four steps.

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, Ruano et al. 2012) and we identify the parameters most relevant to model output. A number of model configurations are generated following the One-At-a-Time (OAT) sampling approach. We then apply the Near Orthogonal Latin Hypercube (NOLH) design of experiment (DoE) to optimise the number of model sampling points to be observed for the selected parameters (Cioppa & Lucas 2007, Barde 2016, 2020). Based on these observed points, we use the Kirging meta-model to study the parameter space (Rasmussen & Williams 2006, Salle & Yıldızoğlu 2014), 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).[6]

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 3.4). We then perform a second global sensitivity analysis (NOLH, Kriging meta-model and Sobol decomposition as described above and in Annex A) on this smaller parametric space, to analyse 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 3.5). We study the consumer characteristics related to the three consumption options.

In the fourth stage, the previous configuration is used to assess two possible policy interventions and their impact on the diffusion of the shared ownership (Section 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.

3.2 Model Initialisation

We initialise the model with 200 heterogeneous consumers, who can establish maximum 20 bidirectional random links each with other consumers (Table 1). Consumers differ with respect to their demand (d_i), income (e_i) and preferences for income/consumption (θ_i), and proportional division

[6] A detailed explanation of these four steps is in Annex A.

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).

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 $f_i = d_i, e_i, \theta_i, \alpha_i, \beta_i$), f_{mean} is the population averages, 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*) of the population or differences within (*delta*) the population.

The remaining model parameters define the characteristics of the good that can be purchased to access the service privately, and the characteristics of the public service. The same good can be purchased individually or by a group. The good's 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 service quality: 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).

We assume that 10% of the consumers are *innovators*.[7] The rate at which the information spreads to allow other consumers to form a coalition depends on parameters Adv and ξ (Eq.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 allow all consumers to opt for shared purchase and shared consumption, should this be their preferred option.

Table 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.

To analyse the shared ownership as an emerging alternative for individual consumers, we run several time steps (set at 360) to allocate consumers to the two standard alternatives for consumption: 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. 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 ownership.

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 results are computed as the average of these simulation runs in the final 240 time-steps when, regardless of the model configuration, on average, 99% of the consumers have evaluated the purchase in coalition at least

[7] *Innovators* are consumers that at t=0 are aware of the possibility of a sharing option and can contact other consumers to form a coalition.

Parameter	Symbol	Benchmark	Initialisation		OAT	NOLH
			Min.	Max.	EE	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	α_{delta}	0.25	0.05	0.49	✓	
division rule	α_{mean}	0.5	0.25	0.75	✓	✓
Preference for contribution	β_{delta}	0.25	0.05	0.49	✓	
division rule	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 1: Model initialisation

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

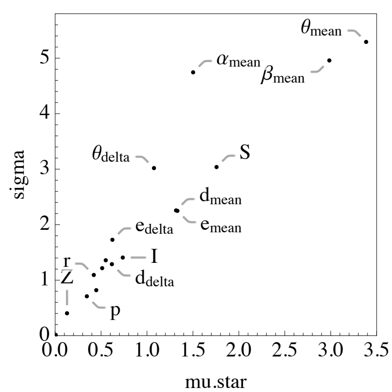
3.3 Global Sensitivity Analysis: Conditions for the Emergence of Shared Ownership

The objective of the global sensitivity analysis is to investigate the conditions under which at least two consumers opt for the shared purchase, over the entire parameter space defining the consumer, product and public service features. We focus on the following output variables: 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 3.1, we select the main parameters using the EE method. We include in the analysis all parameters ticked in Table 1 column (e). EE results in seven main parameters on which we run the NOLH – these are ticked in Table 1 column (f). To run both EE and Kriging methods, the OAT and NOLH 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.[8]

Elementary Effects (EE)

Figure 1 plots the EE for all the parameters, on the number of agents deciding to opt for the shared purchase. 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* that is the overall effect of each parameter. These two values help identifying important input parameters that contribute significantly to the output of a model. A high *sigma* and *mu.star* value indicate a high sensitivity of the model to a parameter.



Notes: The graph plots 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 1, column (e)) on the number of consumers that choose the shared purchase.

Figure 1: Elementary effects of the model parameters in the shared purchase

Considering the parameters that define consumer characteristics, the EE analysis shows that (Figure 1) average preferences (over the population) for income, the proportional division of the consumption of the shared good and the division based on the contribution to the purchase of the good

[8] Annex A reports the Kriging meta-model estimates

(respectively θ_{mean}, α_{mean} and β_{mean}) have a strong impact on the number of consumers opting for shared purchase. The next most influential consumer characteristics (population average) are their 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, except for the preference for income/consumption, θ_{delta}. Among the parameter defining the product features, only the capacity of the good (S) has a relevant impact on the number of consumers choosing the sharing option.

Less relevant for the emergence of shared ownership is the cost of the good (I), 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.6), the shared purchase is not viable, which explains why the good capacity parameter has a strong overall effect on the sharing purchase option.[9]

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. We arbitrarily consider parameters with $mu.star > 1$ and $sigma > 2$ and we exclude the other parameters because of their low impact on the number of sharing consumers. The parameters are initialised (according to the NOLH DoE) at values between the respective Min and Max in Table 1 columns (c) and (d). The remaining parameters are initialised based on the average benchmark value, column (b).

