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Essays in Industrial Organization and Business Models for the Circular Economy

Doctoral Dissertation presented by

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To my parents.

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1

Introduction

The demand for natural resources and materials has increased exponentially in the last few decades. According to the OECD, 80 billion tons of minerals, fossil fuels, and biomass were fed into the global economy in 2011, and more than twice of this quantity will be consumed in 2060 under business as usual (OECD, 2019). Left alone, continued depletion of natural resources causes multiple economic and environmental consequences: the scarcity of resources disrupts raw material supply, puts pressure on productivity and distorts economic development, whereas the extraction, use, and disposal of resources negatively affect the environment, degrading the quality of life and future economic growth.

In addition to population growth and improved living standard, a big part of the problem takes root in our current "linear economy": companies harvest and extract materials, use them to manufacture a product and sell the product to a consumer, who then discards it when it no longer serves its purpose. Consequently, policymakers, practitioners, and researchers are looking for alternative approaches to mitigate, and optimally, reverse the degradation, among which circular economy has risen to the highest prominent in recent years.

In contrast to the traditional linear economy approach within which resources are ultimately converted into waste, a circular economy aims to "recycle, reduce, and reuse" products so that resources circulate in the system with the highest efficiency possible. In Europe, the European Commission adopted its Roadmap for a Resource-Efficient Europe in 2011, aiming at decoupling resource consumption from economic growth. In 2015, the European Commission approved the Circular Economic Action Plan to boost

Europe's transition to the circular economy following the initial roadmap. Then, in December 2019, the European Green Deal was presented as a roadmap for transforming the group into a modern, competitive and resource-efficient economy, which lead to the approval of the new Circular Economy Action Plan in March 2020. Following the initiatives by the European Commission, a number of European countries are leading the transition into the circular economy, including The Netherlands, France, Italy, Germany and Belgium. Outside Europe, the circular economy has also appeared in many governments' agenda, such as China's Circular Economy Promotion Law, Japan's Fundamental Law For Establishing a Sound Material-Cycle Society and The United States' Sustainable Materials Management Program Strategic Plan.

Besides policy frameworks and initiatives from governments, the critical discussions on the circular economy are on the firms' incentive to transit from their legacy ways of doing business into a more circular approach and how they can do that. The transition to the circular economy often requires new visions and strategies and a fundamental redesign of product concepts, service offerings, and channels towards long-life solutions. Hence, it entails holistic adaptations in the existing business models or even the creation of new ones. While there is no clear consensus on what is and what is not such a business model, the common agreement is that those models must reduce the consumption of resources, not only from increasing material productivity but also from more fundamental changes in production and/or consumption patterns. In other words, a business model for the circular economy provides fundamentally different ways of producing and consuming goods and services.

Among various business models in the spotlight, this thesis focuses on three models: *recycling/remanufacturing*, *sharing*, and *product-as-a-service*. *Recycling/remanufacturing* models re-transform end-of-life products into secondary raw materials or like-new products, thereby diverting waste from final disposal while also reduce the extraction and processing of virgin material to produce primary products. *Sharing* models facilitate the sharing of under-utilized products and can therefore reduce the demand for new product and their embodied raw material. As of *product-as-a-service* models, by marketing the services rather than products, the firm can incentivize less usage from consumers while still manages to earn higher profits, creating a win-win situation compared to the legacy selling models. These business models are not necessarily new. Recycling, reuse, and repair can go back as far as the establishment of our society. Sharing under-utilized products also has a millennia-long history. Providing access to products rather than selling them is not too different from traditional product leasing, which can date back to around 2000 BC in ancient Sumer. What is new is the tremendous scales and scopes these business models can grow into, as well as the focus on the environmental benefits they can bring about in nowadays context.

It is also worth noting that new business models do not emerge in isolation. Instead, they compete against the incumbents, which legacy *selling* business models still dominate the industries. The mobility industry can serve as a good example to illustrate the problem. While recycling and refurbishing cars and car parts can hardly be described as new, governments' recent commitments to improve the process have made the substitution of new by refurbished cars more appealing over time. Confronting the threat from recycled/refurbished products, car manufacturers may have to react strategically to soften the competition from the reprocessing industry. Furthermore, car manufacturers also face competition from the newly established peer-to-peer carsharing platforms such as Drivy, Turo, or GetAround. Unlike traditional competitors, these platforms do not produce cars but organize a marketplace where car owners can rent them out to non-owners, allowing consumers to anticipate their consumption modes actively. The emergence of these platforms poses to the car manufacturers another threat that requires them to react by either embracing or fighting against the sharing businesses. To the extreme, car manufacturers may decide to adopt new business models themselves: they can consider renting out cars directly to customers as a service and charging them on a per-use basis instead of selling them for a one-off payment. BMW and Daimler's Share Now and General Motors' Maven are the typical, but not unique, examples of car manufacturers' attempts to establish their carsharing services.

In sum, the emergence of new business models for the circular economy triggers systematic changes in the interactions between various stakeholders in many industries. Therefore, the studies of new business models need to account for these interactions to understand better the mechanism behind the changes and the outcomes.

Bearing that in mind, this thesis contributes to the debate by making use of the analytical toolbox of Industrial Organization, which possesses several advantages worth exploiting to complement the general-equilibrium approach used in most of the existing literature on environmental economics. The focus on partial equilibrium analysis with the use of game-theoretical modeling allows us to concentrate on the strategic interaction among firms and the strategic decision of consumers when they participate actively in the market. With this approach, we can look deeper into the existing interactions and how they shape the market's outcomes. Not only are these elements essential on their own, but they also help establish the microfoundations for further studies using general equilibrium and macroeconomic analyses. Then, the comparative static exercises on the Nash equilibrium given by the model can study potential public measures and changes in the industries that lead to the desired solutions concerning some specific measures of environmental impacts and consumers surplus and indicate potential win-win improvements for both the economy and the environment while still accounting for the interaction among firms and between firms and consumers.

The thesis is organized into three chapters, each investigating one of the three business models *peer-to-peer sharing*, *recycling*, and *pay-per-use*. Chapter 1 addresses the competition between a manufacturer of a product and a platform that organizes the peer-to-peer sharing market of that product, given that consumers actively choose whether to own a product and, if they do, whether to share the product with non-owners. Chapter 2 then proposes a two-period dynamic model to investigate how primary producers/manufacturers react to an improvement in the recycling process and how this reaction affects the environmental benefits of recycling, focusing on the trade-off that the manufacturer faces when using the first-period production to limit the scale of the recycling industry when the latter enters the market. Finally, Chapter 3 discusses the conditions under which renting a product on a per-use basis instead of selling it can benefit both the firm and the environment in a simple stylized model where the firm faces a consumer base with stochastic demand. While Chapter 1 and 2 are connected by the concept of reuse/remanufacture/recycle and focus on the potential to reduce the environmental impacts during the production phase, Chapter 3 concentrates on one possible reaction of the manufacturer - organize the reuse activity itself to avoid the competition from new entries - and discuss the environmental impact during the product's usage phase.

More specifically, in **Chapter 1**, I develop a competition model between a manufacturer and a peer-to-peer (P2P) platform that organizes a marketplace for owners of the manufactured product to rent it out to non-owners for revenue. When participating in the P2P market as *suppliers*, owners incur two types of cost associated with renting: a *bring-to-market* cost that is constant across *suppliers* and a *depreciation in the benefits associated with private ownership* proportional to their preferences. The platform maximizes its profits by charging a commission for each transaction realized on the P2P market. Meanwhile, the manufacturer can acquire an ownership stake in the platform and maximizes the total profit obtained from the manufacturing division and its participation in the platform's profits.

The model first demonstrates that the 'products' provided by the two firms are not pure complements nor substitutes. While they are substitutes in the *renters*' viewpoint, they are complements in the *suppliers*' viewpoint. In fact, the two firms' prices are strategic complements due to the clearing of the P2P market: if the manufacturer increases its price, fewer consumers buy the product. Thus, the demand for renting increases and the supply of renting decreases. The clearing of the P2P market then requires a higher rental price, which benefits *suppliers* and allows the platform to extract some of this surplus via higher platform fees. The mechanism works similarly starting from platform fees.

Second, the model provides a set of comparative static results with respect to the two types of costs associated with renting. The model shows that reducing the costs that are *constant* across *suppliers* leads to an expansion of the P2P market, a higher profit for the platform, but a lower profit for the manufacturer. In contrast, reducing the costs that are *proportional* to *suppliers*' preferences for private ownership leads to a shrinkage of the P2P market and a lower profit for both firms.

Third, due to the 'coopetition' between the two firms, if the manufacturer holds a larger ownership stake in the platform, it can set a higher price for the manufactured product to enlarge the P2P market. By doing so, the manufacturer earns less from the decreasing sales volume. However, the platform can benefit from both a larger volume of rental transactions and a higher fee. Consequently, the manufacturer is also better off as its participation in the platform's increasing profit offsets the loss from manufacturing activities.

Lastly, the model allows discussing the improvements that can lead to a win-win situation: a larger P2P market to lower the environmental impacts of the manufacturer's production and a higher consumer surplus at the same time. The analysis shows that increasing the degree of integration between the two firms can reduce the environmental impacts of the economy but at the cost of consumer surplus. At the other extreme, reducing the costs proportional to *suppliers*' preferences for private ownership can benefit consumers but yields higher impacts on the environment. In fact, reducing the costs that are constant across *suppliers* is the only win-win improvement for both consumers and the environment. Because the platform also benefits from this cost reduction, it has a genuine incentive to promote this change. However, the manufacturer is worse-off and might try to impede such cost reduction by using either the product's nature or the bargaining power over the platform via the integration. As a result, the government's interventions might be necessary to attain this sustainable improvement by targeting the correct cost reduction and balancing the impact of the two firms' integration.

In **Chapter 2**, I exploit the classical two-period Cournot-competition model to analyze the strategic interaction between competing firms that source their inputs from either primary (the *manufacturers*) or recycled material (the *recyclers*). This competition is peculiar because of the link between the manufacturers' primary production in period 1 and the input for the recyclers' production in period 2. Indeed, the available recycled material in period 2 is a fraction of what manufacturers produced in period 1, determined by a collection rate chosen by the authority. Due to this link, improving the recycling process with a higher collection rate generates two opposite effects on primary production. On the one hand, it reduces primary production once recyclers enter the market because the competition they exert on manufacturers gets stronger as recycling is improved. On the other hand, the better the recycling process, the lower the incentives for manufacturers to reduce their primary production before recyclers enter. The benefit for manufacturers from limiting the recyclers' future operating scales must indeed be measured against the cost of forgoing current profits. Improving the recycling process worsens the benefit/cost ratio of this strategy because it forces the manufacturer to accept a more considerable decrease of its current primary production to reach a given reduction of the recyclers' scale of entry. As a result, the analysis establishes that improvements in the recycling process do not necessarily reduce primary material extraction.

Therefore, a government that aims at minimizing total primary production (and that can modify the collection rate at zero cost) chooses to set the collection rate at an intermediate level that achieves the best balance between the incentives given to manufacturers to reduce their production in period 1 (so as to limit the recyclers' operating scale) and the competition exerted by recyclers to limit the manufacturer's production in period 2. There exists, however, a trade-off between the environment and surplus generated in the market: the collection rate chosen by the pro-environment government is too high from the manufacturers' viewpoint and too low from the recyclers and consumers' viewpoint.

In **Chapter 3**, I study the potential of the pay-per-use (PPU) business model; i.e. the firm rents the product on a per-use basis instead of selling it, as a sustainable business model in terms of its capacity to yield a higher profit for the firm and a lower aggregate use level of the product. For this purpose, I propose a stylized model in which a manufacturer faces two segments of customers identified by their usage rate for the product. In addition, the consumers do not know precisely the utility level they can derive from a specific instance of need. Hence, if the firm chooses to sell the product, a consumer decides whether to buy the product based on the expected utility she obtains from owning it. Alternatively, if the firm chooses to serve the product on a per-use basis, a consumer can learn about the utility derived from the instance of need before making the renting decision without the need to form an *ex-ante* expectation.

As a result, if the firm cannot price-discriminate its customers under *selling*, it faces the classical trade-off: set a high price and sell to high-usage customers only or set a low price and sell to both segments of customers. In contrast, because there is no (or insignificant) upfront payment under *PPU*, any customer can use the product at the instances of need that yield a utility higher than the per-use fee she pays to the firm. Consequently, even without the capacity to distinguish different types of customers, the firm under *PPU* can segment its customers by having them pay according to the volume of use they incur.

Therefore, if the firm finds it optimal to focus only on the high-usage segment under *selling*, *PPU* allows the firm to extend the market to the low-usage segment without necessarily appropriating less surplus from high-usage customers. Otherwise, if the firm finds it optimal to cover the market with a low price under *selling*, *PPU* allows the firm to appropriate more efficiently the surplus of high-usage customers without giving up on the low-usage segment.

However, *PPU* is not always more profitable for the firm. Since the product incurs an operating cost each time it is used, the firm may face the trade-off between serving only the high-utility instances of need with high margins or serving all the instances of need with low margins. In the former case, *PPU* can obtain a lower total willingness-to-pay from consumers for serving fewer instances of needs. In the latter case, *PPU* can appropriate less consumers' surplus than *selling* when they encounter high-utility instances of need. For this reason, the profitability of *PPU* compared to *selling* is ambiguous. The firm can earn higher profits under *PPU* if and only if the gain from the segmentation capacity offsets the two aforementioned negative impacts.

As of the two business models' environmental impacts, the dominance of *PPU* over *selling* is also ambiguous. While some customers may use the product less, more customers can access the product under *PPU*. Consequently, the additional customers' usage can offset the reduction in others' and increase the aggregate use level. To conclude, it is not evident that *PPU* can be more sustainable than *selling*; it is a win-win business model only under certain conditions.

2

Manufacturer vs. P2P sharing platform

Coopetition, cost reductions, and a pathway to sustainability

The interaction between a manufacturer and a platform that organizes the peer-to-peer sharing of the former's products such as GetAround and Uber is not a mere competition but a 'coopetition.' Indeed, such a platform enables consumers to gain short-term access to products without buying them and disrupts the manufacturer's demand. However, the opportunity for consumers to earn revenue from sharing also increases their willingness to pay for the manufacturer's product and partially offsets the latter's loss due to the decreasing demand. Therefore, the manufacturer does not have incentive to lower its price if the threat from demand reduction is not too high. Consequently, improving the efficiency of the sharing market by reducing the costs associated with sharing may lead to different outcomes: while a cost reduction that is constant across peer suppliers does not trigger the manufacturer's reaction and increases sharing, a cost reduction that is proportional to the suppliers' valuation for private ownership triggers the manufacturer's reaction and decreases sharing. Furthermore, the manufacturer may react to the threat from the P2P platform by integrating (partially or fully) with the latter; while the integration expands further the sharing market, it does so at the cost of consumer surplus. Hence, public policies aiming at supporting the sharing economy for the sake of both the environment and consumers need to target the correct cost reduction and balance the impacts of the firms' integration.

2.1 Introduction

A group of PhD students in Brussel plans to go for a car trip to the beautiful mountainous zone of Ardenne. Ten years ago, they could do it if they owned a car or were courageous enough to rent one. At that time, renting a car required the renter to spend some time checking the car rental companies and signing a rental contract with a long list of articles concerning the state of the vehicle, the insurance, and various underlying procedures (and costs). Furthermore, the car needed to be picked up at a specific time and a specific place; the key needed to be handled by a specific agent. Flexibility was a real luxe and the best solution was owning a car. Things are different in 2021! One of the PhD students picks up his phone, taps on a small purple "g" icon (stands for GetAround, the American peer-to-peer (P2P) carsharing platform now available in Europe after having acquired Drivy, another P2P carsharing platform that have dominated this region). He then scrolls the screen, taps on some button to reserve and pay. Just a short moment and voilà, the car will be at Jourdan Square the following day, ready to be unlocked by his phone for the day trip, no key needs to be handled, no contract on paper to be signed. Even more strange, the car is not owned by GetAround. The car owner also lives in Brussel; he does not use his car for the moment, so he rents it out via GetAround for some money without knowing who the renters are. Nevertheless, the students and the car owner do not meet face-to-face for the transaction; all thank the platform.

Such transactions are omnipresent nowadays. In the last decade, technological advances and changing consumer preferences from *owning* to *accessing* (particularly among the younger generations) have fueled the emergence of P2P sharing platforms in multiple industries worldwide. For instance, in the mobility industry, P2P carsharing platforms such as Turo, GetAround, and Drivy have enabled millions of users to use hundreds of thousands of cars worldwide without buying them. In 2019, these P2P platforms together accounted for more than 25% of the carsharing market's total revenue of \$2.5 billion (Wadhwani and Saha, 2020).[1] Even more impressive is the development of ride-hailing platforms like Uber, Lyft, Grab, and Didi. While the value of the global ride-hailing market is estimated to decline from \$60.5 billion in 2019 to \$52.07 billion in 2020 due to the

[1] The rest of the market share belongs to business-to-consumer (B2C) carsharing companies that are not parts of the sharing economy defined in this chapter and is the topic of chapter 4.

COVID-19 outbreak, it is then expected to recover and reach $85.48 billion in 2023, representing an average annual growth rate of 17.97% (Research and Markets, 2020). In fact, among the five most valuable firms in the mobility business, only three are carmakers (respectively Tesla, Toyota and Volkswagen); the rest are two P2P sharing platforms Uber and Didi Chuxing. As of May 2021, the market capitalization of General Motors and Ford Motor, two of the biggest established carmakers worldwide, are respectively $86 billion and $56 billion, while Uber is evaluated at $95 billion.[2]

The emergence of P2P sharing platforms raises many questions, both economically and environmentally. From the economic perspective, P2P platforms are considered a disruption to traditional businesses. However, while it is clear that P2P platforms represent a direct threat to traditional service providers such as traditional car rental services and taxi companies,[3] the relationship between a P2P platform and a manufacturer that produces the product to be shared on the platform is less straightforward. On the one hand, the platform competes against the manufacturer by allowing consumers to use the latter's products without buying them. However, on the other hand, the platform increases consumers' willingness to pay for the manufacturer's product by allowing them to earn extra revenue from the product they own. As a result, it is unclear how the manufacturer should react when the P2P platform becomes more efficient.

From the environmental perspective, P2P sharing is touted as a more sustainable alternative than the legacy selling business model. By changing fundamentally the way the product is consumed, sharing reduces the production and consumption of materials and hence, is considered one of the business models for the circular economy (OECD, 2019). Nevertheless, similar to other circular economy business models, sharing still occupies small niches in the economy as of today. Therefore, one question that arises naturally is how to scale up this new business model in a sustainable way for firms, consumers, and the environment.

This paper contributes to these debates by providing a competition model in which the manufacturer is the sole provider of a product and the platform the organizer of a P2P market, where owners of the product rent it out to

[2] https://www.economist.com/business/2021/04/15/new-means-of-getting-from-a-to-b-are-disrupting-carmaking (last accessed June 14, 2021)

[3] see, for instance, Cramer and Krueger (2016) and Berger, Chen and Frey (2018) for the discussion on this topic.

non-owners for a rental price. Consumers choose between three consumption modes based on the personal valuation they attach to ownership. They can (1) buy the product and use it only for themselves (*hoarders*), (2) buy, use, and rent it out on the P2P market (*suppliers*), or (3) rent the product on the P2P market without buying it (*renters*). Relative to *hoarders*, *suppliers* earn a revenue by renting out the product but incur two types of costs associated with sharing: a depreciation in *suppliers*' private benefits from ownership that is proportional to their preferences and a cost to bring the product to the P2P market that is constant across all of them.

By organizing the P2P market, the platform earns a profit by charging *suppliers* a fee, which is a percentage of the rental price that *renters* pay to *suppliers* at the P2P market's clearance. For the manufacturer, besides the profits from selling its products, the firm can also earn a proportion of the platform's profits if acquiring an ownership stake in the platform. In such cases, when setting the purchase price for the product, the manufacturer considers both its operating profits and the participation in the platform's profits secured by the ownership stake.

This setting is useful for investigating the manufacturer's incentive in holding an ownership stake in the P2P platform and how the costs associated with sharing affect the size of the P2P market and the firms' profits. Using the manufacturer's production level as a proxy for the environmental impacts generated by the economy, I also discuss the potential of P2P renting to alleviate the environmental impacts while improving the surplus generated in the economy.

Main results. First, it is worth pointing out that the 'products' of the manufacturer and the platform are not purely complementary or substitutable. From the *renters*' viewpoint, the two 'products' are substitutes because the P2P market provides consumers with another alternative: to rent the product instead of buying it. However, from the *suppliers*' viewpoint, the two 'products' are complements as the manufacturer's product is an input for the rentals on the P2P market. For this reason, the interaction between the two firms are not a mere competition but a 'coopetition' (Brandenburger and Nalebuff, 1996). Indeed, due to the market-cleaning mechanism in the P2P market, the two firms' pricing decisions end up being strategic complements. Suppose the manufacturer sets a higher price, then fewer consumers buy the product. Thus, supply for renting decreases while demand increases. The P2P market clearance then requires a higher rental price, which increases the revenue for *suppliers* and allows the platform to charge them a higher fee to extract the additional surplus. Similarly, suppose the platform sets a higher fee. In that case, fewer owners are willing to supply their product on the P2P market. Thus, supply for renting increases while demand decreases. The P2P market clearance then requires a higher rental price that benefits *suppliers* and increases their willingness to pay for the manufactured product.