Figure 2 plots the outcome of the sensitivity analysis to assess the impact of the selected model parameters on the number of consumers opting for the shared purchase.[10]

The Sobol decomposition (panel a) indicates that the preference for income (θ_{mean}) (population average) is the most important parameter and accounts for about 60% of the variance in the number of consumers opting for the shared purchase.[11] The next two most important parameters are the good's capacity (S) and demand size (d_{mean}) (population average).

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. For example, the consumer's preference for income (θ_{mean}) drives the consumer's choice in relation to the shared purchase option, conditional on demand and size of the good. Despite the model simplicity, consumer choice is the result of a complex interaction among consumer characteristics and the capacity of the good.

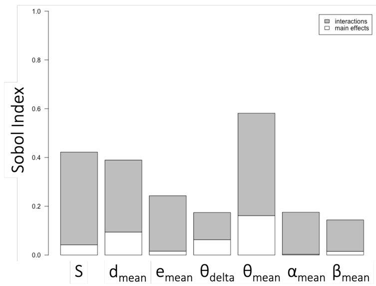
Panels b-d in Figure 2 show that, on average, a small niche of consumers chooses the shared purchase

[9] Annex A reports the EE analysis concerning the other two options: individual purchase and the public service.

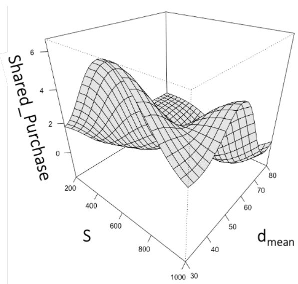
[10] Annex A discusses the results of the sensitivity analysis for the same seven parameters, for the number of consumers that choose the other two options: individual purchase and the public service.

[11] The sum of the parameter variance might be higher than 1 due to double counting the mutual interactions among parameters.

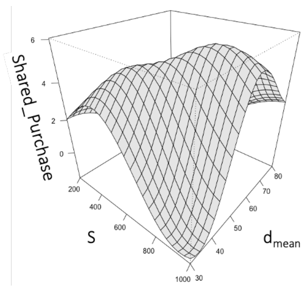
(a) Sobol decomposition



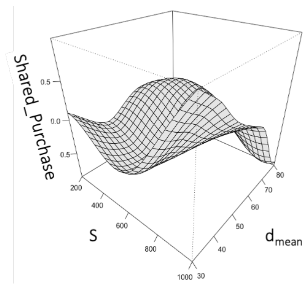
(b) θ_{mean}=0.25



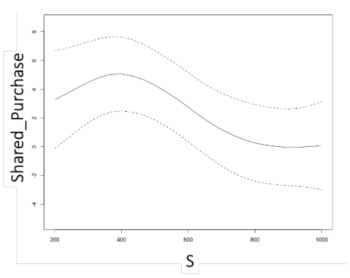
(c) θ_{mean}=0.50



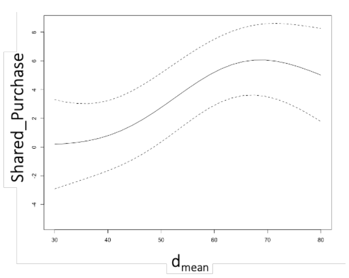
(d) θ_{mean}=0.75



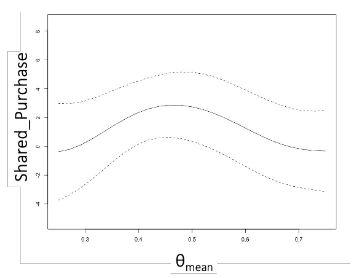
(e) S



(f) d_{mean}



(g) θ_{mean}



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 1). (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 2: Global sensitivity analysis of the impact of model parameters on the number of consumers in shared ownership

option: the maximum value in the meta-model response (average over runs and the final 240 time steps) is about 6 (out of 200) agents. Panels e-g also show that, *cœteris paribus*, consumers choose shared purchase when the preference for income (over the population) is lower than its average value (or preference for consumption higher than its average value)(panel (g))[12] demand is high (panel (f)), and can be satisfied with a small sized good that is large enough to satisfy more than one

[12]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.

consumer for at least one period (panel (e)).

The role of demand (and preference for consumption) is clear: when the average need for the good is high, the public service get congested, consumers that cannot afford an individually owned good may be able to afford a good shared with others. As some consumers at the margin opt out of the public service, congestion reduces, and all other consumers can satisfy their demand.

The role of the smaller good size, given the higher average demand, is less clear. This is explained by the several transaction costs that are required to form and maintain coalitions of consumers. First, as the size of the coalition increases in the process of coalition formation, the likelihood that some consumers drop out also increases, changing the conditions for the other consumers. In other words, the difficulty involved in coordinating the formation of 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.

Second, the larger the size of the group and the larger its total demand for the good, the lower is the duration of the good (Eq.7). Therefore, the coalition also lasts less. When consumers go back in the market, conditions will have changed with respect to the earlier coalition formation and the sharing option may not be the solution yielding the highest utility for at least one member of the previous coalition. As duration reduces, the monetary contributions of group members required to make the shared purchase also increases (Eq.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 reduce the individual cost, 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.

3.4 Exploring the Niche of Sharing Consumers

To further investigate the conditions under which shared ownership emerges, we analyse in detail the results of the 562 simulation runs of the NOLH DoE to select the reduced parameter space under which the number of sharing consumers is consistently higher. We first rank the observed points by the number of consumers choosing shared purchase and select the three configurations that generate the highest number of sharing consumers (these are between 22 and 28).[13]

Second, we refine the range of the seven parameters selected with the EE using their minimum and maximum values in these three configurations. The other parameters are again set at their benchmark values. Third, we perform a second global sensitivity analysis, with sampling points identified via NOLH DoE using the values of the parameters reported in Table 2, columns (c) and (d).

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

[13]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 2).

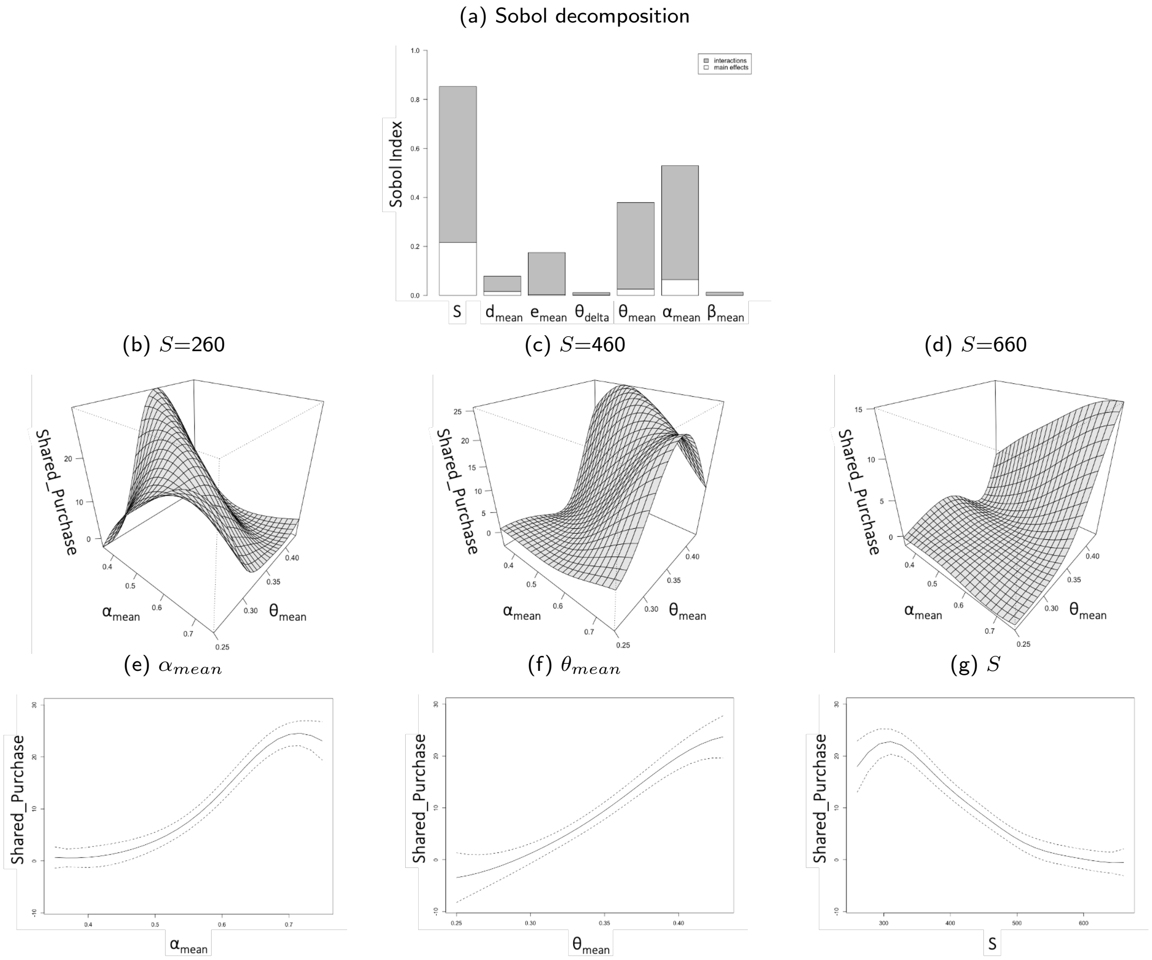
Parameter	Symbol	Benchmark Niche	Initialisation Niche		Benchmark original NOLH (Tab.1)	Initialisation	
			Min	Max		Min	Max
	(a)	(b)	(c)	(d)	(e)	(f)	(g)
Product features							
Capacity	S=S_2=S_3	460	260	660	600	200	1000
Investment	I=I_2=I_3	1300			1300		
Price	p=p_1=p_2=p_3	1.5			1.5		
Consumer features							
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 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 2: NOLH initialisation in a smaller parametric space

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.

Figure 3 plots the result of this sensitivity analysis on the number of agents opting for the shared purchase in this smaller parameter space. The Sobol decomposition (bar chart (a) at the top of the figure), indicates that product capacity (S) is now the parameter which has the largest influence on the decision to opt for shared purchase, accounting for more that 80% of the variance in the number of consumers in coalition. The second most relevant parameter is now the consumer preference for the demand division rule (α_{mean}) (population average), 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 in purchasing it). The preference for income/consumption (θ_{mean}), is also relevant, at a similar level as in the first global sensitivity analysis. Also in this smaller parameter space, the effect of these most influential parameters is based mainly on their interaction, rather than direct.