Second, I provide a set of comparative static results to investigate the effects of a cost reduction in the P2P market on outcomes at equilibrium. While it is reasonable to stimulate that improving the efficiency of sharing by reducing the inherent costs would scale up the P2P market, I prove that this insight is not always correct: it depends on whether the manufacturer perceives that the improvement is too threatening and reduces aggressively its price to gain back the market.

More precisely, I characterize two types of costs associated with sharing: a *bring-to-market cost* constant across *suppliers* and a *depreciation of the benefits from private ownership* that is proportional to their preferences. Examples of a reduction in the bring-to-market cost include Uber's "new car discounts" program, a monetary subsidy for Uber drivers when they buy a new car,[4] or GetAround's standardization of the key-exchange process and provision of dedicated parking slots for its *suppliers*. Imposing universally to all *suppliers* participating in the P2P market, these efforts are expected to bring about the same benefits to all of them. In contrast, the efforts aiming at establishing a sense of community for *suppliers* or improving the virtue of sharing as an act for sustainability are likely to reduce the depreciation of the benefits from private ownership for influencing, each person in a different manner, the owners' desire to keep the product for themselves.

As for results, a cost reduction that is constant across *suppliers* does not trigger the manufacturer's reaction and leads to a larger P2P market, higher consumer surplus, and higher profits for the platform but lower profits for the manufacturer. In contrast, a cost reduction that is proportional to *suppliers*' preferences triggers the manufacturer's reaction, leading to a smaller P2P market and higher consumer surplus but lower profits for both the P2P platform and the manufacturer.

Third, I shed light on the incentive of the manufacturer to own a stake

[4] https://www.uber.com/us/en/drive/vehicle-solutions/new-car-discounts/ (last accessed June 14, 2021)

in the platform and the outcomes of this strategy. In reality, some carmakers react to the platforms' emergence by investing in them. General Motors, for instance, put $500m into Lyft in 2016. Toyota has also invested in Uber, Didi, and Grab, three ride-hailing platforms dominating three different geographical markets in the world. While GM has since sold its stake (with a benefit) to start its own adventure in the sharing space with Maven, Toyota has hold on its investment.

Due to the 'coopetition' nature between the two firms, I show that the manufacturer is interested in integrating with the platform but not to suppress the P2P market. In fact, when holding a larger ownership stake in the platform, the manufacturer is interested in setting a higher price and selling fewer of its product to support the P2P market. In such cases, the platform benefits from both a large volume of transaction and a higher fee. For the manufacturer, despite the loss due to lower sales volume, its participation in the platform's incremental profits can offset the loss and result in higher profits in total.

Lastly, using the results above, I discuss how the new business model can be scaled up sustainably: with a cost reduction constant across the *suppliers*. Indeed, only a cost reduction of this type can scale up the P2P market and increase consumer surplus at the same time. Notably, the total surplus generated in the economy increases with the cost reduction if and only if the cost is small enough and the manufacturer does not hold too large an ownership stake in the platform. However, the manufacturer earns lower profits following such a cost reduction and might react by discouraging the efforts to reduce the cost or acquiring more ownership stake in the P2P platform. Both strategies are detrimental to consumers. Therefore, government interventions might be necessary to attain the desirable outcomes. Policies such as exclusive parking slots for sharing, subsidies for owners when participating in sharing, and establishing a legal framework to reduce rental-related risks can encourage the correct cost reduction. On the impact of the two firms' integration, this paper suggests that the environmental impacts should be included in the evaluation of mergers in these specific markets; while an excessively high level of integration is detrimental, a partial integration between the two firms can support the sharing market, reduce the environmental impact of the economy and if wealth can be redistributed to consumers, can be a sustainable pathway for the economy.

The sharing economy. The term "sharing economy" lacks a unified definition. Due to the novelty of the concept, this umbrella definition includes a wide variety of business models that with different properties.[5] Botsman and Rogers (2010) broadly define the sharing economy or collaborative consumption as *"traditional sharing, bartering, lending, trading, renting, gifting, and swapping, redefined through technology and peer communities."*

In this paper, I focus on the peer-to-peer sharing platforms that organize marketplaces for *"consumers to grant each other temporary access to under-utilized physical assets that they own for money"* (Frenken and Schor, 2017). By organizing the marketplaces, these platforms lower the costs associated with sharing for *suppliers* and attract owners who would not rent out their product otherwise.

Carsharing is arguably a typical example of P2P sharing.[6] Having unused seats for daily commutes most of the time and sitting idling for 95% of the day (Shoup, 2005), cars provide a immense potential for P2P platforms around the world such as GetAround and Turo in the America, Blablacar and Drivy in Europe, or more local services such as CarAmigo and Degage in Belgium. As of 2017, nearly three million individuals in North America have participated in P2P carsharing with a shared fleet of 131,336 vehicles among six operators (Shaheen, Martin and Bansal, 2018). Across the Atlantic, the P2P carsharing platform Drivy has not fallen behind in becoming the most prominent and fastest-growing carsharing platform in Europe. Since 2010 only, the platform has built up a community of two and a half million users in France, Germany, Spain, Austria, Belgium, and the U.K. In April 2019, the acquisition of Drivy by GetAround formed a P2P car-rental platform that spreads internationally over 300 cities with more than five million users.

According to some research, the market of "new transport," including P2P and B2C carsharing, could be enormous. (Accenture, 2020) has estimated that the revenues from new transport will make up 40% of the total revenue from mobility, including car sales, in 2050, which will hit $6.6tr. Uber, in its own research ahead of its IPO, even estimated a larger potential, put the ride-hailing market at $5.7 trillion.

[5] See Codagnone, Biagi and Abadie (2016), Sundararajan (2016), and Frenken and Schor (2017) for detailed discussions on the definitions and typologies of the term.

[6] As of July 2020, Tracxn.com records 447 P2P rental platforms. These platforms allow individuals to rent a wide range of products, from vehicles, to tools (Sparetoolz), to various consumer products (Fat Lama).

As mentioned above, some business models are also classified under the big umbrella of the “sharing economy” but do not make use of the products’ idle capacity. The on-demand service platforms such as Uber and Lift, for instance, are distinguished from P2P car rental platforms like Turo and GetAround by nature. With Uber and Lift, the consumer creates new capacity every time he or she orders a ride. Without the order, the driver would not have made the trip in the first place. By contrast, in car sharing, the consumer occupies the car for the periods that would not have been used by the owner. Indeed, platforms like Uber provide a service similar to a traditional taxi company and are now called “ride-hailing” rather than “ride-sharing” companies. However, in this paper, I do not distinguish between ride-hailing and P2P sharing platform as long as they are short-term rental transactions conducting between peers. With an abuse of vocabulary, both business models are addressed to as P2P rental platforms.

This paper, however, does not cover business-to-consumer (B2C) rental firms such as Zipcar and Cambio. While P2P platforms make use of the existing stock of idle vehicles of consumers, B2C firms own the fleet of cars that they rent out to consumers by making use of advanced technologies to ease the rental process. Thus, this “carsharing” business model is an evolutionary form of the traditional car rental service and should be put in the class of “access-based business models.”

The rest of the paper is organized as follows. Section 2 presents the model and computation of the Nash equilibrium. Section 3 conducts the static comparisons that prove the main results of the paper. Section 4, discussion the literature and contribution of this paper. Section 5 concludes. Proofs are given in the Appendix.

2.2 Model setup and equilibrium

In this section, I set up a simple competition model between a manufacturer and a P2P platform. While the manufacturer is the sole provider of a manufactured product, the P2P platform organizes a marketplace where a consumer, having purchased the product from the manufacturer, can consider renting it out to a non-owner.

Consumers. Consider a unit mass of consumers identified by the benefit that they attach to *private ownership*, denoted by x, that is uniformly distributed over $[0, 1]$. Consumers wish to purchase at most one unit of the product. Assuming that consumers obtain a gross utility high enough when using the product (with or without owning it) so that the P2P market exists and all consumers are active, each consumer then decide to adopt one of the three consumption modes

- *(H)oarder*: buy the product, use it and do not rent it out
- *(S)upplier*: buy the product, use it and rent it out on the P2P market
- *(R)enter*: do not buy the product but rent it on the P2P market

with the corresponding utility functions

- (H): $U_H = v + x - p_M$
- (S): $U_S = v + \alpha x - w - p_M + p_R(1 - p_S)$
- (R): $U_R = v - p_R$

All consumers obtain a utility v by using the product, independent of whether they own it or not. We can think of v as the intrinsic utility that consumers derive from the product's function (such as the essential utility a person derives from using a car to go from A to B).

Additionally, a *hoarder*, by purchasing a product at price p_M and keeping it for herself, enjoys a *benefit of ownership* x that depends on her personal preferences. A benefit of this type can come from many sources. For illustration, we can think of the enhancement of social image by ownership, the capacity to personalize the product or the flexibility and freedom to use the product whenever the consumer wants. These benefits naturally vary from person to person.

A *renter* does not own the product and enjoys no benefit of ownership. However, instead of paying p_M to purchase the product, she only pays a rental price p_R when she rents it on the P2P market and obtain a net utility $v - p_R$.

Relative to a *hoarder*, a *supplier* earns an additional revenue of $p_R(1 - p_S)$ after paying the total commission $p_S \times p_R$ to the P2P platform. However, the *supplier* also incurs two types of costs associated with sharing that a *hoarder* does not.

The first type of cost is a depreciation in the *supplier*'s benefits of ownership; that is, a *suppliers* of type x only obtains the benefit equal αx, with $\alpha \in$

$(0, 1)$. It should be noted that, even though α is constant across all *suppliers*, since each consumer attaches a different value to the benefits of ownership x, the cost $(1 - \alpha)x$ is proportional to the *suppliers*' preferences. Examples of this cost are psychological factors related to sharing, such as the feelings toward independence through ownership, the prestige of ownership, or privacy concerns, among others.[7] These psychological costs are strongly correlated with the preferences toward private ownership and are naturally heterogeneous among *suppliers*.

The second type of cost associated with sharing is the *bring-to-market* cost $w > 0$ that is constant across all *suppliers*. Returning to the example of car renting, *suppliers* incurs costs from listing the car for rent on the platform, organizing key exchanges and car drop-offs, and installing the kits required by the platform. Moreover, *suppliers* also have to pay more attention to vehicle maintenance due to the risk of vehicle damage because of the lack of care during the usage of *renters* (Shaheen et al., 2018). Given that the *suppliers* face the same pool of *renters* and, in this model, own homogeneous products provided by the manufacturer, they have the same expectation for these costs.

The peer-to-peer market. For the sake of tractability, I assume that each *supplier* or *renter* only conducts one transaction on the P2P market, so that the market-clearing rental price p_R is determined when the number of *suppliers* equals the number of *renters*. While there is no explicit network effect with this assumption, the P2P market's clearance generates pecuniary feedbacks that negatively affect consumers within each group and positively consumers across the two groups *suppliers* and *renters*. Indeed, if more *renters* join the P2P market, the higher level of demand will lead to a higher rental price p_R at clearance, which is detrimental to all existing *renters* but beneficial to the *suppliers* on the other side. Similarly, if more *suppliers* join the market, the lower market-clearing rental price p_R due to the higher level of supply will be detrimental to existing *suppliers* but beneficial to the *renters* on the other side.

Firms. Let $n_H(p_S, p_R, p_M)$, $n_S(p_S, p_R, p_M)$, and $n_R(p_S, p_R, p_M)$ denote respectively the number of *hoarders*, *suppliers* and *renters*. The platform charges each *supplier* a fee p_S over the rental price p_R she obtains from a

[7]See, for instance, Hawlitschek, Teubner and Gimpel (2016) among others for empirical discussions on these factors.

certain *renter*.[8] At optimum, the platform sets the fee p_S to maximize its profit $\pi_P = n_S(.)p_R p_S$.[9]

The manufacturer cannot price discriminate between the *hoarders* and *suppliers* and charge a unique price p_M for the purchased product.[10] At optimum, the manufacturer sets the price p_M to maximize its total profits $\Pi_M = \pi_M + \lambda\pi_P$. The manufacturer's total profits include its operating profits $\pi_M = \big(n_H(.) + n_S(.)\big)p_M$ by selling $n_H + n_S$ products at price p_M and its participation in the P2P platform's profits $\lambda\pi_P$ secured by the ownership stake $\lambda \in [0, 1]$ it holds in the platform. If $\lambda = 0$, the two firms are fully separated. If $\lambda \in (0, 1)$, the manufacturer has a partial ownership stake in the platform, and therefore the two firms are partially integrated. Finally, if $\lambda = 1$, the manufacturer entirely owns the platform and the two firms are fully integrated.

It is important to highlight that the P2P platform maximizes its profits arising from organizing the P2P market irrespective of the ownership stake λ; that is, the acquisition of a passive ownership stake ensures the manufacturer a share of the platform's profit but does not imply any corporate control over the latter. This assumption is well justified if λ is small enough. However, even a significantly large λ does not automatically give the manufacturer a control right in the platform. For instance, the platform owners can preserve their voting control by issuing only non-voting stocks to other shareholders.

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[8] In this paper, I only consider a for-profit monopolistic platform and a manufacturer to focus on the interaction between the two firms. This assumption is generally correct in the mobility industry, where both car manufacturers and the platforms like Uber, Grab, and Blablacar have market powers. Even though there are many platforms, each of them tends to dominate a certain geographic segment.

[9] In this model, the platform only sets the commission p_S and let *suppliers* decide on the rental fee p_R. This setting corresponds to the business model of carsharing platforms such as Getaround and Turo. On average, they charge *suppliers* between 25 and 40 % of the value of the transaction. It is also possible that the platform sets both p_S and p_R like in the case of Sparetoolz. However, as shown later, the profit-maximization program requires the P2P market to clear, which results in a one-to-one relationship between p_S and p_R given a price p_M set by the manufacturer. Therefore, the two approaches are equivalent and lead to the same results. See Bikhchandani (2018) for the proof of this mechanism in a similar setting.

[10] Indeed, Varian (2000) shows that the firm is better off if it can price discriminate between two groups of consumers with high and low willingness-to-pay for the product. The intuition is that the firm can sell the same quantity of good at the same price as if it cannot distinguish the two groups and also earn some additional revenue from selling to rental stores which rent the product to consumers with low willingness-to-pay.

Furthermore, suppose competition authorities consider that the ownership stake is above the threshold of *decisive influence*. In that case, they may require the manufacturer to reduce its ownership stake or impose structural and behavioral remedies on the two parties so that the manufacturer may not determine directly or indirectly the strategic commercial conduct of the platform to avoid anticompetitive mergers. Finally, to protect the minority shareholders of the P2P platform, corporation laws can also impose a *fiduciary obligation* that requires the manager of the acquired firm to act in the interest of the firm as an independent, stand-alone entity (O'brien and Salop, 2000).

The independence of the platform also matches with reality. While Toyota and Daimler own a stake respectively in Getaround and Turo, their investments are relatively small compared to other stakeholders and are not likely to secure their majority voting rights in the acquired platforms. One exception might be the case of General Motors, which launched its own P2P rental marketplace using its existing carsharing platform, Maven. However, the firm recently shut down the pilot programs, and it is uncertain that the firm will re-launch the service in the future.

Timeline. The model consists of four stages. In the first stage, the manufacturer sets the price p_M to maximize its total profits $\pi_M + \lambda\pi_P$. In the second stage, the platform sets the fee p_S to maximize its profits π_P. In the third stage, consumers form expectations of their utilities by anticipating the P2P market's outcomes and choose the optimal consumption mode. In the final stage, the P2P market clears; that is, the rental price p_R is determined at $n_S(p_R) = n_R(p_R)$. The model is solved backward to look for the subgame-perfect Nash equilibrium.

2.2.1 The P2P market

Let us assume that v is large enough so that non-owners always choose S over the outside option and that the bring-to-market cost is neither too small nor too large; that is, $w \in \big(\lambda(4-3\alpha), 2(4-3\alpha)\big)$. This assumption ensures that all the three types of consumer H, S, and R co-exist in equilibrium. If the bring-to-market cost is too high, no consumer wants to be *supplier*and the P2P market disappears. If the bring-to-market cost is too small, there is no *hoarder* and $n_S = n_R$ regardless of other parameters.

Under these two assumptions, the consumers who are indifferent between H and S and between S and R are respectively located at x_{HS} and x_{SR} such that $U_H(x_{HS}) = U_S(x_{HS})$ and $U_S(x_{SR}) = U_R(x_{SR})$ as represented in Figure 2.1.[11] It follows that the number of *hoarders*, *suppliers* and *renters*, respectively denoted by n_H, n_S and n_R, are given by

$$\begin{aligned}
n_H &= 1 - x_{HS} = 1 - \frac{p_R(1-p_S) - w}{1-\alpha}\,, \\
n_S &= x_{HS} - x_{SR} = \frac{p_R(2-\alpha-p_S) - p_M(1-\alpha) - w}{\alpha(1-\alpha)}\,, \\
n_R &= x_{SR} = \frac{p_M - 2p_R(2-p_S) + w}{\alpha}\,.
\end{aligned}$$

Since participating in the P2P market depreciates the benefits of ownership of owners, consumers who attach high benefits to ownership choose to be *hoarders* because renting out the product on the P2P market lowers their utilities significantly. Meanwhile, consumers who attach medium benefits to ownership do not lose significantly from renting out the product and participate in the P2P market as *suppliers*. Finally, because renting the product on the P2P market does not yield any benefit of ownership, only consumers who attach low benefits to ownership choose to be *renters*. Under the assumptions mentioned above, the market is covered and the total number of consumer adds up to 1: $n_H + n_S + n_R = 1$.

At the clearance of the P2P market, that is, $n_S(p_R) = n_R(p_R)$, the rental price is determined as

$$p_R^{P2P}(p_M, p_S) = \frac{2p_M(1-\alpha) + w(2-\alpha)}{4 - 3\alpha - p_S(2-\alpha)}\,. \tag{2.1}$$

We can observe in Equation (2.1) that any increases in p_M or p_S will result in a higher rental price p_R^{P2P}. Indeed, a higher p_M or p_S will lower the supply level and raise the demand level on the P2P market upward, which, in turn, results in a higher rental price when the P2P market clears. As I will show in the next section, this market clearing mechanism is key to explain the strategic interaction between the manufacturer and the P2P platform.

[11] Indeed, at the equilibrium values of p_M, p_R, and p_S, $x_{HS} < 0$ (there is no *hoarder*) if $w < \lambda(4-3\alpha)$ and $x_{SR} > 1$ (there is no *renter*) if $w > 2(4-3\alpha)$.

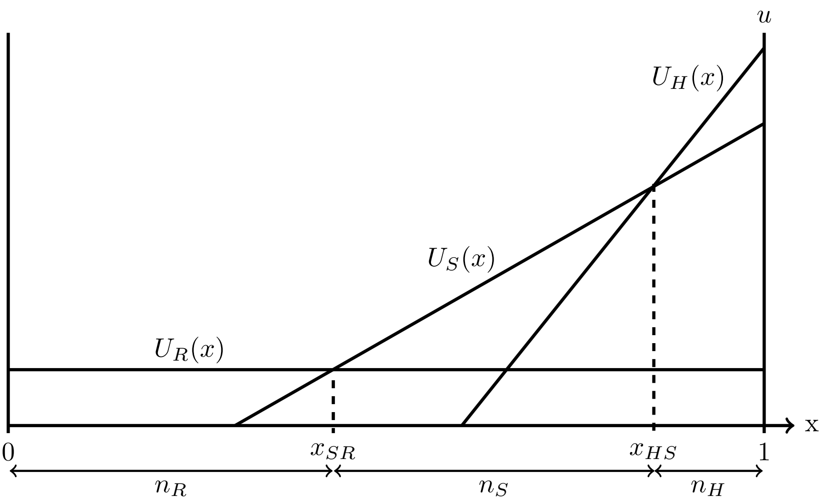


Figure 2.1. Consumers' utility and the masses of consumers of each type

2.2.2 Competition and the equilibrium

Substituting the rental price $p_R^{P2P}(.)$ in Equation (2.1) into the profit functions of the manufacturer and the platform, we obtain

$$\pi_M = \frac{\big(4 + w - 3\alpha - p_S(2-\alpha) - p_M(1-p_S)\big)p_M}{4 - 3\alpha - p_S(2-\alpha)}\,,$$
$$\pi_P = \frac{\big(w(2-\alpha) + 2p_M(1-2\alpha)\big)\big(p_M(1-p_S) - w\big)p_S}{4 - 3\alpha - p_S(2-\alpha)}\,.$$

Before computing the equilibrium, it is worth pausing to look more closely at the two firms' strategic interactions as recorded in the following lemma.

Lemma 1. *Separately, the price set by the manufacturer and the fee by the P2P platform are strategic complements; that is, the best-response function of the manufacturer is increasing in the fee set by the platform and vice-versa,*

$$\frac{dp_M^{BR}(p_S)}{dp_S} > 0 \quad and \quad \frac{dp_S^{BR}(p_M)}{dp_M} > 0\,.$$

Proof. Consider the maximization problems of the two profit functions $\pi_M(p_M)$

and $\pi_P(p_S)$, the first-order conditions can be written as

$$\frac{\partial \pi_M(p_M)}{\partial p_M} = 0 \iff p_M^{BR}(p_S) = \frac{4-3\alpha+w-p_S(2-\alpha)}{2(1-p_S)}\,,$$
$$\frac{\partial \pi_P(p_S)}{\partial p_S} = 0 \iff p_S^{BR}(p_M) = \frac{(p_M-w)(4-3\alpha)}{w(2-\alpha)+p_M(6-5\alpha)}\,,$$

from which we obtain

$$\frac{dp_S^{BR}(p_M)}{dp_M} = \frac{2w(4-3\alpha)^2}{\big(w(2-\alpha)+p_M(6-5\alpha)\big)^2} > 0$$

and

$$\frac{dp_M^{BR}(p_S)}{dp_S} = \frac{2(1-\alpha)+w}{2(1-p_S)^2} > 0\,.$$

□

In fact, classifying the 'products' of the manufacturer and the platform as substitutes or complements is not straightforward. On the one hand, the manufacturer's product is an input for the services of the P2P market. Hence, from the *suppliers*' viewpoint, the two products are complements. Nevertheless, on the other hand, the P2P market provides the consumer another alternative: to rent the product instead of buying it. Hence, from the point of view of the *renters*, the two products are substitutes.

Rather, the strategic complementarity of prices in this case relies on the effects of the two prices p_M and p_S on the rental price $p_R^{P2P}(.)$ at the P2P market's clearance via their effects on the demand and supply of renting. To understand better this mechanism, taking the profit functions of the two firms before substituting therein the rental price $p_R^{P2P}(.)$

$$\pi_M(p_M) = \frac{(\alpha-w+p_R(2-p_S)-p_M)p_M}{\alpha}\,,$$
$$\pi_P(p_S) = \frac{\big((2-\alpha-p_S)p_R-(1-\alpha)p_M-w\big)p_Rp_S}{\alpha(1-\alpha)}\,,$$

and maximizing them with respect to the corresponding prices, we obtain

$$p_M(p_S) = \frac{p_R(2-p_S)+\alpha-w}{2}\,,$$
$$p_S(p_M) = \frac{(2-\alpha)p_R-(1-\alpha)p_M-w}{2p_R}\,,$$

which yields

$$\begin{aligned}\frac{dp_M(p_S)}{dp_S} &= \frac{-p_R}{2} + \frac{\partial p_R}{\partial p_S}\left(1 - \frac{p_S}{2}\right) , \\ \frac{dp_S(p_M)}{dp_M} &= \frac{-(1-\alpha)}{2p_R} + \frac{\partial p_R}{\partial p_M}\frac{(1-\alpha)p_M + w}{2p_R^2} .\end{aligned} \tag{2.2}$$

Indeed, if the rental price p_R^{P2P} was independent of p_M and p_S; that is, $\frac{\partial p_R}{\partial p_M} = \frac{\partial p_R}{\partial p_S} = 0$, we would obtain $\frac{dp_M}{dp_S} = -\frac{p_R}{2} < 0$ and $\frac{dp_S}{dp_M} = \frac{-(1-\alpha)}{2p_R} < 0$; that is, all other factors being constant, the price p_M and the fee p_S are strategic substitutes because the P2P platform and the manufacturer both earn their profits from the surplus of the same consumers (the *suppliers*). However, from the P2P market's clearance, we can derive that $\frac{\partial p_R}{\partial p_S} = \frac{(w(2-\alpha)+2p_M(1-\alpha))(2-\alpha)}{[4-3\alpha-p_S(2-\alpha)]^2} > 0$ and $\frac{\partial p_R}{\partial p_M} = \frac{2(1-\alpha)}{4-3\alpha-p_S(2-\alpha)} > 0$; substituting into Equation (2.2), we obtain the strategic complementarity in Lemma 1.

The intuition behind this result is that, because an increase in p_M makes owning a product more expensive, more consumers will choose *renting* over *owning* the product. Due to this effect, there will be a lower supply and a higher demand for renting. The clearing of the P2P market then requires a higher rental price p_R. Since *suppliers* earn a higher surplus with the higher rental price, the platform can set a higher fee p_S to extract some of this additional surplus.

Similarly, an increase in p_S makes it more expensive to become *suppliers*. Consequently, more consumers will choose *renting* and *hoarding* over *supplying*, which leads to a higher level of demand and a lower level of supply for renting. The clearing of the P2P market then also requires a higher rental price p_R. Since *suppliers* now earn higher revenue by renting out their product, they are willing to pay more to purchase it, allowing the manufacturer to set a higher price p_M.

Equilibrium. In the second stage of the game, the P2P platform sets p_S to maximize its profit function $\pi_P(p_S)$, which yields the best-response function

$$p_S^{BR}(p_M) = \frac{(p_M - w)(4-3\alpha)}{w(2-\alpha) + p_M(6-5\alpha)} . \tag{2.3}$$

Substituting into the profit functions $\pi_P(.)$ and $\pi_M(.)$, we obtain

$$\pi_P(p_M) = \frac{(p_M - w)^2}{4(4-3\alpha)} ,$$
$$\pi_M(p_M) = \frac{(8-6\alpha+w-p_M)p_M}{2(4-3\alpha)} .$$

In the first stage, the manufacturer sets p_M to maximize its total profit $\Pi(p_M) = \pi_M + \lambda\pi_P$. The first-order condition of the profit maximization problem can be written as

$$\frac{d\Pi(p_M)}{dp_M} = 0 \iff p_M^* = \frac{8-6\alpha}{2-\lambda} + w\frac{1-\lambda}{2-\lambda} .$$

Substituting the price p_M^* into Equations (2.3) and (2.1), we obtain the fee set by the platform and the rental price at equilibrium respectively

$$p_S^* = \frac{(8-6\alpha-w)(4-3\alpha)}{2(4-3\alpha)(6-5\alpha)+w(10-7\alpha)-2\lambda w(4-3\alpha)} ,$$
$$p_R^* = \frac{2(4-3\alpha)(6-5\alpha)+w(10-7\alpha)-2\lambda w(4-3\alpha)}{2(4-3\alpha)(2-\lambda)} .$$

The profits of the two firms at equilibrium are then given by

$$\pi_M^* = \frac{\big(2(4-3\alpha)(1-\lambda)+w\big)\big(2(4-3\alpha)+w(1-\lambda)\big)}{2(4-3\alpha)(2-\lambda)^2} ,$$
$$\pi_P^* = \frac{\big(2(4-3\alpha)-w\big)^2}{4(4-3\alpha)(2-\lambda)^2} .$$

2.3 Comparative statics

The objective now is to provide a set of comparative statics to understand (*i*) how the outcomes at equilibrium change following a reduction in different types of cost associated with sharing represented by changes in the two parameters α and w; and (*ii*) the incentive of the manufacturer to integrate with the P2P platform; that is, how the manufacturer's profits depend on the ownership stake λ it holds in the platform. As mentioned previously, the attention is restricted to the values of w in the interval $\big(\lambda(4-3\alpha), 2(4-3\alpha)\big)$ to focus on the interior solution with all three types of consumers co-existing in equilibrium. To concentrate better on the mechanism, the formal proofs are relegated to the Appendices.

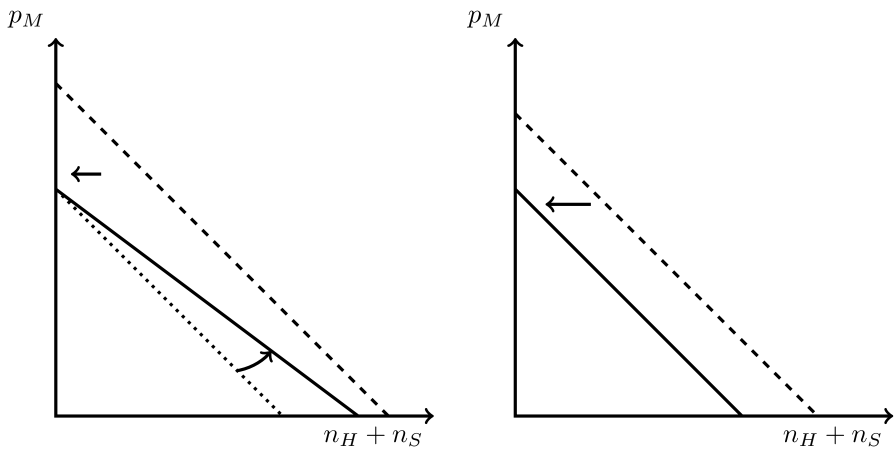
2.3.1 Impacts of reducing the costs associated with sharing

In this section, I investigate the effects on the outcomes at equilibrium of marginal improvements in the P2P market, modeled by reductions in the two types of costs associated with sharing incurred by *suppliers*: the bring-to-market costs w and the depreciation of the benefits from private ownership $(1-\alpha)x$. While reducing both types of costs makes *supplying* cheaper and more attractive, they affect *suppliers* in two different manners: a reduction in w is constant across *suppliers*, whereas an increase in α reduces the cost proportionally to *suppliers*' preferences. The comparative static result is recorded in the following proposition:

Proposition 1. *Reducing a cost associated with sharing always makes the manufacturer worse off. However, the effects on the P2P platform depends on the type of cost reduction: A cost reduction that is proportional to suppliers' valuation for private ownership results in a smaller P2P market and lower profits for the P2P platform. On the contrary, a cost reduction constant across suppliers results in a larger P2P market and higher profits for the P2P platform.*

It is helpful to remind that the population size is fixed and the P2P market is cleared. Hence, even though all *suppliers* are owners, a higher number of *suppliers* is equivalent to a higher number of *renters*, thus, a lower number of owners, which is the demand for the manufactured product. Therefore, if the supply on the P2P market is high, the demand for the manufactured product is low and vice versa.

If the cost reduction comes from an increase in α, we observe a pivot change that affects the slope of the supply on the P2P market; due to the proportional increase in the benefits brought about by this cost reduction, *suppliers* with higher valuations for ownership are more favorably affected. A steeper demand curve means consumer elasticity is lower with respect to an increase in p_S. Thus, the platform is more interested in attracting higher-valuation owners as *suppliers* and pushing low-valuation owners to become *renters*. Since the 'products' of the two firms are substitutes in the *renters*' viewpoint, making renting more appealing to a larger number of consumers poses a significant threat to the manufacturer. Furthermore, this threat is more significant when the owners are of high preferences for ownership since they benefit significantly from the increase in α if they decide to become *suppliers*. Consequently, the manufacturer is interested in reducing the platform's advantage by extending



(a) an increase α **(b)** a decrease in w

Figure 2.2. Change in the demand curve of the manufacturer following an increase in α and a decrease in w

the owner base to lower preferences for ownership to reduce the benefit they obtain from the higher α. Technically, we observe a pivot change that flatters the demand for the manufactured product. A flatter demand curve means consumer elasticity is lower with respect to an increase in p_M. Thus, the manufacturer is more interested in selling more products at a lower price.

In contrast, following a decrease in w, all *suppliers* obtain the same benefits. Hence, we observe an outward parallel shift of the supply on the P2P market, which allows the platform to increase the commission p_S and earn more profit. Unlike the previous case, the benefits brought about by the cost reduction do not depend on the preferences for owners' ownership. Hence, the manufacturer cannot limit the platform's advantage by shifting the consumer base to lower preferences for private ownership as it does in the other case. As a result, we observe an inward parallel shift in demand for the manufactured product, leading to a lower price of p_M and a smaller sales volume.

Due to the reaction of the manufacturer, the platform does not necessarily benefit from all cost reductions: only cost reductions constant across *suppliers* are beneficial for the platform. This is because, following a cost reduction that is proportional to *suppliers*' valuation for private ownership, the manufacturer lowers its price aggressively, which reduces both the transaction volume on the P2P market and the fee that the platform can charge *suppliers*.

2.3.2 Fight or embrace the P2P market?

In this section, I study the incentive of the manufacturer to acquire an ownership stake in the P2P platform. More precisely, I investigate the change in the manufacturer's profits following an increase in the parameter λ. The result is recorded in the following proposition:

Proposition 2. *When the manufacturer holds a larger ownership stake in the P2P platform, it is interested in selling fewer products at a higher price. The platform then benefits from both a larger P2P market and a higher fee. For the manufacturer, the increasing participation in the platform's incremental profits can offset the reduction in the operating profits and allows the firm to earn higher profits in total.*

When the manufacturer holds a larger ownership stake λ in the platform, it internalizes the platform's profits in its objective function to a larger extent. Because the two prices p_M and p_S are strategic complements as presented in Lemma 1, the manufacturer is better off not by lowering down but by raising the manufactured product price p_M. The intuition is that, by selling fewer products at a higher price, the manufacturer creates a higher renting demand on the P2P market. This will benefit the platform by increasing both the transaction volume and the rental price on the P2P market. For the manufacturer, while the operating profits π_M decrease, the increasing participation in the platform's incremental profits $\lambda\pi_P$ is large enough to offset the loss and increases the firm's total profits. Therefore, a higher λ results in a larger P2P market and higher profits for both firms.

It is worth noting that the two firms do not earn profits directly from *renters*. Instead, both the manufacturer and the platform only extract the *renters*' surplus indirectly through the rental price they pay to *suppliers*. Therefore, restricting the number of products available to encourage more renting is the only way the two firms can extract this surplus, which would not otherwise exist. In a sense, the platform's existence unlocks values in the market (the *renters*) that the manufacturer does not have a way to exploit otherwise. For this reason, the interaction between the manufacturer and the P2P platform can be classified as 'coopetition' rather than competition, following the guideline of Brandenburger and Nalebuff (1996).

In reality, given the relatively small size of P2P carsharing compared to the mobility industry, it is understandable that these investments and acquisitions nowadays do not attract much of the competition authorities' attention. However, P2P carsharing is growing fast. Ride-hailing and P2P sharing are expected to occupy more than 25% of the American mobility market, and ride-hailing alone occupying more than half of the Chinese market in 2030 terms of market volume (Accenture, 2020). Hence, scrutinizing the integration between manufacturers and P2P platforms will soon become necessary, as shown in Proposition 2.

2.3.3 Is there necessarily a trade-off between the environment and economic surplus?

A full analysis of how the competition between the manufacturer and the P2P platform affects the environment goes beyond the scope of this paper. Nevertheless, it is generally accepted that a larger scale of the P2P market is better for the environment since it reduces the production level $n_O^* = n_H^* + n_S^*$ and hence, the consumption of materials.[12]

The comparative statics above point out that increasing λ or decreasing w results in a larger P2P market and a lower production level of the manufactured product, whereas increasing α raises the manufacturer's production level. However, the question of interest now is whether there is necessarily a trade-off between environmental benefits and the economic surplus; or it is possible to reduce the environmental impacts while still increasing the economic surplus generated in the economy. The answer to this question is recorded in the following corollaries:

Corollary 1. *A higher degree of integration between the manufacturer and the P2P platform reduces the environmental impacts of the economy. However, while it is beneficial for both firms, it results in a lower consumer surplus.*

When the manufacturer holds a larger ownership stake in the platform, it internalizes the platform's profits in its objective function to a larger extent and

[12]This paper on focus on the environmental impacts of the production phase; that is, a lower production level use less raw materials and energy. It can also be a concern that the environmental impacts during the usage rate increases with the scales of the P2P market and offsets the gain from producing less. The framework of this model does not allow this analysis. For more discussion on the effect of carsharing on the usage rate, see Chapman, Eyckmans and Van Acker (2020).

has an incentive to soften the competition between the two firms. Consequently, they extract a more significant part of consumer surplus and make consumers worse off. Logically, a higher degree of integration between the firms gives them a larger market power, which benefits them at the cost of a reduction in consumer surplus and the deadweight loss in total surplus. Nevertheless, the manufacturer then sells fewer products, supporting the P2P market and generating lower environmental impacts.

Corollary 2. *A cost reduction that is proportional to suppliers's valuation for private ownership makes consumers better off but makes the firms worse off and leads to higher environmental impacts.*

As proven in Proportion 1, a cost reduction that is proportional to *suppliers*'s valuation for private ownership leads to fiercer competition between the two firms by increasing the price elasticity of demand. Consequently, it results in lower prices, lower profits for both firms, and higher consumer surplus at equilibrium. However, because the manufacturer sells more products, such a cost reduction increases the environmental impacts of the economy. Hence, a cost reduction that is proportional to *suppliers*' valuation for private ownership benefits the P2P platform and consumers at the expense of the manufacturer's profits and the environment.

Corollary 3. *A cost reduction that is constant across suppliers is beneficial for consumers, the P2P platform, and the environment. However, because the manufacturer's profits decrease, the total surplus of the economy does not vary monotonically with the cost reduction. Consequently, the total surplus increases only if the cost is lower than a certain threshold. Notably, this threshold decreases in the ownership stake the manufacturer holds in the platform, making it impossible to improve the total surplus if the ownership stake the manufacturer holds in the platform is too large.*

We have seen that only a cost reduction that is constant across *suppliers* can lead to a win-win situation for both the environment and consumers. Since a decrease in w also benefits the P2P platform, the latter may be willing to invest in reducing the costs. However, the manufacturer is worse off when w decreases as the loss in its operating profits offsets the increase in its participation in the platform's profits. Consequently, the manufacturer may prevent the cost reduction, for instance, by applying a technology that makes it harder for the *suppliers* and the platform to reduce the cost.

Moreover, the manufacturer may react to the loss in profits by acquiring more ownership stakes in the platform, which results in a lower total surplus. Thus, reducing w only leads to a higher total surplus if the gain from reducing w is large enough to offset the loss caused by the high ownership stakes λ that the manufacturer holds in the platform. In other words, w must be smaller than a certain threshold $\bar{w}$. This threshold decreases with λ, meaning that the larger the manufacturer's ownership stake in the platform, the harder it is for the cost reduction to increase the total surplus. The following corollary records the implication of this result.

Corollary 4. *To attain a win-win improvement for both the economic surplus and the environment, the government might need to intervene in the market to reduce w and balance the manufacturer's incentive to acquire too large an ownership stake in the platform.*

One example of the government's policy that can help reduce w in carsharing is the one related to parking. Providing more accessible parking options is indeed a good policy to lower the bring-to-market costs of sharing, notably in a highly dense city, where parking costs significantly to car owners. Many municipalities in Sweden, including Gothenburg and Umeå, already provide favorable parking conditions for carsharing and ratified parking policy that allows property owners and developers to build fewer parking spaces with developments if they offer access to carsharing. Many cities in Europe also provide exclusive parking slots for carsharing, typically the "parking de covoiturage" in France and Belgium. In Brussel, the municipality has allowed the P2P carsharing platform GetAround to use some 24 parking spots in 12 central areas of the capital, including Brussels Central Station, rue Dansaert, the Sablon and Yser metro in a five-year contract, reducing the cost of car owners to rent their car out, particularly in a city with expensive parking like Brussel.[13]

Alternatively, the government is also the potential major player in this improvement and the most trustworthy candidate to reduce risk and improve security for the sharing economy. *Suppliers* on the P2P market face theft, robbery, property damage, and even risk to their safety. Good support from the government with legal frameworks and regulations is naturally the best

[13] https://www.thebulletin.be/brussels-extends-car-sharing-service-getaround (last accessed June 14, 2021)

approach to reduce these risks for all participants of the P2P platform homogeneously and lead to a win-win improvement for society.

It is worth discussing here the trade-off between market power and the environment. While the higher level of integration between the two firms hurt consumers, it also leads to a larger P2P market and is better for the environment. The analysis shows that if the manufacturer's ownership stake in the platform is not too large, reducing the bring-to-market costs can lead to a win-win situation for both the environment and total surplus in the economy. This result suggests that anti-trust discussions should also include the environmental perspectives, at least until the point that wealth can be reallocated so that consumers are compensated for their loss. In such cases, a not-to-large ownership stake in the platform can be a win-win situation for both the environment and the economy.

2.4 Related literature

In a broad sense, this paper contributes to the literature on the relationship between the reuse of products and the demand for new products, which roots back to the early developments of the literature on *durable goods* and *secondary markets*. This strand of the literature[14] generally concludes that secondary market limits the manufacturer's market power and hence, its profits; however, some studies have found that a secondary market can increase demand for new goods. To justify the underlying mechanism, Fox (1957) argues that the secondary market turns consumer products into "liquid assets' that consumers can easily sell, hence promotes sales on the primary market. Along the same line, Kursten (1991) shows that the overall effect of the secondary market is to increase consumers' wealth and thus, increase overall demand. A more recent study of Thomas (2003) shows that increasing secondary sales of products that have abundantly used items to be brought to the market, such as electronics, furniture, and clothing, decreases the demand for new goods. However, if there is not a ready supply of waste-used goods, as in cars, housing, and books, the growth of the secondary market increases the demand for new goods, thereby increasing material consumption. While being primarily concluded by Waldman (2003), the literature has recently obtained renewed interests

[14]started with Swan (1970) then followed by numerous studies such as Rust (1986), Kim (1989), Anderson and Ginsburgh (1994), Waldman (1996) , and Hendel and Lizzeri (1999b)

from economists due to the emergence of P2P sharing, a new type of "reuse" markets. There are at least three reasons for this return on the topic. First, the analyses aforementioned focus on the reuse of used products that has lower quality than the new one. This vertical-differentation setting is not exactly the characteristics of a P2P sharing market, which allows consumers to access to the same underused products. Second, this strand of the literature often considers a decentralized secondary market with limited intervention from an intermediary that organizes and regulates the reuse market in a two-sided platform nature as in the context of the P2P sharing economy. Third, the P2P sharing market does not concern a transition of ownership as in secondary markets. By breaking the transaction into small units of short-term rental activities and focusing on the access to the service rather than the product itself, P2P platforms minimize the problem of adverse selection in secondary markets as discussed in Akerlof (1970), Bond (1982), and Hendel and Lizzeri (1999a).