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

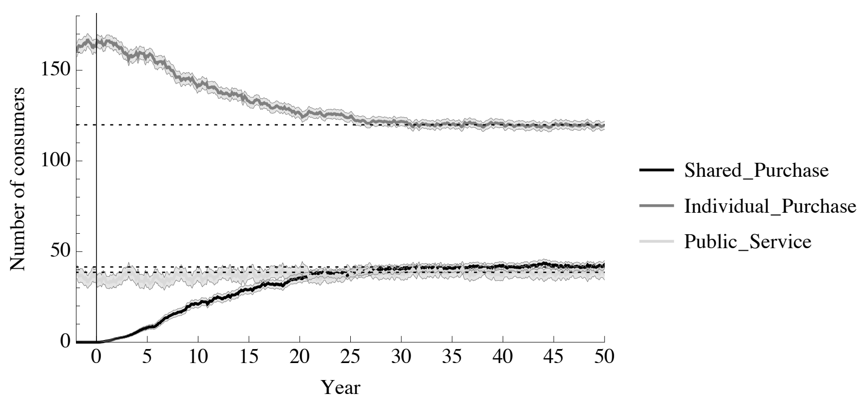
Panels e-g in Figure 3 plot the estimated direct impact of the three most relevant parameters when all other are at their benchmark values: α_{mean} (e), θ_{mean} (f) and S (g). They show that, in the economy defined by this smaller parameter space, the likelihood of consumers choosing shared purchase 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 reach 20 (over 200), on average across runs, and over the last 240 time steps. The number of consumers in coalition increases with their (average) preferences for the demand division rule (α_{mean}) and for income (θ_{mean}),[14] and decreases with the size of the good (S), which as discussed is also a proxy for the size of the coalition.

3.5 Transition to Shared Ownership: Dynamics, Impact and Consumer Features

In this section we use the model to investigate what leads consumers to choose the shared ownership option, and examine who are the consumers most likely to opt for this option. Among the 562 parameter combinations sampled using NOLH DoE 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 3 presents this configuration (column (b)) and, for reference purposes, includes the parameter values of the niche group (columns d-f).

Transition to Shared Purchase

Figure 4 summarises the evolution of agents' consumption decisions over 600 time periods. 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 consumers, to allow the model to settle around a long term steady state, *cœteris paribus*.[15]



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: Number of agents in the three options over time.

[14] 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-$\theta_{mean} > 0.57$).

[15] For ease of reading, Figure 4 shows only the last 24 time steps (i.e., the final two years, t<0) of this initial period with no sharing option.

Parameter	Symbol	Initialisation	Policy	Benchmark niche	Initialisation NOLH (Tab.2)	
					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		

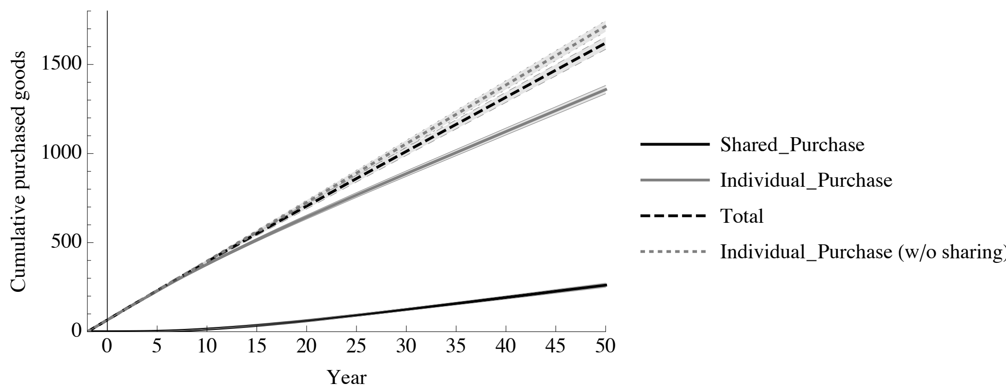
Notes: Column (b) shows the value of each model parameter that maximises the number of agents that opt for the shared purchase. Column (c) indicates the parameters for which we study the effect on the model output as proxy of the impact of policy measures. Columns (d), (e) and (f) report the initialisation values for benchmark, minimum and maximum of the the smaller parametric space, as in Table 2.

Table 3: Initialisation of the configuration generating the highest ratio of shared purchase

Under this parameterisation, before the sharing option is introduced, more than 80% of consumers choose individual purchase, with the remaining 20% consumers using the public service. If we consider the transport example, this is close to recent commuting figures across the UK (except London) (UKDfT 2019). At t=0, the shared purchase option is made available. 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.

The figures show that 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 can changes consumption decisions, but takes long to diffuse. 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. This happens because only consumers that can afford to purchase a private good, can afford to purchase it in coalition. Consumers that choose the public service do not find it convenient to purchase a mean of transportation, alone or shared, due to the low budget constraint. Consumers that purchase a private good individually, and have a low budget constraint, find it more convenient to participate in shared purchase, under the condition that their demand is fully satisfied. In the case of transport, this finding recalls the evidence that owners switch from owning a second car to participating in car sharing programmes (Kim et al. 2017, Nijland & van Meerkerk 2017).

Because the transition does not involve switching from the public service to a shared good, shared purchase implies a net reduction in the number of goods purchased, which leads to a reduction in the total number of goods produced. But by how much? Figure 5 plots the cumulative number of goods purchased over time.