Analyzing the P2P sharing platform, this paper is also closely related to the literature started with Rochet and Tirole (2003) and Armstrong (2006) on multisided platforms: platforms that allow multiple sets of agents to interact and the decisions of each set of agents affects the outcomes of other sets, typically through "network effects".[15] While the literature is enormous, all the studies typically assume distinct sets of agents and do not allow them to change sides.[16] This assumption is generally correct in many markets, including the credit-card market with shop owners vs. consumers and the media market with advertisers vs. users. However, it is not the same for P2P platforms: consumers are not defined ex-ante as *suppliers* or *renters*; each consumer endogenously chooses to be one or the other. In light of this, I allow consumers to self-select into different sides of the P2P market: consumers can decide to buy the product and become *suppliers* or not to buy the product and become *renters*.[17] This specific setting creates another relationship between the two groups of users:

[15]See Belleflamme and Peitz (2018) for a review of key findings from the literature on network effects and multisided platforms.

[16]To the best of my knowledge, Gao (2018) is the only paper until now analyzing the "mixed two-sided markets," where agents can appear on both sides of the platform.

[17]This setting is relevant for products such as cars. If a consumer chooses to buy a car, she will not rent somebody else's car, whereas she has no other choice than to rent if she does not buy a car. Yet, for other products such as tools, a consumer could acquire a limited set of tools and rent them out to other users while relying on other users to rent the tools she misses; in this case, being a *supplier* or a *renter* would be a matter of degree. The second case is not tackled in the scope of this paper.

on the dynamic toward equilibrium, beside the co-movement due to network effects between the two sides, in case of a fully covered market, if the size of one group of consumers increases, it is necessary that the size of the other group of consumers decreases. Consequently, this assumption imposes one more constraint on the platform: beyond attracting more users to the P2P market, it also needs to balance users' incentives to switch from one side to another.

It is also important to note the link between the "sharing economy" in this paper and the sharing of information goods such as books, music, movies, and digital products. In the context of information products, Varian (2000) focuses on the same trade-off as in this paper: the presence of a sharing institution, for instance, a library, may reduce the demand of purchases of books, but the price the library is willing to pay will be higher and can benefit the content provider. He points out that the content producer's profits can increase with the presence of sharing under certain circumstances, among which, a low transaction cost of sharing. To add to his conclusion, in this paper, I also prove that the outcomes also depend on the cost's nature; not all cost reductions can benefit the product's producer (and the sharing institution).

Another strand of literature related to this paper deals with piracy - the illegal sharing of digital products. Studies in this literature also cover one side of the trade-off mentioned above: the content producers' profits decrease because piracy has "displaced" legitimate products. While the content producers may still benefit from piracy via the network effect, sample, and indirect appropriation (Belleflamme and Peitz, 2014a,b), they do not benefit from the higher willingness to pay of the owners who share the file illegally. In contrast, this paper allows *suppliers* to anticipate the revenues (and costs) she incurs in the P2P market and endogenizes her willingness-to-pay for the manufactured product.

Also related to this paper is an increasing number of studies investigating the competition between the peer-to-peer platforms and the traditional providers, mainly focusing on the impacts of Airbnb on the hotel industry. This literature has shown mixed results, depending on the dataset samples and the geographical focus of the study.[18] Blal, Singal and Templin (2018), for instance, estimate the impacts of Airbnb on hotel sales performance in San Francisco and find that the entry of Airbnb does not represent a serious disruption to the hotels. On the contrary, studies such as Zervas, Proserpio

[18]See Guttentag (2019) for the most recent literature review

and Byers (2017), and Dogru, Mody and Suess (2017) estimate the impacts of Airbnb respectively in Texas, Boston and conclude that Airbnb negatively affects hotels' profitability by reducing hotels' prices and occupancy rates, particularly during peak demand periods. I do not explore the same issue: these studies focus on the competition between the peer-to-peer platforms and traditional providers on the markets, whereas I focus specifically on the interaction between the manufacturer and the P2P platform that benefits from the products sold by the former to organize the P2P rental market. While competing against the manufacturer, the P2P platform also relies on the former to build up the stock of products to rent, leading to a more peculiar interaction between the two firms.

Finally, this paper contributes to a small but growing literature on the peer-to-peer rental market of physical goods. Fraiberger and Sundararajan (2015) develop a dynamic model of peer-to-peer Internet-based rental market for durable goods to characterize the stationary equilibrium of the model. Using the data of rental transactions through Getaround to calibrate their dynamic model, the authors confirm that a small fraction of below-median income consumers switches from being non-owners to owners. They also predict an increase in consumer surplus, particularly in the below-median income population following the entry of the peer-to-peer P2P market. The authors also examine bringing-to-market costs and consider the platform's pricing problem, showing mixed results of the sharing economy's impacts on ownership and surplus. Benjaafar, Kong, Li and Courcoubetis (2018) considers the ownership choice with and without the possibility of peer-to-peer rental and points out similar conclusions. Weber (2016) studies the impact of the peer-to-peer economy on social welfare, concludes that consumer surplus always goes up with the introduction of an efficient P2P market while the producer's profit may decrease, particularly when the product's marginal cost is low. Filippas, Horton and Zeckhauser (2020) model a simple sharing economy to look for the equilibrium in the short and long run without the interaction between the manufacturer and the platform. They find that the sharing economy always expands consumption and increases consumer surplus. However, the level of ownership may not decreases, particularly when there exist bring-to-market costs. In a subset of this strand of literature, researchers also study settings in which co-exist both P2P and B2C sharing business models. Wang, Ng and Ciwei (2020) investigate the manufacturer's incentive to provide, alongside selling, the B2C renting service itself when there is a P2P market between consumers. However, the authors do not consider a P2P platform that organizes the market and, thus, no strategic reaction from this institution. Most recently, Lin, Sun, Cao, Zhou and Chen (2020) investigate the cooperation between P2P car rental services and on-demand ride-sharing to solve the shortage of cars when drivers who want to provide the transport service do not have a car. They find that this cooperation can result in a win-win-win situation for the ride-sharing platform, consumers, and drivers. All these studies, however, do not take into account either the decision of the manufacturer or the P2P platform, which is the main focus of this paper.

This paper is closest to Abhishek, Guajardo and Zhang (2019). They analyze the P2P market's impact on a manufacturer's profitability by characterizing consumers by two segments of different usage rates. Within each segment, consumers have different valuations for the usage of the product sold by the manufacturer. Using this setting, they show that both the manufacturer and consumers are worse off with the P2P market if consumers' heterogeneity in usage rate is too high or too low and better off otherwise. However, they focus on the heterogeneity of consumers and do not consider the strategic interaction between the manufacturer and the P2P platform, neither the impacts of reducing the *costs associated with sharing* on the outcomes.

2.5 Discussion and concluding remarks

This paper discusses the emergence of the sharing economy, focusing on the interaction between a manufacturer and a P2P platform. Specifically, I investigate the case in which the manufacturer is the sole provider of a product and the platform the organizer of a marketplace where consumers who purchased the product from the manufacturer rent it out to non-owners for a rental price. Using a simple model, I show how the manufacturer can benefit from holding an ownership stake in the P2P platform by selling fewer products and how reductions in different types of costs associated with sharing affect the outcomes at equilibrium. Based on these results, I also discuss the trade-off between the environment and economic surplus and point out a potential pathway to a more sustainable economy: reducing the costs that are constant across *suppliers* in the P2P market. Such an improvement can reduce the production level of the manufactured product and increase the economic surplus at the same time. Furthermore, we can increase the market's total surplus if the costs are low enough and the manufacturer does not hold too large an ownership stake in the P2P platform. Because the manufacturer is worse off following the cost reduction, this analysis emphasizes the role of the government's intervention to encourage the cost reduction and prevent counter-productive reactions from the manufacturer.

I also highlight the strategic complementarity between the two firms' choices of prices due to the clearance of the P2P market. It is crucial to notice that the relationship between the two firms is not "purely" competitive. While the two firms' 'products' are substitutes in the non-owners' viewpoint, they are considered complements by the renters. Hence, the manufacturer and the P2P platform do not merely compete but also benefit from each other. The P2P platform relies on the manufacturer to provide the stock of goods needed to establish the P2P market. Meanwhile, the manufacturer can sell the product at a higher price with the presence of the P2P platform because a product owner can earn extra money by renting it out on the P2P market and has a higher willing-to-pay for the product. Thus, to some extent, the two firms are at the same time competitive and cooperative, or "coopetitive", using the terminology of (Brandenburger and Nalebuff, 1996).

Unlike other papers studying the two-sided platform business model, I endogenize consumers' choice between *suppliers* and *renters*. In practice, this assumption aligns better with the rental platforms' properties, where consumers can endogenously decide to join one side or the other. Technically, this assumption is also necessary to avoid the all-too-apparent results that the platform always finds it beneficial to make all owners *suppliers* when the mass of non-owners is sufficiently large. Indeed, in this setting, if the platform focuses extensively on attracting *suppliers* by charging a low fee, it makes *supplying* so attractive that many consumers choose to be *suppliers*. The high level of supply and low level of demand on the P2P market, in their turn, leads to a low market-clearing rental price. Consequently, both the revenue for *suppliers* and the platform's profits decrease.

The results in this paper can also point to further empirical tests to investigate how improving the P2P market can affect the production level of manufacturers in the industry. According to the model, improvements that benefit *suppliers* in the same manner, such as Uber's subsidy, GetAround's key-exchange standardization, or municipalities' provision of dedicated parking slots, should lead to a larger sharing market and lower production level of the product. In contrast, efforts such as marketing campaigns or community building should lead to the opposite outcomes.

It is vital to highlight one limitation of this model. While I assume that each consumer only uses the product once, consumers repeatedly use the product numerous times during its lifecycle with different usage rates in reality. Allowing for this feature will change the model in several ways. Firstly, a consumer's choice of consumption depends on her usage rate; that is, she is more likely to buy the product if she uses it intensively and more likely to rent it otherwise. Consequently, the product's under-utilized capacity is small, limiting the frequency that its owner can rent it out. Therefore, relative to the current model, the P2P platform will have to attract more *renters* and *suppliers* to increase the volume of transactions on the P2P market, which reduces the competitive advantage it has over the manufacturer. Secondly, this feature will affect the pricing structure of the P2P platform. The platform, counting for consumers' heterogeneous usage rates, will not be indifferent between different pricing structures, namely a fee per transaction, a membership fee, or a two-part tariff pricing scheme. Also, whether the platform charges the *suppliers* or *renters* might yield more complex interactions and richer results for the model. However, introducing this additional dimension in the model increases computation complexity dramatically and is left for further research.

Another limitation of the model comes from the assumption of a covered market with a fixed population. Under this assumption, one more owner means one less *renter*, one more *hoarder* means one less *supplier*. Indeed, if the market is not covered, the P2P platform's existence might lead to expanding the market, which can be favorable to the manufacturer. In such a case, the availability of *supplying* will encourage more non-owners to become owners. The manufacturer will then sell the product at both a high price and a large volume. Hence, this model puts the manufacturer in the worst-case scenario and is still useful to frame a benchmark for the analysis.

So far, the paper assumes that the manufacturer cannot price-discriminate its customers based on whether they rent the product on the P2P market. Another extension worth investigating is introducing the manufacturer's capacity to conduct this strategy. In the context of information products, Varian (2000) find that the content producer can benefit from sharing if it can price discriminate consumers using the sharing market. In the context of manufactured products, we can think of different price-discriminating mechanisms. For instance, the manufacturer can offer a particular insurance/warranty contract to *suppliers*. An investigation in this direction may yield richer incentives and implications for the manufacturers and is worth considering for further research.

Appendix

2.A Proofs

Proposition 1.

Proof. Under the assumption $w < 2(4-3\alpha)$, differentiating the number of *suppliers* at equilibrium n_S^*, the profit functions π_P^* , π_M^*, and $\Pi^* = \pi_M^* + \lambda\pi_P^*$ with respect to λ yields:

$$\frac{dn_S^*}{d\lambda} = \frac{2(4-3\alpha)-w}{(2-\lambda)^2} > 0 \, ,$$
$$\frac{dp_M^*}{d\lambda} = \frac{2(4-3\alpha)-w}{2(4-3\alpha)(2-\lambda)^2} > 0 \, ,$$
$$\frac{d\pi_P^*}{d\lambda} = \frac{2(4-3\alpha)-w)^2}{4(4-3\alpha)(2-\lambda)^3} > 0 \, ,$$
$$\frac{d\pi_M^*}{d\lambda} = -\lambda\frac{\big(2(4-3\alpha)-w\big)^2}{2(4-3\alpha)(2-\lambda)^3} < 0 \, ,$$
$$\frac{d\Pi^*}{d\lambda} = \frac{\big(2(4-3\alpha)-w\big)^2}{4(4-3\alpha)(2-\lambda)^2} > 0 \, .$$

□

Proposition 2.

Proof. Differentiating the functions of interest with respect to α yieds

$$\frac{\partial n_S^*}{\partial\alpha} = \frac{-3w}{2(4-3\alpha)^2(2-\lambda)} < 0 \, .$$
$$\frac{\partial\pi_P^*}{\partial\alpha} = -\frac{3(8-6\alpha+w)(8-6\alpha-w)}{4(4-3\alpha)^2(2-\lambda)^2} < 0 \, .$$
$$\frac{\partial\pi_M^*}{\partial\alpha} = -(1-\alpha)\frac{3(8-6\alpha+w)(8-6\alpha-w)}{4(4-3\alpha)^2(2-\lambda)^2} < 0 \, .$$

Because both π_P^* and π_M^* decrease in α, the total profit of the manufacturer Π^* evidently decreases in α as well.

Contrarily, differentiating the functions of interest with respect to w yields

$$\begin{aligned}
\frac{\partial n_S^*}{\partial w} &= \frac{-1}{2(4-3\alpha)(2-\lambda)} < 0\,,\\
\frac{\partial \pi_P^*}{\partial w} &= \frac{w-2(4-3\alpha)}{2(4-3\alpha)(2-\lambda)^2} < 0\,,\\
\frac{\partial \pi_M^*}{\partial w} &= \frac{(1-\lambda)(w+8-6\alpha)}{(4-3\alpha)(2-\lambda)^2} + \frac{\lambda^2}{(2-\lambda)^2} > 0\,,\\
\frac{\partial \Pi^*}{\partial w} &= \frac{1-\lambda}{2-\lambda} + \frac{w}{2(4-3\alpha)(2-\lambda)} > 0\,;
\end{aligned}$$

that is, increasing w leads to a smaller P2P market, lower profits for both the P2P platform and the manufacturer even though the latter earns higher operating profits. □

Corollary 1.

Proof. As proven in Proposition 2, the size of the P2P market and the total profits of the two firms increase when λ increases. It is hence sufficient to prove that consumer surplus is decreasing in λ. Deriving the consumer surplus at equilibrium with respect to λ, we obtain

$$\frac{\partial CS^*}{\partial \lambda} = \frac{\big(2(4-3\alpha)\big(2\lambda(4-3\alpha)-15+11\alpha\big)-w(1-\alpha)\big)\big(2(4-3\alpha)-w\big)}{4(4-3\alpha)^2(2-\lambda)^3}\,.$$

Under the assumptions $w < 2(4-3\alpha)$, $\alpha < 1$ and $\lambda < 1$, we have $\frac{\partial CS^*}{\partial \lambda} < 0$; that is, consumers surplus is decreasing in λ. □

Corollary 2.

Proof. Because $\frac{\partial^2 CS^*}{\partial \alpha^2} = -3w\frac{16+3\alpha w-12\alpha-w}{4(4-3\alpha)^4(2-\lambda)^2} < 0$; that is, $\frac{\partial CS^*}{\partial \alpha}$ decreases with α and at the maximal value of α we have $\left.\frac{\partial CS^*}{\partial \alpha}\right|_{\alpha=1} = \frac{92-48\lambda+4w-w^2}{8(2-\lambda)^2} > 0$, we obtain $\frac{\partial CS^*}{\partial \alpha} > 0$; that is, consumer surplus increases with α. □

Corollary 3.

Proof. Because $\frac{\partial^2 CS^*}{\partial w^2} = \frac{1-\alpha}{4(4-3\alpha)^2(2-\lambda)^2} > 0$; that is, $\frac{\partial CS^*}{\partial w}$ increases with w and at the maximal value of w, we have $\left.\frac{\partial CS^*}{\partial w}\right|_{w=2(4-3\alpha)} = -\frac{1-\lambda}{2-\lambda} < 0$, we obtain $\frac{\partial CS^*}{\partial w} < 0$; that is, consumer surplus decreases with w or equivalently, increases with a decrease in w.

Taking the derivative of total surplus at equilibrium $TS^* = \pi_M^* + \pi_P^* + CS^*$ with respect to w, we obtain

$$\frac{\partial TS^*}{\partial w} = \frac{64\lambda - 2(4-3\alpha)(9-7\alpha-8\lambda+6\alpha\lambda) + w(25-19\alpha-16\lambda+12\alpha\lambda)}{4(4-3\alpha)^2(2-\lambda)^2}$$

For the total surplus to increases when w decreases; that is, $\frac{\partial TS^*}{\partial w} < 0$, we must have

$$w < \frac{2(4-3\alpha)(9-7\alpha-8\lambda+6\alpha\lambda) - 64\lambda}{25-19\alpha-4\lambda(4-3\alpha)} \equiv \bar{w}$$

The threshold $\bar{w}$ decreases in λ and satisfies the assumption $w > \lambda(4-3\alpha)$ if and only if

$$\lambda < \frac{9-7\alpha}{4(4-3\alpha))} \equiv \bar{\lambda}$$

Since $\bar{\lambda} < 1$ for all value of $\alpha \in (0,1)$, if $\lambda > \bar{\lambda}$, the total surplus decreases when w decreases for all value of $w \in (\lambda(4-3\alpha), 2(4-3\alpha))$. Only if $\lambda > \bar{\lambda}$ that there exists a threshold $\bar{w}$ so that total surplus increases when w decreases if $w < \bar{w}$. □

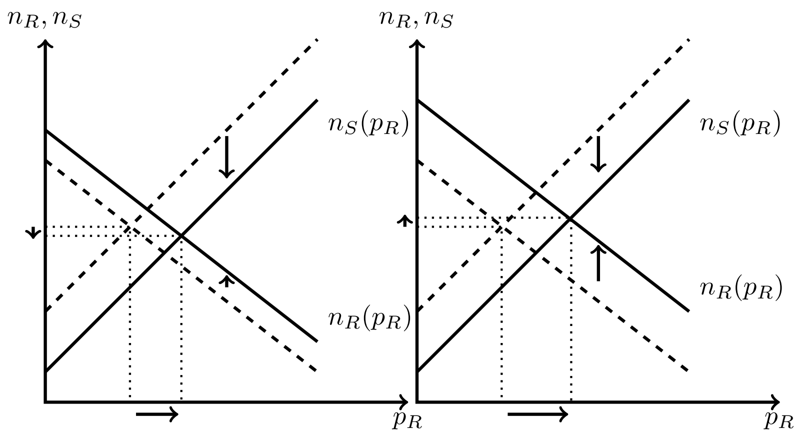
2.B Impacts of p_M, p_S, w and α on the P2P market

Impacts of p_M and p_S. It is worth noting here that, because the market is covered, all non-owners become *renters*. Hence, one fewer *owner* automatically transforms into one more *renter* and the total number of consumer is one; that is $\lambda(n_H + n_S) = -\lambda n_R$ and $n_H + n_S + n_R = 1$. Therefore, at a given rental price p_R, an increase in prices p_M or p_S reduces $n_H + n_S$ and increases n_R simultaneously.

However, since p_M are incured by all *owners* in the same way, it does not affect the marginal consumer x_{HS} but only affects the marginal consumer x_{SR}. Hence, changes in p_M does not influent n_H, leaving the mass $n_S + n_R$ intact. Therefore, on the P2P market, an increase in p_M will only shift the supply curve downward and the demand curve upward at the same magnitude, i.e. $\frac{\partial n_S(.)}{\partial p_M} = -\frac{\partial n_R(.)}{\partial p_M}$.

Meanwhile, because p_S affects both marginal consumer x_{SR} and x_{HS}, an increase in p_S reduces the financial gain from becoming *suppliers*, hence makes not only *hoarding* but also *renting* more appealing than *supplying* for some consumers. As a consequence, $\frac{\partial n_S(.)}{\partial p_S} < 0$ but $\frac{\partial n_H(.)}{\partial p_S} > 0$ and $\frac{\partial n_R(.)}{\partial p_S} > 0$

so that, when the market is covered, $\left|\frac{\partial n_S(.)}{\partial p_S} + \frac{\partial n_H(.)}{\partial p_S}\right| = \left|\frac{\partial n_R(.)}{\partial p_S}\right|$. Therefore, on the P2P market, an increase in p_S will shift the supply curve downward at a larger magnitude than the demand curve upward and leads to a larger volume of consumer n_S and higher rental price p_R at clearance of the market.



(a) Impacts of an increase in p_S **(b)** Impacts of an increase in p_M

Figure 2.B.0.1. Impacts of an increase in p_S and p_M on the P2P market

Impact of w and α. From Equation (2.2.1), we notice that w does not affect the slopes of the supply $n_S(p_R)$ and demand $n_R(p_R)$ curves on the P2P market. Decreasing w, hence, simply shifts the supply curve upward and the demand curve downward at the same magnitude, i.e. $\frac{\partial n_S(p_R)}{\partial w} = \frac{1}{\alpha} < 0$ while $\frac{\partial n_R(p_R)}{\partial w} = \frac{-1}{\alpha} < 0$ as illustrated in Figure 2.B.0.2).

An increase in α, however, has two impacts on the demand and supply curve on the P2P market: not only it shifts the demand curve $n_R(p_R)$ downward and the supply curve $n_S(p_R)$ upward but it also changes the slope of the two curves. Indeed, if we look closer to the slope of the two curves,

$$\frac{\partial n_S(p_R)}{\partial p_R} = \frac{2-\alpha}{\alpha(1-\alpha)} > 0\,,$$
$$\frac{\partial n_R(p_R)}{\partial p_R} = -\frac{2}{\alpha} < 0.$$

the impacts of an increase in α on the slope of the demand and supply curves

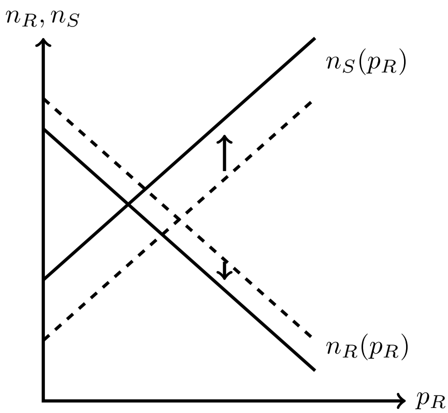


Figure 2.B.0.2. Impacts of a decrease in w

are given by

$$\frac{\partial^2 n_S(p_R)}{\partial p_R \partial \alpha} = \frac{4\alpha - \alpha^2 - 2}{\alpha^2(1-\alpha)^2} \,,$$
$$\frac{\partial^2 n_R(p_R)}{\partial p_R \partial \alpha} = \frac{2}{\alpha^2} > 0 \,.$$

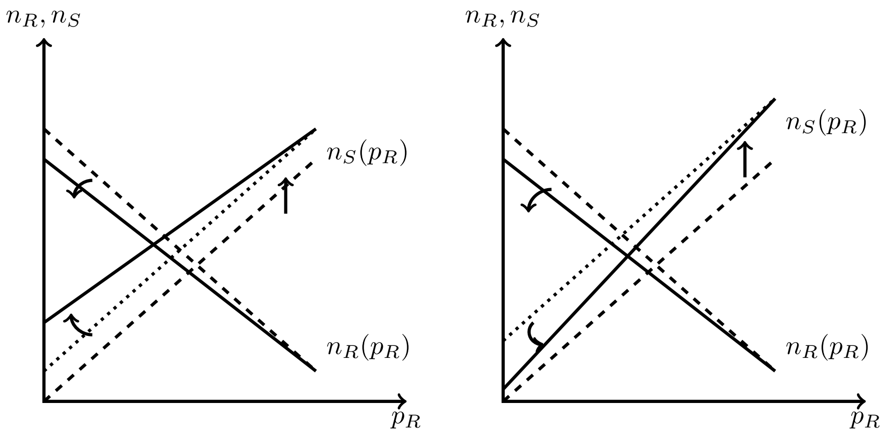
Since $n_R(p_R)$ increases in p_R, $\frac{\partial^2 n_R}{\partial p_R \partial \alpha_R} > 0$ indicates that the demand curves become steeper when α increases; that is, the demand of renting become more elastic with respect to p_R.

On the other hand, the sign of $\frac{\partial^2 n_S}{\partial p_R \partial \alpha}$ depends on the value of α. Indeed, $\frac{\partial^2 n_S}{\partial p_R \partial \alpha} < 0$ for $\alpha < 2 - \sqrt{2}$ and is positive otherwise. Since n_S decreases in p_R, this indicates that if $\alpha < 2 - \sqrt{2}$, the supply of renting become more elastic with respect to p_R following a reduction in α (Figure 2.B.0.3a). Otherwise, the supply of renting become less elastic with respect to p_R following a reduction in α instead (Figure 2.B.0.3b).

2.C Extension: lump-sum platform fee

Instead of a percentage fee, if the platform charges *suppliers* a fixed fee f_S, the utility functions of consumers of each consumption mode are given by

- (H): $U_H = v + x - p_M$,
- (S): $U_S = v + \alpha x + w - p_M + p_R - f_S$,



(a) Impacts of an increase in α if $\alpha < 2-\sqrt{2}$ **(b)** Impacts of an increase in α if $\alpha > 2-\sqrt{2}$

Figure 2.B.0.3. Impacts of an increase in w and α on the P2P market

- (R): $U_R = v - p_R$.

The numbers of consumers choosing each consumption mode are then

$$n_H = 1 - \frac{p_R - f_S + w}{1-\alpha},$$
$$n_S = \frac{p_R(2-\alpha) - p_M(1-\alpha) - f_S + w}{\alpha(1-\alpha)},$$
$$n_R = \frac{f_S + p_M - 2p_R - w}{\alpha},$$

which leads to the market-clearing rental price

$$p_R^{P2P} = f_S\frac{2-\alpha}{4-3\alpha} + p_M\frac{2(1-\alpha)}{4-3\alpha} - \frac{w(2-\alpha)}{4-3\alpha},$$

and the corresponding profit functions of the two firms as

$$\pi_M(p_M) = \frac{(4 - w - 3\alpha + f_S - p_M)p_M}{4-3\alpha}$$
$$\pi_P(f_S) = \frac{(w + p_M - f_S)f_S}{4-3\alpha}.$$

In the second stage of the game, the best-response function of the platform can be written as

$$p_S(p_M) = \frac{w + p_M}{2}.$$

Substituting in the objective function $\Pi(p_M) = \pi_M + \lambda\pi_P$ and maximizing it yields the price at equilibrium of the manufacturer

$$p_M^* = \frac{8-6\alpha}{2-\lambda} - w\frac{1-\lambda}{2-\lambda} \,.$$

The prices and profits at equilibrium are then:

$$\begin{aligned}
f_S^* &= \frac{8-6\alpha+w}{2(2-\lambda)} \,, \\
p_R^* &= \frac{48+30\alpha^2+7\alpha w-76\alpha-10w}{2(4-3\alpha)(2-\lambda)} + \lambda\frac{w}{(2-\lambda)} \,, \\
\pi_M^* &= \frac{(6\alpha\lambda-6\alpha-8\lambda-w+8)(\lambda w-6\alpha-w+8)}{2(4-3\alpha)(2-\lambda)^2} \,, \\
\pi_P^* &= \frac{(6\alpha-w-8)^2}{4(4-3\alpha)(2-\lambda)^2} \,.
\end{aligned}$$

We obtain exactly the same outcomes as if the platform sets a percentage fee as in the main model.

3

Collection for recycling - how far should we go?

(This chapter is co-authored with Paul Belleflamme.)

We investigate how improving the recycling process affects the quantity of primary production by analyzing the strategic interaction between competing firms that source their inputs from either primary or recycled material. This competition is peculiar because the primary production of manufacturers in period 1 serves as input for the production of recyclers in period 2. Manufacturers can thus limit the recyclers' scale of operation by reducing their own output. In this context, improving the recycling process generates two opposite effects: it reduces primary production in period 2 by exposing manufacturers to stronger competition from recyclers, but it also lowers the incentives for manufacturers to reduce their primary production in period 1 in view of limiting the recyclers' scale of operation. So, even if improving the recycling process was costless, it would be counterproductive for the environment to make it too efficient.

3.1 Introduction

Research question. Authorities around the world have committed to scale up the collection of scraps for recycling. The expectation is that, by increasing the inputs for the recycling sector, they can reduce the volume of primary production and hence, lower the economy's impacts on the environment.[1] The European Parliament, for instance, signed in 2019 a legislation procedure requiring the Member States to achieve a 90% collection target for plastic bottles by 2029.

While recycling can reduce the negative impact of waste on the environment (arguably better than landfill and incineration), one may ask *to which extent an improvement in the collection of scraps for recycling can reduce the volume of primary production.* To answer this question properly, we need to analyse the strategic interaction between competing firms that source their inputs from either primary or recycled material. What makes this competition peculiar is that the firms producing from primary material (which we call the '*manufacturers*') also supply inputs for the firms producing from recycled material (which we call the '*recyclers*'). In consequence, the manufacturers can control the scale at which the recyclers can operate; in particular, they may want to reduce their current production to limit the competition that recyclers will exert in the future.[2] It is thus crucial to take this possibility into account when evaluating the impacts of improving the recycling process.

Main result. Our analysis establishes that *improvements in the recycling process do not necessarily contribute to reduce the extraction of primary material.* The intuition behind this result is the following. Improving the

[1] Recycling of aluminum products, for example, requires as little as 5% of the energy and emits as little as 5% of green-house gas compared to production of primary aluminum (International Aluminium Institute, 2009)

[2] The same intuition applies to remanufacturing, which is "a specific type of recycling in which used durable goods are repaired to a like-new condition" (Bernard, 2011, p. 337). Örsdemir, Kemahlioğlu-Ziya and Parlaktürk (2014) explain that manufacturers have an incentive to reduce the competitive threat exerted by 'remanufacturers' "through limiting quantity, specifically by creating scarcity of cores available for remanufacturing." They give the example of Lexmark, which made cores ineligible for remanufacturing (see https://archive.grrn.org/lexmark/background.html, last accessed June 2, 2021). We return to remanufacturing in the literature review.

recycling process generates two opposite effects. On the one hand, it reduces primary production once recyclers enter the market because the competition they exert on manufacturers gets stronger as recycling is improved. On the other hand, the better the recycling process, the lower the incentives for manufacturers to reduce their primary production *before* recyclers enter. The benefit for manufacturers of limiting the recyclers' future entry must indeed be measured against the cost of foregoing current profits. An improvement of the recycling process worsens the benefit/cost ratio of this strategy because it forces the manufacturer to accept a larger decrease of its current primary production to reach a given reduction of the recyclers' scale of entry.

To establish this result, we consider a model with three periods. In period 0, an authority determines the efficiency of the recycling process (e.g., the rate of scrap collection). In period 1, manufacturers extract primary material and use it to produce some final product. In period 2, recyclers enter the market; they produce the final product using recycled material while manufacturers continue to produce from primary material. Periods are linked as follows: the available recycled material in period 2 is a fraction of what manufacturers produced in period 1, and this fraction is determined by the authority's choice in period 0. In Section 3.2, we analyze a simplified version of this model with one manufacturer, one recycler and linear demand and costs. In Section 3.3, we show that our results hold in more general settings, with general demand and cost functions or with an arbitrary number of manufacturers and recyclers.

Related literature. Economists have studied the "recycling problem" since the notorious Alcoa case (Walter, 1951). In 1945 Alcoa, the producer of primary aluminum, was found in a monopolistic position by virtue of its control over 90% of primary aluminum output, limiting the competitiveness of the recycling industry, which captured roughly 20% of the total aluminum market. Judge Learned Hand concluded that Alcoa constituted an illegal monopoly, in violation of the Sherman Antitrust Act: Alcoa was found to control strategically the recycling sector's supply by manipulating the primary aluminum production. Questioning the correctness of this judgment, a strand of literature in industrial organization started in the mid-1970s to analyze theoretically and empirically the so-called "recycling problem."

The literature started with Gaskins (1974). Using an optimal control model to simulate the Alcoa scenario, the paper proposes that the manufacturer dominates the market when demand grows at steady state and confirms Hand's judgment. Swan (1977) then criticizes Gaskin's model for the sensitivity of its results to the rate of demand growth. In an overlapping-generations setting, he predicts that the long-run price is close to the monopoly price in the absence of recycling, proving that Alcoa strategically controls the supply of primary aluminum to maintain its monopoly position. In another paper, Suslow (1986) estimates that it is the degree of substitutability between primary and recycled aluminum on the demand side that determines the Alcoa's market power. Finally, Grant (1999) presents a more general model of the "recycling problem" and proposes that Alcoa's market power is due to the recyclers' inability to recycle the aluminum scraps economically, and that the existence of recycling is welfare-reducing relative to a monopoly in all aluminum production. However, these studies, among others[3], only focus on the impact of a competitive recycling sector on the market power of the manufacturer by integrating the collection decision in the recycling entities. In reality, while reprocessing entities are mostly private, the collection system relies heavily on the government's effort to scale it up. Playing a significant role in organizing the curb-side collection and subsidizing the collection entities, governments' commitments influence the collection rates beyond the market-based mechanism. Therefore, the impact of an exogenous variation of the collection rate is worth further analyses.

A second related strand of the literature focuses on the performance of the collection system and echoes our recommendation that recycling should not be pushed too far. Kinnaman, Shinkuma and Yamamoto (2014) use data in Japan to estimate the average social cost of waste management as a function of the recycling rate. Defining the social cost as the sum of all municipal costs and revenues, costs to recycling households, external disposal costs and external benefits of recycling, the authors suggest that the recycling rate that minimizes the average social costs in Japan should only be 10% and concluded that *"the 20% recycling rate in Japan is higher than the socially optimal rate"* and that *"the current recycling rates in the United States (35%) and the EU27 (34%) may also be too high."* Dijkgraaf and Gradus (2017) estimate the cost function resulting from different policies in waste recycling in the Netherlands and find that it seems nearly impossible for the Netherlands to reach the EU-goal of 70% recycling rate because of the high cost of the recycling system. These studies, however, largely ignore interaction in the industry between the primary and

[3]See, for example, Hoel (1984), Hollander and Lasserre (1988), Gaudet and Van Long (1999), Gaudet and Van Long (2003), Eichner (2005) and Honma and Chang (2010)

secondary producers.[4]

Our work is also closely related to the literature on "remanufacturing." This strand of literature analyses the impacts of remanufacturing on primary manufacturers' profitability.[5] For instance, Atasu, Sarvary and Van Wassenhove (2008) investigate the conditions for the benefits from remanufacturing to outweigh the losses from cannibalization when manufacturers conduct remanufacturing themselves. They show that remanufacturing is more beneficial under competition than under monopoly. Ferguson and Toktay (2009) analyze the competition between a manufacturer and a remanufacturing firm. They discuss the conditions for the manufacturer to choose to remanufacture its products or not, and compare two entry-deterrent strategies: remanufacturing and preemptive collection.

Three papers are closer to our work. First, Örsdemir et al. (2014) study the competition between a manufacturer and a remanufacturer, incorporating the constraint that the remanufactured product quantity cannot exceed the quantity of the original product. Their model share some features with ours but also differs in important aspects: competition takes place on a single period, and public policy is not considered. Second, in a two-period model with linear demand, Mitra and Webster (2008) discuss the impact of the government's subsidies on remanufacturing by conducting numerical simulations with some given collection rates. The closest to ours is Ba and Mahenc (2019). They study the impact of recycling on a monopolistic extractor of exhaustible resources, proving that recycling can speed up of slow down primary resource extraction relative to the Hotelling rule, depending on the objective of the extractor (for-profit or social welfare improvement). However, similar to the other strand of literature, these studies are not concerned with the impact of changes in the collection rate of end-of-life products on the manufacturer's strategy.

[4]In this stream of the literature, we can also cite Hamilton, Sproul, Sunding and Zilberman (2013), Kinnaman (2013), Fullerton and Kinnaman (1995), Kinnaman and Fullerton (2000), Callan and Thomas (2001), Kinnaman (2006), Bohm, Folz, Kinnaman and Podolsky (2010), Kinnaman (2010), and Hamilton et al. (2013).

[5]Although remanufacturing differs from recycling from a technological perspective, it shares with recycling the same procedure of collection and reprocessing of end-of-life products. Therefore, with an abuse of vocabulary, we consider both processes as recycling in this paper.

3.2 A baseline model

We consider here a simplified setting with one manufacturer, one recycler and simple specifications for demand, costs and recycling technology. In the next section, we show the robustness of our results by extending the model in several directions. We consider the market for some homogeneous good (think, e.g., of aluminum cans). The manufacturer produces the good from primary material (that it extracts itself or acquires on some, not modeled, upstream market), whereas the recycler does so by reprocessing a fraction of the manufacturer' end-of-life products.[6] The collection of end-of-life products is organized by some authority, which we refer to as the *'government'*.

Because the government aims at setting the 'rules of the game' with the aim to reduce the environmental impact of the extraction of primary material, and because the manufacturer's initial production conditions the recycler's production capacity, we assume the following timeline. *In period 0*, the government sets a commitment for the collection rate $\tau \in [0, 1]$, with $\tau = 0$ corresponding to the total absence of collection, and $\tau = 1$ corresponding to the complete collection of all the scraps.[7] *In period 1*, the manufacturer learns this information and chooses the quantity of production for this period, q_1; by the end of the period, all products in use wear out and the government collects the committed proportion τ of the scraps (the rest of the scraps is dumped). *In period 2*, the recycler enters the market and uses the scraps collected as input to compete with the manufacturer *à la Cournot*; we denote by r the quantity produced by the recycler and by q_2 the quantity produced by the manufacturer.

The other ingredients of the baseline model are as follows.

Demand. The inverse demand for the good is $p_1 = 1 - q_1$ in period 1 and

[6]We do not allow the manufacturer to be active in the recycling market as well, as is observed in some industries (for instance, Rio Tinto produces aluminum from both bauxite and recycled scraps). Even if it could enter the recycling market, the manufacturer would decide against in our setting. This is so because we assume constant marginal costs and higher production costs from recycling. To consider properly this possibility, we would thus need to modify our model substantially, which we leaves for future research.

[7]In the context of remanufacturing, instead of the collection rate, τ can also be interpreted as the repairability of the product, the easier it is to repair, the more products the remanufacturer can recover. Policies such as the 'repairability scores' for electronic devices in France aims to this improvement (see https://resource-recycling.com/e-scrap/2020/10/22/france-will-assign-devices-a-repair-rating/, last accessed June 14, 2021.)

$p_2 = 1 - q_2 - r$ in period 2. That is, we assume that consumers perceive the manufacturer's and the recycler's products as homogeneous, and that the recycler's entry does not contribute to increase total demand (i.e., the maximum price that consumers are willing to pay is the same in both periods and is normalized to 1).[8]

Production costs. We assume that both firms have a constant marginal cost of production and no fixed cost. Without loss of generality, we normalize the manufacturer's production cost to zero. Meanwhile, the recycler bears the cost of buying, sorting, and reprocessing old scraps to produce recycled products; the total cost to produce a quantity r of recycled products is equal to cr, with $c \geq 0$, meaning that recycling is at least as expensive as primary production.[9] Prior to the recycler's entry, the manufacturer does not know precisely the value of c; it expects c to be drawn from a uniform distribution over the interval $[0, 1/2]$. As we assume no entry cost, $c \leq 1/2$ guarantees that the recycler enters the market.[10]

Recycling technology. We assume for simplicity a 1:1 recycling technology

[8] In the next section, we consider a general demand function $P(Q)$ such that $P(Q) = 0$ for a finite Q and $P''(Q)Q + P'(Q) < 0$ for all $Q > 0$ and $P(Q) > 0$. The assumption of homogeneous products is generally correct in the case of metal recycling (the quality of aluminum, copper, iron after the recycling process is the same as the virgin metal).

[9] It could be objected that this assumption is limitative, as in some industries (e.g., the aluminum industry), more energy is needed for virgin production than for recycling. The total cost of recycling, however, is more expensive. The whole process of recycling includes among many other sorting, classifying, and separating, which are labor intensive and returns in higher cost than extraction primary resources. We claim, furthermore, that our model still applies to the case in which recycling is cheaper than extraction if we also take into account that consumers may perceive the recycler's product as of lower quality than the manufacturer's product. We would then write the demand for the recycler's product as $p_2^r = 1 - d - q_2 - r$, where $0 < d < 1$ measures the difference in the consumers' willingness to pay between the manufacturer's and the recycler's product. This formulation would fit, for instance, the case of recycled plastic in the food industry (the demand may be lower because recycled plastic does not meet certain safety requirements). Relabeling the recycler's marginal cost as c_r, we can define $c \equiv c_r + d$. In this linear model, c can be seen as the 'true' unit cost: The recycler's profit is indeed equal to $\pi_r = (1 - d - q_2 - r)r - c_r r = (1 - q_2 - r)r - cr$. It is then perfectly possible to have $c_r < 0$ (the recycler has a lower marginal cost than the manufacturer, which we normalized to zero), while $c > 0$ (the manufacturer has a competitive advantage over the recycler).

[10] For $c > 1/2$, the recycler stays out because entry is not profitable even when the manufacturer produces the monopoly quantity. Using the terminology of Bain (1956), we say that entry is 'blockaded' in this case. In our setting, the manufacturer cannot 'deter' entry and must 'accommodate' it when $c < 1/2$.

that allows recyclers to produce one unit of output with one unit of scrap as input (which explains the recycler's marginal cost of production).[11] As for the collection of scraps, we put its organization in a black box. That is, we abstract away all the mechanisms that need to be put in place to implement a given collection rate.[12] We just assume, realistically, that the government has the capacity to modify this rate and, thereby, the 'rules of the game' that the two firms will play.