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 5: Cumulative number of goods purchased and utilised

The results show that, under this parameter 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 if the shared option was not available.[16]

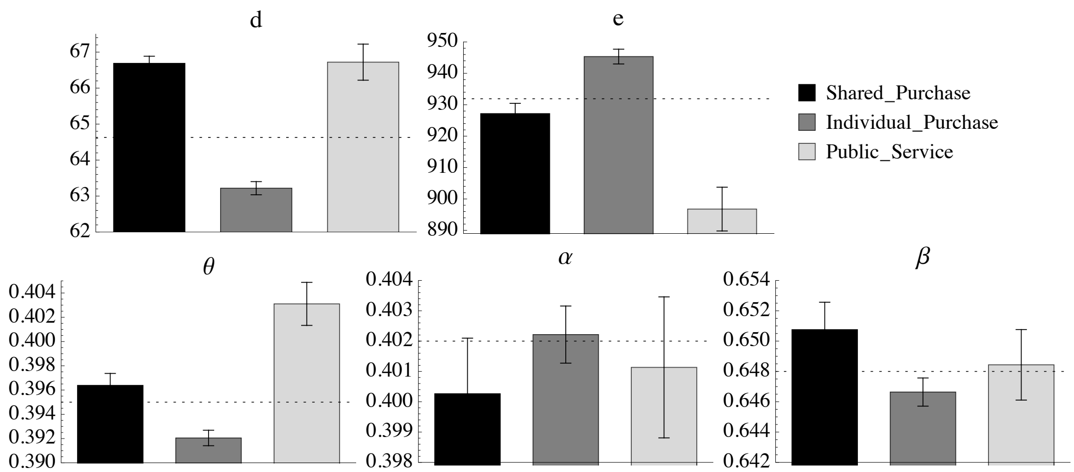
In this configuration, the shared purchase increases environmental sustainability through a reduction in the number of goods purchased, but does not reduce inequality by changing the number of consumers that have access to the good.[17] In sum, our results indicate that, even in the absence of sustainability concerns, several consumers find more attractive to share ownership, under this paramterisation.

[16]Given N, L_2 and L_3, we can compute the average number of goods purchased yearly. The capacity of the good is relatively small and results 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): a shared good depreciates more quickly. Before t=0, 32.9 products are individually purchased per year. This reduces to 23.6 at t<0. Consumers in coalition purchase approximately 6.8 goods per year, reducing by about 2.5 units the number of goods purchased annually.

[17]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. Note also that, to avoid results being driven by sustainability preferences the model does not include consumer preferences related to sustainability.

Features of Sharing Consumers

To allow for better targeting of policies to increase shared purchase, we analyse which consumers are likely to switch from individual to shared ownership. Figure 6 plots the average characteristics of the consumers choosing the three options. On average, and compared to the population mean, 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.[18]



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 represent population means, as in Table 3, column (b). At the top of each bar we plot the 95% confidence interval.

Figure 6: Consumers' features of consumers grouped by their consumption decision

Results suggest that 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 which have a relatively low budget. They can increase their utility (and available income) 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 constant. Consumers with the highest incomes pay individually to satisfy their need and do not enter a coalition. Consumers with the lowest incomes cannot afford any kind of purchase and, hence, use the public service.[19]

[18] Recall that this is the configuration that maximises the diffusion of shared ownership.

[19] In Annex A we also discuss consumers' total cost and utility based on the three consumption options.

3.6 Policy Interventions

Starting from the model configuration leading to a high ratio of shared purchase (Table 3 column (b)), we study the effect of varying the unit price of the services provided by the purchased good (p_i), and the good's size (S) and cost (I). These experiments could provide insights for policies to increase the proportion of consumers sharing ownership and reducing the number of goods produced.

Unit prices

The unit price is the variable cost of accessing the service (in all three options). We investigate the role of heterogeneous unit prices for the three consumption options, to consider the effect of taxes and subsidies.[20] 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. We selected the sampling points via a NOLH DoE where the three unitary prices vary between ∈[1;2].

As expected, figure 7 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 individually, 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%.

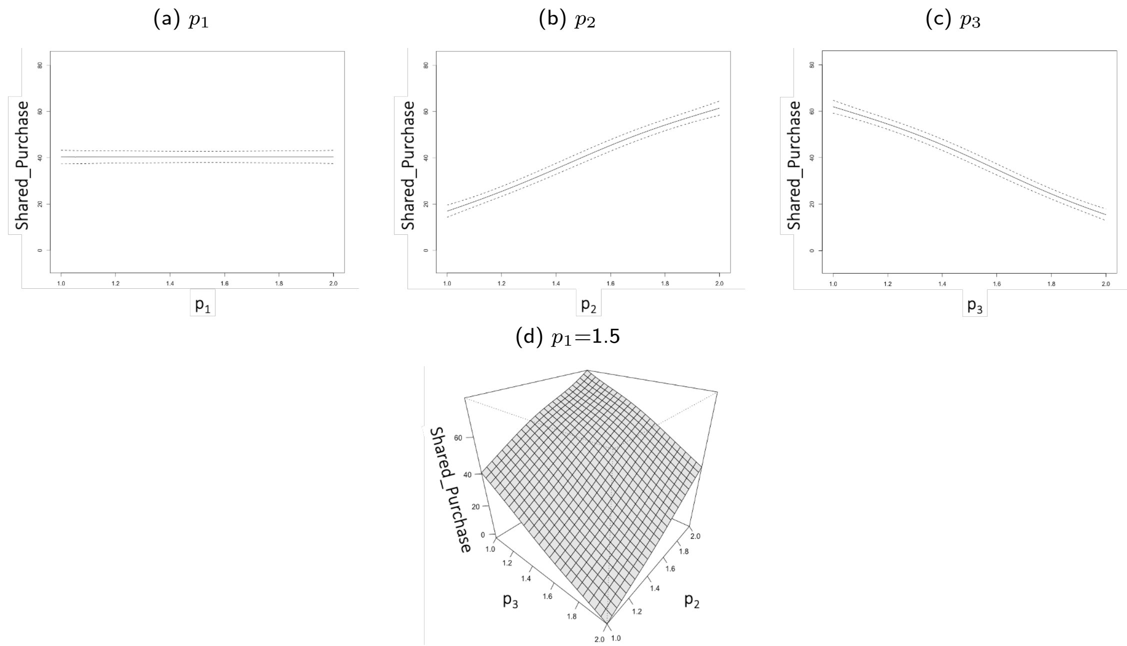
Good's characteristics: Capacity and Cost