We solve the game for its subgame-perfect equilibrium, assuming that the manufacturer does not discount its future profit when choosing its quantity in period 1.[13] Before doing so, we briefly outline the benchmark case with no possibility of recycling. This is so, in our setting, when the collection rate τ is equal to zero: with no scrap collected, the recycler cannot enter the market. In this case, the manufacturer would simply behave as an unconstrained monopolist in both periods: it would choose q_1 and q_2 to maximize $\pi = (1 - q_1)q_1 + (1 - q_2)q_2$, which yields $q_1 = q_2 = q^m = 1/2$. Over the two periods, the manufacturer would then produce a total quantity of primary products $2q^m = 1$ and earn a total profit of $\Pi(1/2, 1/2) = 1/2$.

We now turn to the situations in which $\tau > 0$: scraps are collected and the recycler can enter the market in period 2. Solving the game backwards, we first analyze the Cournot competition in period 2; we then move to the manufacturer's choice in period 1 before considering the government's problem in period 0.

[11] Alternatively, we could assume a linear technology that transforms one unit of scrap into μ units of output with $0 < \mu \leq 1$. Then, given a quantity q_1 of primary production and a collection rate τ', the maximum production for the recycler would be equal to $\mu\tau' q_1$. Letting $\tau \equiv \mu\tau'$ brings us back to our formulation.

[12] The collection system can be organized into centralized or decentralized industries, with different policies to encourage consumers and firms to participate in scrap collection. To compare the merits of different organizations, see, e.g., Beatty, Berck and Shimshack (2007), Viscusi, Huber and Bell (2012), Hamilton et al. (2013), Kinnaman (2013), or Kinnaman et al. (2014).

[13] Our assumptions are meant to put the manufacturer in the worst-case scenario as far as entry is concerned. If the manufacturer had a stronger preference for the present or if products were (horizontally or vertically) differentiated, entry would be less of a threat, but this would not alter the results in any meaningful way.

3.2.1 Competition between manufacturer and recycler

In period 2, the two firms simultaneously choose their quantity. The manufacturer chooses q_2 to maximize $\pi_2 = (1 - q_2 - r)\, q_2$; we derive the manufacturer's best-response function from the first-order condition:

$$q_2\,(r) = (1 - r)\,/2. \tag{3.1}$$

The recycler chooses r to maximize $\pi_r = (1 - q_2 - r)r - cr$ under the constraint $r \leq \tau q_1$ (as it cannot produce more than the amount of scrap collected, i.e., τq_1). Solving the constrained maximization program, we find that the recycler's best-response function is kinked:

$$r^*\,(v_2) = \begin{cases} \frac{1}{2}\,(1 - c - q_2) & \text{if} \quad \frac{1}{2}\,(1 - c - q_2) \leq \tau q_1, \\ \tau q_1 & \text{otherwise}\,. \end{cases} \tag{3.2}$$

Crossing the two best-response functions, we can identify two possible Cournot-Nash equilibria in period 2, depending on the amount of scraps collected (τq_1) and the recycler's unit cost (c): an *'unconstrained equilibrium'* in which scraps are in large supply and/or the recycler is not efficient enough to reprocess them all, and a *'constrained equilibrium'* in which scraps are in short supply and/or the recycler is efficient enough to be bounded by the input availability. These two equilibria are characterized as follows:

- Quantities at the *unconstrained equilibrium* are found by solving the system of equations made of (3.1) and the top branch of (3.2):

  $$q_2^u = \tfrac{1}{3}\,(1 + c) \text{ and } r^u = \tfrac{1}{3}\,(1 - 2c)\,,$$

  (with $r^u \geq 0$ as we assume $c \leq 1/2$). The equilibrium profits are then computed as

  $$\pi_2^u = \tfrac{1}{9}\,(1 + c)^2 \text{ and } \pi_r^u = \tfrac{1}{9}\,(1 - 2c)^2\,.$$

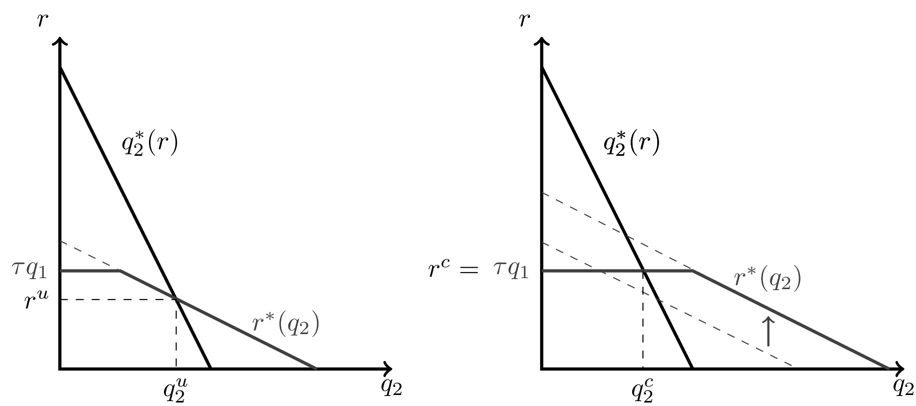
- In the *constrained equilibrium*, the recycler's quantity is bounded by the input constraint and the manufacturer reacts according to (3.1), so that

  $$q_2^c = \tfrac{1}{2}\,(1 - \tau q_1) \text{ and } r^c = \tau q_1,$$

  leading to equilibrium profits of

  $$\pi_2^c\,(q_1) = \tfrac{1}{4}\,(1 - \tau q_1)^2 \text{ and } \pi_r^c\,(q_1) = \tfrac{1}{2}\tau q_1\,(1 - 2c - \tau q_1)\,.$$

Figure 3.2.1.1 depicts the two possible equilibria in period 2. Due to the input constraint, the recycler's reaction function is kinked at $r = \tau q_1$. If the recycler is not efficient enough, it cannot economically recycle all the scraps collected. In this case, we obtain the unconstrained equilibrium (q_2^u, r^u) in which $r^u < \tau q_1$ (Figure 3.2.1.1a). Because the input constraint is not binding, the firms' outputs are independent of the collection rate τ and the quantity of primary products in the first period q_1, but they depend on the marginal recycling cost c (a higher marginal cost c leads to lower recycling r^u and higher primary production q_2^u in period 2). In contrast, if the recycler is efficient enough, its best-response function is shifted upward, as in Figure 3.2.1.1b. Here, the quantity of recycled product is constrained by the initial primary production q_1. The market then reaches the equilibrium (q_2^c, r^c) in which the recycler reprocesses all the scraps collected ($r^u = \tau q_1$), whereas the manufacturer produces a larger quantity q_2^c than in the unconstrained equilibrium. In this case, the manufacturer can control the scale of the recycler through its initial production q_1 (a lower q_1 leads to a lower r^c and a larger q_2^c).



(a) Unconstrained equilibrium **(b)** Constrained equilibrium

Figure 3.2.1.1. Cournot-Nash equilibrium in period 2

We observe that, given a quantity of scraps collected τq_1, the unconstrained equilibrium occurs if $r^u < \tau q_1$ and the constrained equilibrium occurs otherwise. Since r^u decreases with the recycler's marginal cost c, we obtain the following lemma.

Lemma 2. *(1) For a given quantity of scraps collected τq_1, the unconstrained equilibrium ($r^u < \tau q_1$) obtains if the recycler's marginal cost c is above $\tilde{c} \equiv (1 - 3\tau q_1)/2$ and the constrained equilibrium ($r^u = \tau q_1$) obtains otherwise. (2) As the threshold $\tilde{c}$ decreases with τ and q_1, only the unconstrained equilibrium can occur if $\tau q_1 \geq 1/3$.*

Proof. (1) The threshold $\tilde{c}$ is the value of c that solves $r^u = \frac{1-2c}{3} = \tau q_1$; for $c > \tilde{c}$, we have $r^u > \tau q_1$. (2) Given that $c \geq 0$, only the unconstrained equilibrium can occur if $\tilde{c} \leq 0$, which is equivalent to $\tau q_1 \geq \frac{1}{3}$; for instance, if $q_1 = q_1^m = \frac{1}{2}$, then the condition becomes $\tau \geq \frac{2}{3}$. □

3.2.2 Manufacturer's 'limit entry' strategy

We now analyze whether and how the manufacturer wants to follow a 'limit entry' strategy, whereby it reduces its production in period 1 so as to limit the quantity of input that the recycler will be able to use in period 2. We are also interested in evaluating how the level of the collection rate affects the manufacturer's decision.

In period 1, the manufacturer chooses the quantity q_1 to maximize its expected profits over the two periods. There are two possible courses of action. First, we know from Lemma 1 that if the manufacturer sets a sufficiently large quantity–namely, $q_1 \geq 1/(3\tau)$–it can make sure that the equilibrium in period 2 will be unconstrained irrespective of the marginal cost drawn by the recycler. In that case, the manufacturer's profit in period 2 is $\pi_2^u = (1+c)^2/9$, which is independent of q_1. Hence, the manufacturer's optimal quantity is period 1 is $q_1^m = 1/2$. This quantity satisfies the constraint as long as $q_1^m \geq 1/(3\tau)$, or $\tau \geq 2/3$.

Alternatively, the manufacturer can choose $q_1 < 1/(3\tau)$. Then, the equilibrium prevailing in period 2 depends on the cost drawn by the recycler: the manufacturer obtains the profit π_2^c in the constrained equilibrium if $c < \tilde{c}$, and obtains the profit π_2^u in the unconstrained equilibrium if $c > \tilde{c}$. Consequently, if $q_1 < 1/(3\tau)$, the manufacturer's expected profit function can be written as

$$\Pi^e = \pi_1(q_1) + \hat{\pi}_2^c(q_1) + \hat{\pi}_2^u(q_1), \tag{3.3}$$

where $\pi_1(q_1) = q_1(1 - q_1)$ and, given the uniform distribution of c over the interval $[0, 1/2]$,

$$\hat{\pi}_2^c(q_1) = \int_0^{\tilde{c}} 2\pi_2^c(q_1)\,dc = \int_0^{\frac{1}{2}(1-3\tau q_1)} \tfrac{1}{2}(1-\tau q_1)^2\,dc$$
$$= \frac{1}{4}(1-\tau q_1)^2(1-3\tau q_1), \qquad (3.4)$$

$$\hat{\pi}_2^u(q_1) = \int_{\tilde{c}}^{\frac{1}{2}} 2\pi_2^u dc = \int_{\frac{1}{2}(1-3\tau q_1)}^{\frac{1}{2}} \tfrac{2}{9}(1+c)^2\,dc$$
$$= \tfrac{1}{4}\tau q_1\left(\tau^2 q_1^2 - 3\tau q_1 + 3\right). \qquad (3.5)$$

Because $\tilde{c}$ decreases with q_1, the manufacturer faces a trade-off when increasing q_1. From (3.5), we observe that $\hat{\pi}_2^u(q_1)$ increases with q_1 as the probability that the unconstrained equilibrium occurs increases with q_1 while the manufacturer's profit remains constant. In contrast, we observe from (3.4) that $\hat{\pi}_2^c(q_1)$ decreases with q_1 for two reasons: not only the constrained equilibrium becomes less likely but also the manufacturer gets a smaller profit (as $q_2^*(\tau q_1)$ decreases with q_1 because of strategic substitutability).

Clearly, the level of the collection rate τ affects the balance between these two conflicting forces. As we now show, it does so in a non-monotonic way. Denote by $q_1^*(\tau)$ the quantity that maximizes expression (3.3) for a given τ. Note first that if τ is close to zero, the unconstrained equilibrium is very unlikely (as $\tilde{c}$ is close to $1/2$) and the manufacturer is hardly affected by the small scale of the recycler's operation in the constrained equilibrium. It follows that the manufacturer choice of quantity $q_1^*(\tau)$ tends to $q_1^m = 1/2$ as τ tends to zero. Note also that we have just established that the manufacturer chooses $q_1^m = 1/2$ as well for $\tau \geq 2/3$. To understand how $q_1^*(\tau)$ evolves with τ for $0 < \tau < 2/3$, we use the implicit function theorem to write

$$\tfrac{dq_1^*(\tau)}{d\tau} = -\tfrac{\partial^2\Pi^e(q_1^*)}{\partial q_1 \partial\tau} \Big/ \tfrac{\partial^2\Pi^e(q_1^*)}{\partial q_1^2}.$$

Because $q_1^*(\tau)$ maximizes the firm's expected profit, $\partial^2\Pi^e(q_1^*)/\partial q_1^2 < 0$ by the second-order condition. So $dq_1^*(\tau)/d\tau$ takes the sign of

$$\frac{\partial^2\Pi^e(q_1^*)}{\partial q_1\partial\tau} = \underbrace{\frac{\partial^2\pi_1(q_1^*)}{\partial q_1\partial\tau}}_{=0} + \underbrace{\frac{\partial^2\hat{\pi}_2^c(q_1^*)}{\partial q_1\partial\tau}}_{(i)} + \underbrace{\frac{\partial^2\hat{\pi}_2^u(q_1^*)}{\partial q_1\partial\tau}}_{(ii)}.$$

As τ only influences the first-period profit via its impact on q_1, we have that the first term is equal to zero. The variation of q_1 with respect to τ

depends then on two factors: (i) the marginal impact of τ on the expected loss following an increase in q_1^* under the constrained equilibrium and (ii) the marginal impact of τ on the expected gain following an increases in q_1^* under the unconstrained equilibrium. Therefore, the profit-maximizing quantity in period 1, q_1^*, decreases with τ if the first impact dominates the second, and increases with τ otherwise. As noted above, the former case certainly occurs when τ is close to zero (as the second impact vanishes), while the latter case certainly occurs when τ is close to 2/3 (as the first impact vanishes). We expect thus $q_1^*(\tau)$ to be a U-shaped function of τ.

We now confirm our intuition by computing the exact value of $q_1^*(\tau)$. The first-order condition for profit-maximization is:

$$\frac{\partial \Pi^e}{\partial q_1} = \frac{1}{2}\left(-3\tau^3 q_1^2 - 4\left(1-\tau^2\right)q_1 + 2 - \tau\right) = 0. \tag{3.6}$$

At $\tau = 0$, it is equivalent to $1 - 2q_1 = 0$, which confirms that $q_1^*(0) = 1/2 = q_1^m$. For $\tau > 0$, the solution to Equation (3.6) is[14]

$$q_1^*(\tau) = \frac{\sqrt{4 - 8\tau^2 + 6\tau^3 + \tau^4} - 2\left(1-\tau^2\right)}{3\tau^3}. \tag{3.7}$$

We check that $q_1^*(\tau) < 1/(3\tau)$ if and only if $\tau < 2/3$. We also observe that for $\tau < 2/3$, $q_1^*(\tau) < 1/2$ (while $q_1^*(2/3) = 1/2$). As represented in Figure 3.2.2.1, $q_1^*(\tau)$ is a U-shaped function of τ: $q_1^* = 1/2$ at the two extreme values of the interval ($\tau = 0$ and $\tau = 2/3$), it decreases with τ for $0 < \tau < \tilde{\tau} \approx 0.325$ and increases with τ for $\tilde{\tau} < \tau < 2/3$. For $\tau \geq 2/3$, $q_1^*(\tau) = 1/2$: as explained above, the manufacturer can no longer constrain the recycler's input once the collection rate becomes too large; it therefore maintains the monopolistic production q_1^m to maximize its profits in the first period.

The next proposition records our results.

Proposition 3. *(1) If the collection rate τ is lower than $2/3$, then the manufacturer contracts its period 1 production, $q_1^*(\tau) < q_1^m$, to limit the recycler's scale of operation in period 2; the contraction is the largest for $\tau = \tilde{\tau} \approx 0.326$. (2) If the collection rate τ is larger than $2/3$, then the manufacturer maintains the monopolistic production level in period 1, $q_1^*(\tau) = q_1^m$.*

[14] It can easily be checked that the other root is negative and that the second-order condition is satisfied.

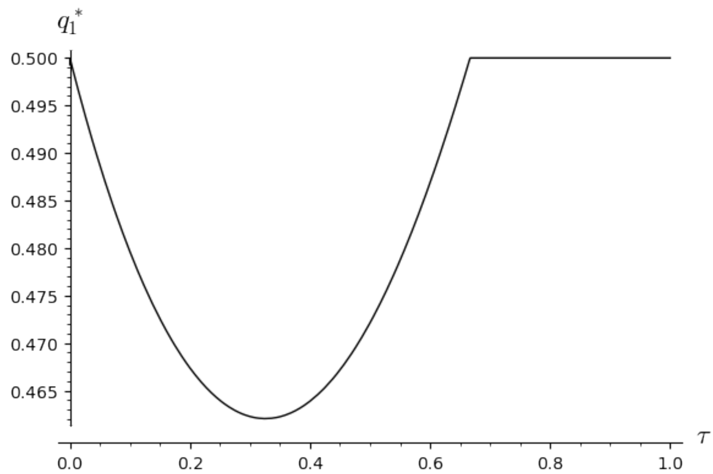


Figure 3.2.2.1. variation of first-period production with respect to the collection rate

Intuitively, when the collection rate is small, the manufacturer can constraint the recycler's scales by reducing slightly its production in period 1. Hence, in this case, the manufacturer finds it profitable to sacrifice part of its period 1 profits to increase its expected period 2 profits. As long as the collection rate remains smaller than $\tilde{\tau}$, the manufacturer reduces further its initial production. Yet, once the collection rate becomes larger than $\tilde{\tau}$, the manufacturer continues to apply the limit entry strategy, but it does so by reducing its initial production by smaller amounts; in fact, as the recycler can access a larger share of the initial production, the manufacturer must forgo more profits in period 1 to reach a given increase in expected profits in period 2. Eventually, the limit entry strategy becomes unprofitable (and even unfeasible) when the collection rate gets larger than 2/3; the manufacturer is then no longer willing to contract its initial production and prefers to produce the monopoly output in period 1, as though the recycler's was not to enter in period 2.

3.2.3 Government's choice of collection rate

Finally, we examine the choice of the collection rate τ by the government.[15] We first assume that the government's sole objective is to minimize the extraction of primary material. We then examine how the optimal collection rate according to this purely environmental objective compares with the collection rate that would maximize consumer surplus. Throughout the analysis, we take the simplified view that increasing the collection rate is costless.

How to minimize primary production?

Total primary production is the addition of the quantities produced by the manufacturer in periods 1 and 2. As for period 1 production, we found above that $q_1^*(\tau)$ is equal to expression (3.7) for $\tau < 2/3$ and to $q_1^m = 1/2$ for $\tau \geq 2/3$. The manufacturer's production in period 2 also depends on whether the collection rate τ is below or above the threshold of $2/3$. If $\tau < 2/3$, the manufacturer produces $q_1^*(\tau) < q_1^m$ to limit the recycler's entry. If the recycler's cost is such that $c < \tilde{c}$, then the manufacturer produces $q_2^c = (1/2)\left[1 - \tau q_1^*(\tau)\right]$; otherwise, if the recycler's cost is such that $c > \tilde{c}$, then the manufacturer produces $q_2^u = (1+c)/3$. In contrast, if $\tau \geq 2/3$, the manufacturer knows that it cannot limit the recycler's entry; then, irrespective of the recycler's cost c, the manufacturer's period 2 production is $q_2^u = (1+c)/3$. Hence, the expected quantity of primary production over the two periods can be written as

$$q_2^*(\tau) = \begin{cases} v_1^* + 2\displaystyle\int_0^{\frac{1}{2}(1-3\tau q_1^*)} \frac{1-\tau q_1^*}{2} dc + 2\int_{\frac{1}{2}(1-3\tau q_1^*)}^{\frac{1}{2}} \frac{1+c}{3} dc & \text{if} \quad \tau < \dfrac{2}{3} \\ \dfrac{1}{2} + 2\displaystyle\int_0^{\frac{1}{2}} \frac{1+c}{3} dc & \text{otherwise.} \end{cases}$$

It is worth noting that period 2 primary production is the average of q_2^c and q_2^u weighted by the probability that each equilibrium occurs. While q_2^u does not depend on τ, q_2^c decreases with τ. Moreover, the threshold $\tilde{c}(q_1^*)$ increases with τ. In other words, increasing the collection rate reduces primary

[15] As our objective is to demonstrate the counter-intuitive impacts of modifying the collection rate, we limit our analysis to this policy instrument, abstracting away other instruments–such as taxes on primary products or subsidies on recycled products–that the government could use to limit the extraction of primary resources. For a survey on the economics of environmental policy instruments, see, e.g., Sterner and Robinson (2018).