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. To assess how both 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 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 8 plots the number of consumers for each of the three consumption options, for different combinations of good capacity and cost.

The results show that, even in a population of consumers with a likely high proportion of sharing consumers, and under a favourable price setting, the number of purchases in coalition depends on the characteristics of the good. Large sized goods, regardless of their cost, are purchased exclusively individually. Small and expensive goods are not purchased at all.

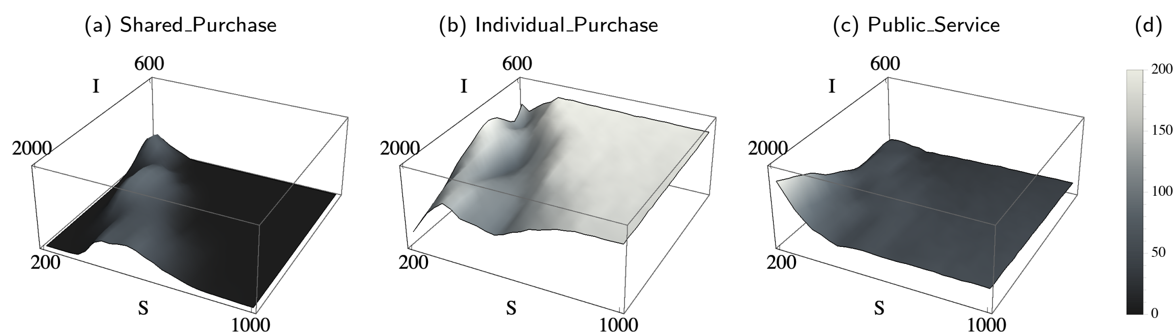
Shared ownership appeals to consumers in the case of a relatively low capacity good whose cost increases with capacity: the number of shared consumers is maximised when the cost is in the

[20] Following the mobility example, if we measure demand in kilometres, p_1 (Eq.1) is the cost of a bus ticket covering a given zone, while p_2 (Eq.4) and p_3 (Eq.5) refer to the variable costs (i.e., fuel, road taxes) of the purchased good.



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 7: Impact of unit prices on the number of consumers in coalition



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

medium range and capacity is low-medium. 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.

4 Discussion and Conclusion

In this paper we developed a simple model to analyse the choice of heterogeneous consumers in accessing a service via a public provider or a private good. The private good can be purchased individually or in coalition with other consumers. In the latter case, its 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 over 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 entire cost of 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.

In the model, consumer utility depends on the behaviour of the other consumers in the economy, in the current and past periods, which influence the congestion of the public service, and the coalition formation. These simple interactions generate complex dynamics, which we analysed using an agent-based model and simulating emergent properties for different initial conditions. 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. Instead, we use a multi-step global sensitivity analysis to iteratively analyse the full parameter space of the model and 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. The novelty of this procedure is that it enables to find the relevant niche as a sub-space of the parameter space, where the niche is defined as the model configuration whose parameters provide supporting conditions for shared ownership to emerge.

We find that shared ownership is considered a viable option for the population of consumers with relatively low income (which does not allow them to make an individual purchase) and with relatively high need for the service (high demand and high preference for consumption). This increases the utility of purchasing the good, especially if the public service is congested. Therefore, consumers with tighter budgets, but higher demand, are more willing to coordinate over shared purchase. However, due to several coordinating costs, they prefer to form smaller coalitions to purchase relatively smaller goods.

We also find that shared purchase replaces individual consumption, but does not increase the number of consumers that have access to the private good. Shared ownership is appealing only for the portion of the population that used to purchase a good individually, and which benefit from sharing costs and consumption. Under specific characteristics of the economy, therefore 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, even when we do not consider preferences for sustainability in the consumer choice.

Reducing the relative price of using the shared good with respect to the individual good, can push more consumers to share. These results are important to inform policy interventions aimed at modifying the price of the different options using taxes and subsidies or promoting shared purchase among consumers for given goods that are particularly polluting. By applying a tax that increases the cost of using a private good individually, or a subsidy that reduces the cost of using a shared good, the number of people opting for the shared purchase can increase, reducing the total number of goods.

Further, the capacity and cost of the good are critical and results suggest that policies may not be effective 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.