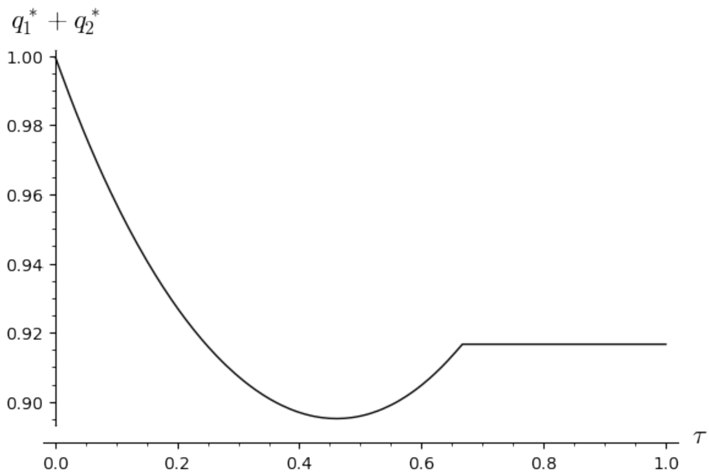


Figure 3.2.3.1. variation of the expected quantity of primary product with respect to τ

production under the constrained equilibrium and, at the same time, increases the probability of occurrence of the unconstrained equilibrium, in which the manufacturer produces a smaller quantity of primary production. Under these two effects, *the expected primary production in period 2 decreases when* τ *increases.* We recall, however, that q_1^* does not vary monotonically with τ: it first decreases with τ, then increases with τ and finally reaches a plateau. We observe that the same pattern applies to the total primary production, $q^*(\tau) = q_1^*(\tau) + q_2^*(\tau)$. As represented in Figure 3.2.3.1, $q^*(\tau)$ decreases with τ for $0 < \tau < 0.46$, then increases with τ for $0.46 < \tau < 2/3$ and finally stays constant for $2/3 \leq \tau \leq 1$. We therefore conclude the following.

Proposition 4. *A government that aims at minimizing total primary production (and that can modify the collection rate at zero cost) chooses to set the collection rate at an intermediate level that achieves the best balance between the incentives given to the manufacturer to reduce its production in period 1 (so as to limit the recycler's entry) and the competition exerted by the recycler to limit the manufacturer's production in period 2.*

Do consumers support environmental measures?

In our baseline model with homogeneous products, the consumer surplus increases with the level of total production (primary *and* recycled). For a given pair of quantities (q_1, q_2) produced by the manufacturer in periods 1 and 2, and a given quantity r produced by the recycler in period 2, the consumer surplus is indeed computed as $CS = \frac{1}{2}[q_1^2 + (q_2 + r)^2]$. A priori, recycling has ambiguous impacts on the consumer surplus: on the one hand, the recycler's entry in period 2 benefits consumers (because in a homogeneous product market, duopolists produce together a larger equilibrium quantity than a monopolist does); on the other hand, the prospect of the recycler's entry induces the manufacturer to (weakly) decrease its production in period 1. As we state in the next lemma, it turns out that the former effect always outweighs the latter, and even more so as the collection rate increases.

Lemma 3. *The consumer surplus weakly increases with the collection rate.*

We thus see from Lemma 3 that consumers would vote for pushing the improvement of the recycling process to at least $\tau = 2/3$, that is, past the level that would be optimal for the environment. Protecting the environment may thus reduce the consumers' well-being in the short-run, as summarized in the next proposition and illustrated in Figure 3.2.3.2 (which contrasts the evolutions of primary and total production with respect to τ).

Proposition 5. *Increasing the collection rate from a low level benefits both consumers and the environment. However, increasing the collection rate over a certain threshold creates a trade-off between consumer surplus and environment: while consumers have access to more products, the quantity of primary production also increases with the collection rate.*

The intuition behind this proposition should be clear by now. While it is clear that consumers will enjoy more surplus when there are more products in the economy, this also implies a trade-off between consumer surplus and the environment. However, when the collection rate is initially low, the increasing substitution of primary by recycled products can reduce the primary production and increase total production at the same time. Hence, any improvement of the collection rate below $\bar{\tau}$ is a win-win situation for both consumers and the environment. However, if $\tau > \bar{\tau}$, improving the collection rate leads to an increase in the primary production. In this case, increasing the collection rate will benefit consumers but make the economy deviate from the best scenario

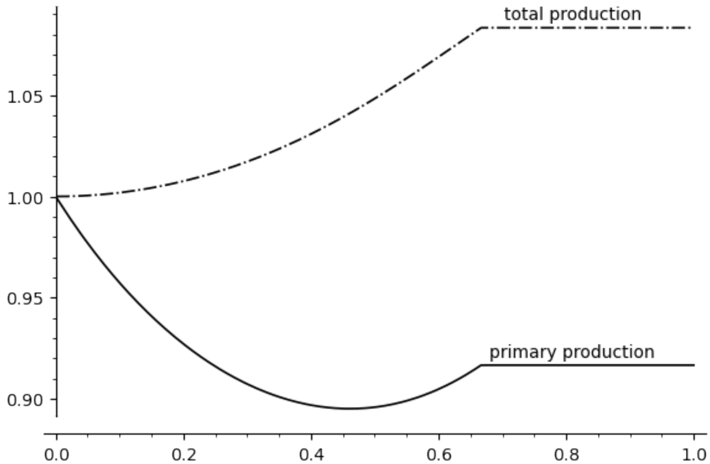


Figure 3.2.3.2. evolution of primary and total production with respect to τ

for the environment (not to mention that it is costly to improve the collection system, particularly when the collection rate is already high).

Do firms support environmental measures?

Unsurprisingly, the firms' preferences regarding the level of the collection rate are completely at odds with one another: the manufacturer's profit is the largest for $\tau = 0$, while the recycler's profit is the largest for $\tau = 1$. So, *if the government aims at minimizing total primary production, the chosen collection rate is too high from the manufacturer's viewpoint and too small from the recycler's viewpoint* (the recycler sides thus with the consumers). The chosen collection rate is also too high if we take the point of view of total industry profits, as they decrease with τ; this follows from the fact that, in our model, the manufacturer earns profit over one more period than the recycler.

3.3 Generalization

In this section, we show that the results that we obtained in the previous simplified setting continue to hod in more general settings. First, we continue to assume that there is a single manufacturer and a single retailer but we generalize the demand function for the final product. Second, we revert to a linear demand function but we extend the model to an arbitrary number of symmetric firms in each group.

3.3.1 General demand function

We now take a general demand function, $P = P(Q)$, that is strictly decreasing and twice differentiable in $\mathbb{R}^+$, and that satisfies the following assumptions: (i) $P(Q) = 0$ for a finite Q; (ii) $P''(Q)Q + P'(Q) < 0$ for all $Q > 0$; and (iii) $P(Q) > 0$. Under these assumptions, the best-response functions are downward sloping with the slope belonging to the interval $(-1, 0]$. These are the sufficient conditions to assure the existence of a unique and locally stable Cournot equilibrium in period 2.[16] These conditions also assure that products are substitutes so that per-firm outputs decrease with the number of firms in the symmetric equilibrium.[17]

In period 2, the manufacturer chooses q_2 to maximize its profit $\pi_2 = P(q_2 + r)q_2$, while the recycler chooses r to maximize its profit $\pi_r = P(q_2 + r)r - cr$ under the constraint that $r \leq \tau q_1$. Letting $r^*(q_2) = \operatorname{argmax}_r \pi_r$, we can write the recycler's best-response function as

$$r^* = \begin{cases} r^*(q_2) & \text{if} \quad r^*(q_2) \leq \tau q_1, \\ \tau q_1 & \text{otherwise}. \end{cases}$$

Hence, the unconstrained and constrained equilibria, $\big(r^u(c), q_2^u(c)\big)$ and $\big(r^c(\tau q_1), q_2^c(\tau q_1)\big)$, are respectively given by

$$\begin{cases} P(Q) - q_2^u P'(Q) = 0 \\ P(Q) - r^u P'(Q) - c = 0 \end{cases} \quad \text{where } Q = r^u + q_2^u,$$

and

$$\begin{cases} P(Q) - v_2 P'(Q) = 0 \\ r^c = \tau q_1 \end{cases} \quad \text{where } Q = \tau q_1 + q_2^c.$$

[16] See (Novshek, 1985) for the existence, (Kolstad and Mathiesen, 1987) on the uniqueness and (Dastidar, 2000) on the local stability of Cournot equilibrium. See Vives (2001) for the discussion of these conditions.

[17] In fact, Amir and Lambson (2000) prove that the necessary condition can be weaker: $P(Q)$ is log-concave, i.e. $P''(Q)P(Q) - P'^2 < 0$. However, for the existence of a unique Cournot equilibrium, it requires strictly increasing, convex cost functions. Therefore, we use the assumption of declining marginal revenue to cover the case with zero production cost.

Using the fact that q_2^c satisfies the first-order condition for profit maximization (i.e., $\frac{d\pi_2}{dq_2} = P'(Q)q_2^c + P(Q) = 0$, with $Q = \tau q_1 + q_2^c$), along with the implicit function theorem, we can compute the derivative of q_2^c with respect to q_1 as

$$\frac{dq_2^c}{dq_1} = -\frac{\frac{\partial \pi_2}{\partial^2 q_2 \partial q_1}}{\frac{\partial^2 \pi_2}{\partial q_2^2}} = -\tau \frac{P'' q_2^c + P'}{P'' q_2^c + 2P'}.$$

Because $P'' q_2^c + P' < 0$ and $P'' q_2^c + 2P' < 0$ under our assumptions, we obtain that $\frac{dq_2^c}{dq_1} < 0$; that is, q_2^c decreases with q_1.

From there, we can show that the results of Lemma 2 still hold with the general demand $P(Q)$. The quantities of recycled and primary product in the unconstrained equilibrium $r^u(c)$ and $q_2^u(c)$ are indeed such that

$$\begin{cases} P' v_2^u(c) + P = 0, \\ P + P' r^u(c) - c = 0. \end{cases}$$

Because $P' < 0$ by assumption, $r^u(c)$ decreases in c, equals zero at $c = \bar{c}$, and reaches its maximum at $c = 0$, where the two firms are symmetric.[18] We then obtain $r^u(c) < r^u(0) = q_2^u(0)$ for all $c \in [0, \bar{c})$. As per-firm outputs decrease with the number of firms under our assumptions, we also have that $q_2^u(0) < q^m$.[19] Therefore, there exists a threshold $\bar{\tau} < 1$ such that $r^u(0) = \bar{\tau}$ and hence, $r^u(c) < \bar{\tau} q^m$ for all $c \in [0, \bar{c})$. (In the linear case, we had $\bar{\tau} = 2/3$.) Moreover, for any $\tau < \bar{\tau}$ and $q_1 < q^m$, there must exist a value $\tilde{c} \in (0, \bar{c})$ such that $r^u(\tilde{c}) = \tau q_1$. Because $r^u(c)$ decreases in c, we have $\tilde{c}$ decreasing with q_1 and τ, such that

$$\begin{cases} r^u(c) \leq \tau q_1 & \text{if} \quad c \geq \tilde{c}(q_1) \\ r^u(c) > \tau q_1 & \text{otherwise.} \end{cases}$$

We can then proceed (see the details in Appendix 3.A) by solving the manufacturer's maximization problem in period 1. In particular, we establish that $q_1^* = q^m$ for $\tau \geq \bar{\tau}$ and $q_1^* < q^m$ for $\tau < \bar{\tau}$, with q_1^* decreasing with τ when τ is close to zero, and increasing in τ when τ is close to $\bar{\tau}$; we also show that the expected quantity produced by the manufacturer in period 2 decreases with τ. This allows us to state that the results of Proposition 3 continue to hold in the general case. In particular, we show that the total primary production

[18]By definition, $\bar{c}$ is such that $\pi_r^u(r^u(\bar{c}), q_2^u(\bar{c})) = 0$; in a Cournot competition without degeneration following our assumption, this is equivalent to $r^u(\bar{c}) = 0$.

[19]See (Amir and Lambson, 2000)

is a U-shaped function of τ, which implies that *an environmentally-oriented government does not want to improve the collection process beyond a certain point.*

3.3.2 Competition in the manufacturing and recycling sectors

In this second extension, we revert to the linear formulation but we consider an arbitrary number of symmetric firms in each sector; that is, we assume m identical manufacturers and n identical recyclers. We adjust our notation as follows:

- q_{i1} and q_{i2} denote the quantities produced by manufacturer $i = 1 \dots m$ in period 1 and 2 respectively; Q_1 and Q_2 are the corresponding total quantities, summing over all m manufacturers;
- r_j is the quantity produced by recycler $j = 1 \dots n$ in period 2; R is the total quantity produced by the n recyclers, with $R \leq \tau Q_1$;
- the inverse demand is $P = 1 - Q_1$ in period 1 and $P = 1 - Q_2 - R$ in period 2.

As in the baseline model, we assume that all firms produce at a constant marginal cost; this cost is normalized to zero for manufacturers and is equal to c for all recyclers, with c drawn from a uniform distributed over $[0, 1/(m+1)]$. We solve the game by backward induction for its subgame-perfect equilibrium.

Period 2

Suppose that $n \geq 1$ recyclers have entered the market. The maximization problem of recycler j is

$$\max_{r_j} (1 - c - r_j - r_{-j} - Q_2)\, r_j \text{ subject to } r_j + r_{-j} \leq \tau Q_1,$$

where r_{-j} denotes the total quantity produced by the other recyclers.

We derive recycler j's reaction function as follows. From the first-order condition, we find the quantity that recycler j would choose if it were unconstrained: $r_j = \frac{1}{2}(1 - c - r_{-j} - Q_2)$. This quantity is valid as long as the constraint is satisfied, i.e.,

$$\tfrac{1}{2}(1 - c - r_{-j} - Q_2) + r_{-j} \leq \tau Q_1 \iff r_{-j} - Q_2 \leq 2\tau Q_1 - (1 - c)\,.$$

In sum, we have

$$r_j\left(r_{-j},Q_2\right)=\begin{cases}\frac{1}{2}\left(a-c-r_{-j}-Q_2\right) & \text{if } r_{-j}-Q_2\leq 2\tau Q_1-(a-c)\\ \tau Q_1-r_{-j} & \text{otherwise.}\end{cases}$$

Defining

$$Q_1^{\mathrm{lim}}\equiv\frac{1}{\tau}\frac{n\left(1-\left(m+1\right)c\right)}{m+n+1},$$

we can establish the following result (the proof is relegated to Appendix 3.B).

Lemma 4. *The Nash equilibrium at the second stage of the game is characterized as follows. (1) For $Q_1<Q_1^{\mathrm{lim}}$, all recyclers are constrained and equilibrium profits for manufacturers and recyclers are respectively given by*

$$\pi_2^c=\frac{\left(1-\tau Q_1\right)^2}{\left(m+1\right)^2}\text{ and }\pi_r^c=\frac{1-\left(m+1\right)c-\tau Q_1}{n\left(m+1\right)}\tau Q_1.$$

(2) For $Q_1\geq Q_1^{\mathrm{lim}}$, no recycler is constrained and equilibrium profits are equal to

$$\pi_2^u=\frac{\left(1+nc\right)^2}{\left(m+n+1\right)^2}\text{ and }\pi_r^u=\frac{\left(1-\left(m+1\right)c\right)^2}{\left(m+n+1\right)^2}.$$

The condition to obtain the unconstrained equilibrium ($Q_1\geq Q_1^{\mathrm{lim}}$) can be rewritten as

$$c\geq\frac{n-\tau\left(m+n+1\right)Q_1}{n\left(m+1\right)}\equiv\tilde{c}\left(m,n\right).$$

We note that $\tilde{c}\left(m,n\right)$ decreases with m and increases with n, implying that, other things being equal, the unconstrained equilibrium is more likely if there are more manufacturers or fewer recyclers. We also note that the unconstrained equilibrium is the only possible equilibrium if Q_1 is sufficiently large, that is

$$\tilde{c}\left(m,n\right)\leq 0\Leftrightarrow Q_1\geq\frac{n}{\tau\left(m+n+1\right)}. \tag{3.8}$$

Period 1

Our objective here is not to solve the game fully but to characterize the two symmetric equilibria that correspond to what we found in the baseline model, namely a 'limit strategy' subgame-perfect equilibrium in which manufacturers reduce their total quantity below the oligopoly level, and an 'unconstrained equilibrium' in which they do not. We start with the latter. As we just established, the equilibrium in period 2 is unconstrained, irrespective of the retailers' marginal cost if the total quantity produced by the manufacturers is above some threshold. In this case, the manufacturers' profits in the two periods are independent of one another. It follows that the equilibrium in period 1 is the classic Cournot-Nash equilibrium. In the present setting, each firm produces a quantity $q_1 = 1/(m+1)$. Then, condition (3.8) is satisfied as long as

$$Q_1 = \frac{m}{m+1} \geq \frac{n}{\tau(m+n+1)} \Leftrightarrow \tau \geq \frac{n(m+1)}{m(m+n+1)} \equiv \tilde{\tau}(m,n).$$

We note that $\tilde{\tau}(1,1) = 2/3$ (as we found in the baseline model), $\tilde{\tau}(m,n)$ decreases with m, increases with n, and $\tilde{\tau}(m,n) < 1$ if and only if $n < m(m+1)$. We can thus conclude that *the symmetric 'unconstrained equilibrium' occurs if the collection rate is above some threshold and becomes more likely as the number of manufacturers increases and the number of recyclers decreases.*

We now characterize the symmetric 'limit equilibrium'. If $Q_1 < Q_1^{\lim}$, a manufacturer's profit in period 2 is π_2^c if $c < \tilde{c}(m,n)$, and π_2^u if $c > \tilde{c}$. Letting $q_{-i1} = Q_1 - q_{i1}$, we can write manufacturer i's expected profit function as

$$\Pi^e(Q_1) = \pi_1(Q_1) + \hat{\pi}_2^c(Q_1) + \hat{\pi}_2^u(Q_1),$$

where $\pi_1(Q_1) = (1 - q_{i1} - q_{-i1})\, q_{i1}$ and, given the uniform distribution of c over the interval $[0, 1/(m+1)]$,

$$\begin{aligned}
\hat{\pi}_2^c(Q_1) &= \int_0^{\frac{n-\tau(m+n+1)Q_1}{n(m+1)}} \frac{(1-\tau Q_1)^2}{m+1} dc \\
&= \frac{1}{n(m+1)^2}(1-\tau Q_1)^2 (n - \tau(m+n+1)Q_1), \\
\hat{\pi}_2^u(Q_1) &= \int_{\frac{n-\tau(m+n+1)Q_1}{n(m+1)}}^{\frac{1}{m+1}} \frac{(m+1)(1+nc)^2}{(m+n+1)^2} dc \\
&= \frac{m+n+1}{3n(m+1)^2} \tau Q_1 \left(\tau^2 Q_1^2 - 3\tau Q_1 + 3\right).
\end{aligned}$$

The first-order condition for profit-maximization evaluated at $q_{i1} = q_1$ for all i can be written as

$$\begin{aligned}
-2m^2\tau^3(m+n+1)\, q_1^2 + \left(2m(m+2n+1)\tau^2 - n(m+1)^3\right) q_1 \\
+ n\left((m+1)^2 - 2\tau\right) = 0.
\end{aligned}$$

Solving for q_1, we find

$$q_1^*(\tau,m,n) = \frac{(m+1)\sqrt{4m^2\tau^4+8m^2n(m+n+1)\tau^3-4mn(m+1)(m+2n+1)\tau^2+n^2(m+1)^4}}{4m^2(m+n+1)\tau^3} - \frac{n(m+1)^3-2m(m+2n+1)\tau^2}{4m^2(m+n+1)\tau^3},$$

and we check that the total quantity $mq_1^*(\tau,m,n)$ is inferior to $n/(\tau(m+n+1))$ if and only if $\tau < \tilde{\tau}(m,n)$.

We can now compute the value of τ that minimizes $q_1^*(\tau,m,n)$ and assess how this value, which we denote $\tilde{\tau}(m,n)$, changes with the numbers of manufacturer and recyclers in the market. Given the complexity of the expressions, we only consider cases with one or two firms in each group; we find:

$$\tilde{\tau}(2,1) = 0.178 < \tilde{\tau}(2,2) = 0.272 < \tilde{\tau}(1,1) = 0.326 < \tilde{\tau}(1,2) = 0.474,$$

which suggests that $\tilde{\tau}(m,n)$ decreases with m and increases with n. Further computations show that the same conclusion seems to apply to the total quantity of primary production, $Q_1(m,n) + Q_2(m,n)$, as illustrated in Figure 3.3.2.1. This suggests that a government aiming at limiting primary production should choose a larger collection rate if more recyclers can enter the market and a lower collection rate if more manufacturers are present on the market (other things being equal). Now, if the government can also regulate the number of firms, Figure 3.3.2.1 suggests that it should limit the number of manufacturers while increasing the collection rate and facilitating the entry of more recyclers.