The finding of this study can be adapted to 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, but is not affordable for everyone (Sheller & Urry 2000, Urry 2006), or there is higher level of substitution in case of multi-vehicle portfolios in households (Archsmith et al. 2020). Car-sharing schemes, already operating in some large cities, are aimed at reducing the purchase 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, that are more likely to have the need for alternative vehicle-sharing transportation modes (Efthymiou et al. 2013). 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.

The model presents some limitations, which suggest new lines for future research. For instance, for the sharing option, we ignore any additional costs related, perhaps, to the technology to enable the sharing such as a platform or insurance. Further, the model does not consider the rebound effect (Binswanger 2001, Sorrell & Dimitropoulos 2008): sharing consumers that reduce expenses may be motivated to over-use the shared good, reducing societal benefit of the sharing purchase. These features can be included in our simple and flexible model.

In the model, we consider fixed unitary prices for the three options over time, 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 the shared car, depends on the cost of 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 via our model, but need a separate model or separate models for different markets.

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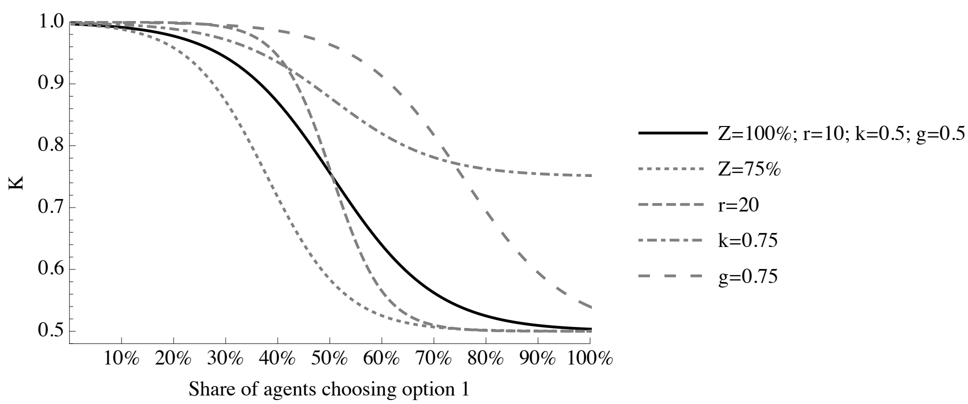
A Annex A

The congestion to access the service of the public sector

In the model we refer to congestion as the reduced likelihood to get access to a service (that has limited capacity) in a specific point in time, due to limited capacity, not the congestion that the use of the service can determine (e.g. traffic in the case of transport). The model may refer to different products, some of which create more congestion in use (e.g. traffic in the case of transport) than others (e.g. access to an internet provider router), and some of which can adapt capacity more rapidly (e.g. routers) than others (e.g. subways).

In the paper, we model congestion as a decreasing logistic function (see Eq.2). $A_{1,t-1}$ is the number of users in t-1 and Z the share of the population of agents in the model already using the public service. 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.



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 than 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 A1: Logistic function K for different parameter values

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.5, D_{-i}=0, X_{-i}=0 and N=1, then the second term in the equation is equivalent to Eq.1 and Eq.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 four steps of the global sensitivity analysis

We run the global sensitivity analysis over the entire parametric space of the model following the method proposed by Dosi et al. (2018). 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, Barde 2016, 2020).

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 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.

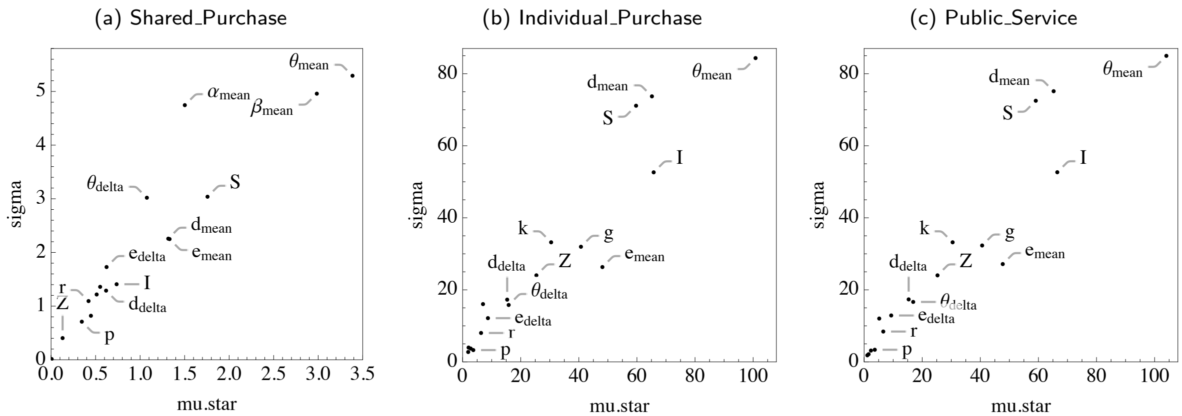
In the fourth step, the Kriging estimates are combined with the Sobol decomposition to enable a global sensitivity analysis of all the parameters in the meta-model (Saltelli et al. 2000, Saltelli & Annoni 2010). The Sobol decomposition is a variance-based sensitivity analysis that measures each parameter's 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.

The Elementary Effect (EE) analysis

Figure A2 plots the EE for all the parameters, on the number of agents deciding to opt for the shared purchases (a), individual purchase (b) and the public service (c). Plot (a) has been already commented in text.

In the cases of individual purchase and the public service, 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. 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. 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.3): the higher the capacity, the longer the duration and the lower the cost per period.



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 1, column (e)) on the number of consumers that choose the shared purchases (a), individual purchase (b) and the public service (c).

Figure A2: Elementary effects of the model parameters - the three consumption options

The parameters for the public service features are 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.1 and Eq.2).

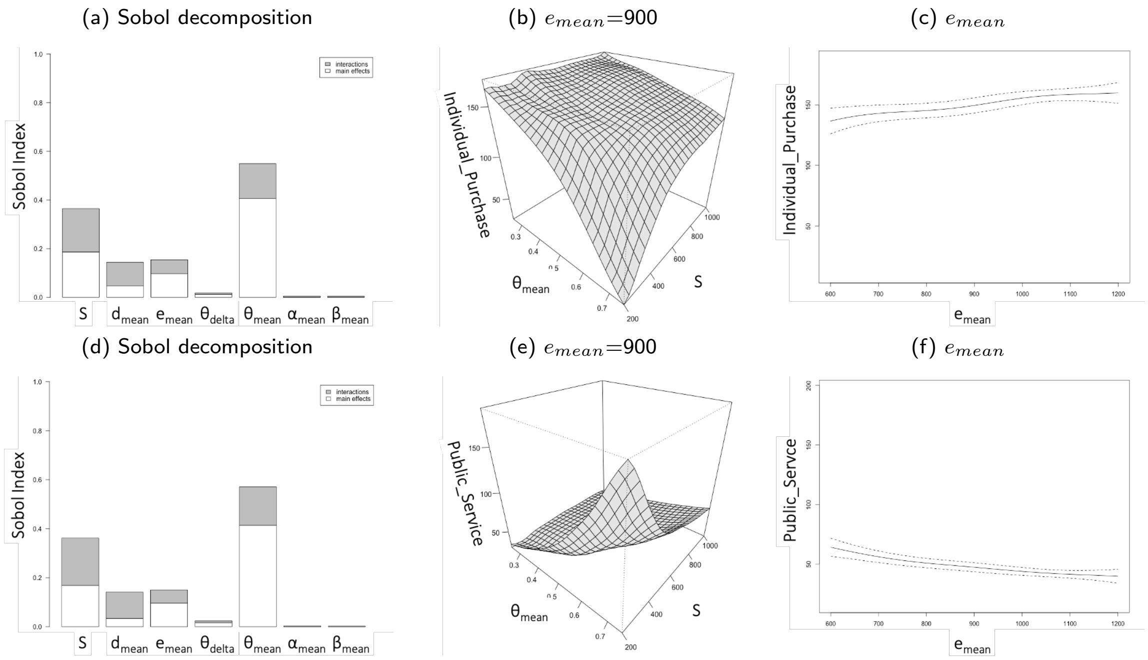
Note that the size of the parameter effects differs substantially between the shared purchase and the other two options (Figure A2). All the parameters have a lower effect on the sharing option because the maximum number of consumers choosing this option, among the 180 model configurations generated by the OAT sampling procedure, is 11 (over 200) which already suggests this option is chosen by a small number of consumers.

Global sensitivity analysis for the individual purchase and the public service

One of the main results of the global sensitivity analysis 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 2 suggests, also, that the interaction among the model parameters is important for determining the number of consumers that choose the shared purchase. 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.

Figure A3 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 1 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 A3: 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.1, 4 and 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 A3 do not depend on these two parameters which determine the sharing rules (see Eq.1 and Eq.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 A3, 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 consumers that purchase the good individually increases linearly with both the preference for consumption (1-θ_{mean}) and the good size (S).

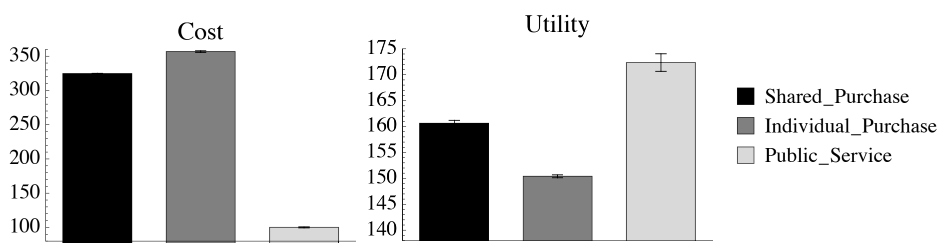
In the case of individual purchase and in the context of Eq.3 and Eq.4, large capacity increases good duration and reduces the cost to be paid in each time period. In the case of a low capacity good, the convenience of purchasing it individually for the same cost decreases and agents who do not choose 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.

Consumers' total cost and utility based on the three consumption options

The utility of consumers opting for the individual purchase and the public service is determined mostly by the direct effect of consumer characteristics (Figure A3). In the case of consumers maximising their utility through shared purchase, the interaction among these characteristics is more important (Figure 2). 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 A4). Individual consumers have the lowest utility, but, based on their characteristics (see Figure 6), 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 the 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 A1 and Eq.1).



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 A4: Consumers' cost and utility grouped by their consumption decision

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 A1) and the coefficient estimation of the best performing one among these alternatives (Table A2).

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 2, Individual Purchase and Public Service in Figure A3 and Shared Purchase smaller space in Figure 3. Higher Q^2 and lower $RMSE$ values are preferred.

Table A1: 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 A2: Kriging meta-model estimation

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