3.4 Conclusion

We show in this paper that increasing the rate of scrap collection for recycling does not reduce monotonically the quantity of primary production. This is due to the strategic reaction of manufacturers in period 1 when anticipating the recyclers' entry in the next period. In fact, increasing the collection rate from a low level reduces the quantity of primary production as manufacturers constrain the recyclers' scale of operation to soften competition in period 2. However, if the initial collection rate is higher than a certain threshold, increasing the rate will lead to an increase in the quantity of primary production as constraining the recyclers' entry becomes too expensive for manufacturers (as they need to reduce further their production–and thus their profit–in period

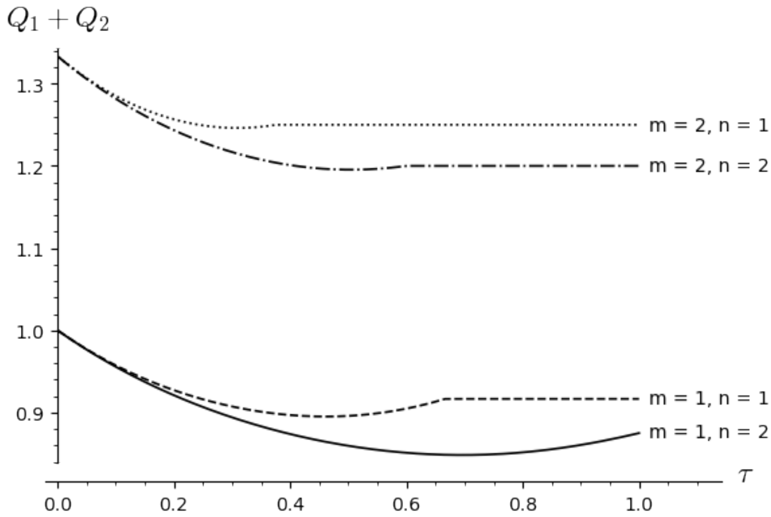


Figure 3.3.2.1. Evolution of total primary production

1). Consequently, it may be counterproductive from an environmental point of view to make the recycling process too efficient because, above some level, manufacturers would prefer to increase their extraction of primary material. Our model also shows that the collection rate that minimizes the extraction of primary material would be considered as too low by the consumers and the recyclers, and too large by the manufacturers.

Appendix

3.A Proof of Proposition 3 with a general demand function

Manufacturer's maximization problem in period 1. We compute the total differentiation of the manufacturer's expected profit function with respect to v_1:

$$\frac{d\Pi^e(q_1)}{dq_1} = \frac{d\pi_1(q_1)}{dq_1} + \frac{d\hat{\pi}_2^c(q_1)}{dq_1} + \frac{d\hat{\pi}_2^u(q_1)}{dq_1}.$$

The impact of q_1 on the expected profit in the second period is computed as

$$\begin{aligned}\frac{d\hat{\pi}_2^c(q_1)}{dq_1} + \frac{d\hat{\pi}_2^u(q_1)}{dq_1} &= \frac{1}{\bar{c}}\frac{d}{dq_1}\int_0^{\tilde{c}(q_1)} \pi_2^c(q_1)dc + \frac{1}{\bar{c}}\frac{d}{dq_1}\int_{\tilde{c}(q_1)}^{\bar{c}} \pi_2^u(c)dc \\ &= \frac{1}{\bar{c}}\left[\underbrace{\frac{d\tilde{c}(\tau q_1)}{\partial q_1}\big(\pi_2^c(q_1) - \pi_2^u(\tilde{c})\big)}_{(a)} + \underbrace{\tilde{c}\frac{d\pi_2^c(q_1)}{dq_1}}_{(b)}\right].\end{aligned}$$

Because $r^u(\tilde{c}) = r^c = \tau q_1$, we obtain $\pi_2^c(q_1) = \pi_2^u(\tilde{c})$, which makes $(a) = 0$. Therefore, we obtain

$$\frac{\partial\hat{\pi}_2^c(q_1)}{\partial vq_1} + \frac{\partial\hat{\pi}_2^u(q_1)}{\partial q_1} = \frac{1}{\bar{c}}\left[\tilde{c}(q_1)\frac{\partial\pi_2^c(q_1)}{\partial q_1}\right]. \tag{3.9}$$

Given that the profit of the manufacturer under the constrained equilibrium is $\pi_2^c(q_1) = P(\tau q_1 + q_2^*)q_2^*$, with $q_2^* = q_2^*(\tau q_1)$ the best response of the manufacturer when the recycler produces τq_1, we have

$$\begin{aligned}\frac{\partial\pi_2^c(q_1)}{\partial q_1} &= \left(\tau + \frac{\partial q_2^*}{\partial q_1}\right)P'q_2^* + P\frac{\partial q_2^*}{\partial q_1} \\ &= \tau P'q_2^* + \frac{\partial q_2^*}{\partial q_1}(P'q_2^* + P).\end{aligned} \tag{3.10}$$

Because q_2^* maximizes π_2^c, according to the first-order condition of the profit-maximization problem, $P'q_2^* = -P$. Replacing in (3.10), we obtain

$$\frac{\partial\pi_2^c(q_1)}{\partial q_1} = -P\tau < 0. \tag{3.11}$$

The first derivative of the manufacturer's profit function can then be written as

$$\frac{d\Pi^e}{dq_1} = P'(q_1)q_1 + P(q_1) - \frac{\tilde{c}}{\bar{c}}P(q_2+r)\tau. \tag{3.12}$$

Since $\frac{\tilde{c}}{\bar{c}}P(.)\tau$ is positive and $P'(q_1)q_1 + P(q_1)$ is negative by assumption, there can be a value q_1^* so that $\frac{d\pi}{dq_1} = 0$. Furthermore, $P'(q_1)q_1 + P(q_1)$ decreases with all $q_1 > 0$ as $\pi_1(q_1)$ is concave and $\frac{\tilde{c}}{\bar{c}}P\tau$ increases with all $q_1 > 0$ as both P and $\tilde{c}$ decrease with q_1. Therefore, q_1^* is unique if it exists.

Profit-maximizing primary production in period 1. When q_1 converges to 0, $\frac{d\Pi}{dq_1}$ converges to $P'(0)0 + P(0)$, which is strictly positive under our assumptions (i). Furthermore, at $q_1 = q^m$, the manufacturer's period 1 profit is separately maximized, i.e., $P'(q_m)q_m + p(q_m) = 0$ by the first-order condition. Equation (3.12) then becomes

$$\frac{d\Pi}{dq_1} = -\frac{\tilde{c}}{\bar{c}}P\tau. \tag{3.13}$$

Since $\frac{\tilde{c}}{\bar{c}}P\tau > 0$, $\frac{d\Pi}{dq_1}$ is strictly negative at $q_1 = q^m$ (ii). Together, (i) and (ii) impose that, if $\tau < \bar{\tau}$, the profit function increases with q_1, reaches a unique maximum then decreases with q_1 when q_1 tends to q^m. Therefore, for $\tau < \bar{\tau}$, choosing $q_1^* \in (0, q^m)$ is the optimal choice for the manufacturer.

At $\tau = \bar{\tau}$, because $\tilde{c}(\bar{\tau}q^m) = 0$, Equation (3.12) is equivalent to

$$P'(q_1)q_1 + P(q_1) = 0.$$

Thus, the firm's profit is maximized at $q_1^* = q^m$ if $\tau = \bar{\tau}$. Because q_1^* is unique, this is also the global optimal choice of the manufacturer.

For $\tau > \bar{\tau}$, $\tilde{c}(\tau q^m)$ is negative, imposing that the constrained equilibrium does not obtains. The manufacturer's profit is independent of τ. The firm then chooses $q_1^* = q^m$.

Impact of the collection rate on primary production in period 1. To formalize the impact of $\tau \in (0, \bar{\tau})$ on q_1^*, we use the implicit function theorem to write

$$\frac{dq_1^*(\tau)}{d\tau} = -\frac{\frac{\partial^2 \pi(q_1^*)}{\partial q_1 \partial \tau}}{\frac{\partial^2 \pi(q_1^*)}{\partial q_1^2}}.$$

Because q_1^* maximizes the firm's expected profit, $\frac{\partial^2 \pi(q_1^*)}{\partial q_1^2} < 0$ by the second-order condition. So $\frac{dq_1^*(\tau)}{d\tau}$ takes the sign of

$$\frac{\partial^2 \pi(q_1^*)}{\partial q_1 \partial \tau} = \frac{\partial^2 \pi_1(q_1^*)}{\partial q_1 \partial \tau} + \underbrace{\frac{\partial^2 \hat{\pi}_2^c(q_1)}{\partial q_1 \partial \tau}}_{(i)} + \underbrace{\frac{\partial^2 \hat{\pi}_2^u(q_1)}{\partial q_1 \partial \tau}}_{(ii)}.$$

From (3.9), we obtain

$$\begin{aligned}
\frac{\partial^2 \pi(q_1^*)}{\partial q_1 \partial \tau} &= \frac{\partial^2 \hat{\pi}_2^c(q_1)}{\partial q_1 \partial \tau} + \frac{\partial^2 \hat{\pi}_2^u(q_1)}{\partial q_1 \partial \tau} = \frac{1}{\bar{c}} \frac{\partial}{\partial \tau} \left[\tilde{c}(q_1^*) \frac{\pi_2^c(q_1^*)}{\partial q_1} \right] \\
&= \tilde{c}(q_1^*) \frac{\partial^2 \pi_2^c(q_1^*)}{\partial q_1 \partial \tau} + \frac{\partial \tilde{c}(q_1^*)}{\partial \tau} \frac{\partial \pi_2^c(q_1^*)}{\partial q_1} = -\frac{1}{\bar{c}} \frac{\partial}{\partial \tau} [\tilde{c} \tau P] \\
&= -\frac{1}{\bar{c}} \left[P\tilde{c} + \tau \left(\frac{\partial \tilde{c}}{\partial \tau} P + \frac{\partial P}{\partial \tau} \tilde{c} \right) \right].
\end{aligned}$$

Because both $\tilde{c}$ and P decrease with τ, the sign of $\frac{\partial^2 \pi(q_1^*)}{\partial q_1 \partial \tau}$ is ambiguous.

Consider τ close to 0, we have

$$\lim_{\tau \to 0} \frac{\partial}{\partial \tau} \left[\tilde{c} \frac{\pi_2^c}{\partial q_1} \right] = [-P\tilde{c}]_{\tau=0} < 0.$$

Furthermore, when $\tau \to 0$, $q_1^* \to \operatorname{argmax}_{q_1}(\pi_1 + \pi_2^c)$ but $\pi_2^c(\tau q_1, q_2^*(\tau q_1)) \to \pi_2^c(0, q_2^*(0))$, which is independent of q_1, thus $q_1^* \to \operatorname{argmax}_{q_1} \pi_1 = q^m$.

Consider $\tau = \bar{\tau}$, we have $q_1 = q^m$, leading to $\tilde{c} = 0$. In this case,

$$\lim_{\tau \to \bar{\tau}} \frac{\partial}{\partial \tau} \left[\tilde{c} \frac{\pi_2^c}{\partial q_1} \right] = -\bar{\tau} P \frac{\partial \tilde{c}}{\partial \tau} > 0.$$

As $\frac{\partial}{\partial \tau} \left[\tilde{c} \frac{\pi_2^c}{\partial q_1} \right]$ is negative for τ close to zero, whereas $q_1^* \to q^m > 0$ when $\tau \to \bar{\tau}$, we can deduce that the initial production of the manufacturer decreases from the monopolistic value when τ is small and increases with τ when τ is close to $\bar{\tau}$ to reach the monopolistic level $q_1^* = q^m$ again at this threshold.

Recall that the threshold $\tilde{c}$ is determined at $r^u(\tilde{c}) = \tau q_1$, from the first-order condition of profit maximization of the recycler, we obtain

$$\tilde{c} = P'(Q)\tau q_1 + P(Q), \tag{3.14}$$

with $Q = \tau q_1 + q_2^c(\tau q_1)$.

To study the variation of $\tilde{c}$ with respect to $\tau \in (0, \bar{\tau})$, we take the total differentiation of equation (3.14) with respect to τ and rearrange the terms to obtain

$$\begin{aligned}\frac{d\tilde{c}}{d\tau} &= \left(q_1 + \frac{\partial q_2}{\partial \tau}\right) P' + P''\tau q_1 \left(q_1 + \frac{\partial q_2}{\partial \tau}\right) + P'q_1 \\ &= \left(q_1 + \frac{\partial q_2}{\partial \tau}\right) (P''\tau q_1 + P') + P'q_1 \\ &= P'q_1 \left(\frac{P''\tau q_1 + P'}{P''q_2 + 2P'} + 1\right) < 0.\end{aligned}$$

Hence, given a level of q_1, we have

$$\begin{aligned}\frac{d\tilde{c}}{d\tau} &= q_1 P' + \tau P' \frac{dq_1}{d\tau} + \left(q_1 + \tau \frac{dq_1}{\tau} + \frac{dq_2}{d\tau}\right) (P''\tau q_1 + P') \\ &= P' \left(\tau \frac{dq_1}{d\tau} + q_1\right) \left(\frac{P''\tau q_1 + P'}{P''q_2 + 2P'} + 1\right).\end{aligned}$$

For $\frac{d\tilde{c}}{d\tau} \geq 0$, we should have $\frac{dq_1}{d\tau} \leq -\frac{q_1}{\tau}$. Intuitively, this inequality means that, at an initial level of τ, in order to compensate for the marginal effect of an increase in τ on the reduction of $\tilde{c}$, the manufacturer has to reduce its initial production by more than q_1/τ, which is larger than q_1. That means that the manufacturer has to reduce more than what it is producing. Since this is impossible, we can conclude that $\tilde{c}$ always decreases with τ.

Impact of the collection rate on primary production in period 2. In period 2, the manufacturer's profits in the constrained equilibrium is given by $\pi_2^c = P(\tau q_1 + q_2)q_2$. Applying the implicit function theorem on the first-order condition $\frac{\partial \pi_2^c}{\partial q_2} = P'q_2 + P = 0$, we obtain the variation of q_2 with respect to τ due to the substitution effect in the second period as

$$\frac{\partial q_2}{\partial \tau} = -\frac{\partial \pi_2}{\partial^2 q_2 \partial q_1} \Big/ \frac{\partial^2 \pi_2}{\partial q_2^2} = -\tau q_1 \frac{P''q_2 + P'}{P''q_2 + 2P'}.$$

Hence, the total variation of q_2 with respect to τ, taking into account both the substitution effect in the second period and the strategic effect in the first period is given by

$$\begin{aligned}\frac{dq_2}{d\tau} =& \frac{\partial q_2}{\partial \tau} + \frac{\partial q_2}{\partial q_1}\frac{dq_1}{d\tau} \\ &= -\tau q_1 \frac{P''q_2 + P'}{P''q_2 + 2P'} - \tau \frac{P''q_2 + P'}{P''q_2 + 2P'} \frac{dq_1}{d\tau} \\ &= -\frac{P''q_2 + P'}{P''q_2 + 2P'} \left(\frac{dq_1}{d\tau} + q_1\right) \tau.\end{aligned}$$

Similar to the logic above, since $\frac{dq_1}{d\tau} > q_1$, $\frac{dq_2}{d\tau} < 0$; that is, the quantity of primary product in the constrained equilibrium decreases in τ.

We know that $\tilde{c}$ decreases in τ; that is, the probability of occurrence of the constrained equilibrium is smaller. Moreover, given the same recycling cost c, $q_2^c > q_2^u$. Hence, the expected quantity of primary product in period 2 decreases τ. Now given that q_1^* decreases with τ when τ is small, the total quantity of primary production decreases when τ is small. However, Since q_2^u is independent of τ, the higher the weight of q_2^u in the computation of expected primary production in period 2, the smaller the variation of $\hat{q}_2$ with respect to τ. Hence, when τ is large, the negative impact of increasing τ on the total primary production via $\hat{q}_2$ converge to zero while the positive impact via q_1^* is larger. Therefore, the total primary production decreases, then increases with τ, that is, it also has an interior minimum with respect to τ.

3.B Proof of Lemma 4

We first show that *there cannot be an equilibrium where some but not all recyclers are constrained.* Suppose, by contradiction, that we have an equilibrium with a strict subset of recyclers being in the constrained part of their reaction function. Suppose that recyclers 1 to k are in the unconstrained part, while recyclers k to n are in their constrained part (with $1 < k < n$). Define

$$R_u \equiv \sum_{s=1}^{k} r_s \text{ and } R_c \equiv \sum_{t=k+1}^{n} r_t.$$

We can sum up the first-order conditions of the unconstrained recyclers:

$$\begin{aligned}\sum_{s=1}^{k} r_s &= \sum_{s=1}^{k} \tfrac{1}{2}\left(1-c-r_{-s}-Q_2\right) \Leftrightarrow R_u = \tfrac{1}{2}k\left(1-c-Q_2-R_c\right) - \tfrac{1}{2}\left(k-1\right)R_u \\ &\Leftrightarrow \left(k+1\right)R_u + kR_c = k\left(1-c-Q_2\right).\end{aligned}$$

Proceeding in the same way for the constrained recyclers, we have

$$\begin{aligned}\sum_{t=k+1}^{n} r_t &= \sum_{t=k+1}^{n} \left(\tau Q_1 - r_{-t}\right) \Leftrightarrow R_c = \left(n-k\right)\left(\tau Q_1 - R_u\right) - \left(n-k-1\right)R_c \\ &\Leftrightarrow R_c + R_u = \tau Q_1\end{aligned}$$

Solving the system of the last two equations gives:

$$\begin{aligned} R_u &= k\left(1-c-Q_2-\tau Q_1\right), \\ R_c &= \left(k+1\right)\tau Q_1 - k\left(1-c-Q_2\right). \end{aligned}$$

We need to check if the condition for being in the unconstrained part of the reaction function is satisfied for all recyclers $s \in \{1, k\}$. If it is, then we have:

$$\begin{aligned} \sum_{s=1}^{k}\left(r_{-s}-Q_2\right) &\leq k\left(2\tau Q_1-(1-c)\right) \Leftrightarrow k\tau Q_1 - R_u \leq k\left(2\tau Q_1-(1-c)\right) \\ &\Leftrightarrow \tau Q_1 - \left(1-c-Q_2-\tau Q_1\right) \leq 2\tau Q_1-(1-c) \\ &\Leftrightarrow 2\tau Q_1-(1-c)-Q_2 \leq 2\tau Q_1-(1-c) \iff Q_2 \leq 0, \end{aligned}$$

a contradiction.

It follows that the only two equilibria are such that either none or all recyclers are constrained. Take first the case such that *no recycler is constrained*. Summing up the reaction functions of the n recyclers, we have $R_u\left(Q_2\right) = n\left(1-c-Q_2\right)/\left(n+1\right)$. As for manufacturer i, its problem is $\max_{q_{i2}}\left(a-q_{i2}-q_{-i2}-R_u\right)q_{i2}$, where q_{-i2} is the sum of the quantities produced by the other manufacturers. The first-order condition yields $q_{i2}\left(q_{-i2}, R_u\right) = \left(1-q_{-i2}-R_u\right)/2$. Summing up the m previous expressions, we have

$$Q_2 = \tfrac{1}{2}\left(ma-(m-1)Q_2-mR_u\right) \Leftrightarrow Q_2\left(R_u\right) = \tfrac{m}{m+1}\left(1-R_u\right).$$

A the Nash equilibrium, we have $Q_2^* = Q_2\left(R_u^*\right)$ and $R_u^* = R_u\left(Q_2^*\right)$; solving and assuming $c < 1/\left(m+1\right)$, we obtain

$$Q_2^* = m\frac{1+nc}{m+n+1}, R_u^* = n\frac{1-(m+1)c}{m+n+1}.$$

At the symmetric equilibrium, each manufacturer produces Q_2/m and each recycler produces R_u/n. This equilibrium is valid as long as all recyclers are indeed in the unconstrianed part of their reaction function, which supposes

$$\sum_{j=1}^{n}\left(r_{-j}-Q_2^*\right) \leq n\left(2\tau Q_1-(1-c)\right) \Leftrightarrow (n-1)R_u^* - nQ_2^* \leq n\left(2\tau Q_1-(1-c)\right)$$

$$\Leftrightarrow Q_1 \geq \frac{1}{\tau}\frac{n}{m+n+1}\left(1-(m+1)c\right) \equiv Q_1^{\lim}.$$

Consider now the case in which *all recyclers are constrained*. Summing up the reaction functions of the n recyclers, we have $R_c = \tau Q_1$.As $Q_2(R_c) = m(1-R_c)/(m+1)$, we find that $Q_2^{**} = m(1-\tau Q_1)/(m+1)$ and $R_c^{**} = \tau Q_1$. At the symmetric equilibrium, each manufacturer produces Q_2/m and each recycler produces R_c/n. This equilibrium is valid as long as all recyclers are indeed in the constrained part of their reaction function, which supposes that $(n-1)R_c^{**} - nQ_2^{**} > n(2\tau Q_1 - (1-c))$. A few lines of computations establish that the latter condition is equivalent to $Q_1 < Q_1^{\lim}$.

We can now compute the equilibrium profits in both cases. In the unconstrained case, we have

$$\begin{aligned}
\pi_2^u &= (1-Q_2^* - R_u^*)\frac{1}{m}Q_2^* \\
&= \left(1 - m\frac{1+nc}{m+n+1} - n\frac{1-(m+1)c}{m+n+1}\right)\frac{1}{m}m\frac{1+nc}{m+n+1} \\
&= \frac{(1+nc)^2}{(m+n+1)^2}, \\
\pi_r^u &= (1-c-Q_2^* - R_u^*)\frac{1}{n}R_u^* \\
&= \left(1 - c - m\frac{1+nc}{m+n+1} - n\frac{1-(m+1)c}{m+n+1}\right)\frac{1-(m+1)c}{m+n+1} \\
&= \frac{(1-(m+1)c)^2}{(m+n+1)^2}.
\end{aligned}$$

In the constrained case, we have

$$\begin{aligned}
\pi_2^c &= (1-Q_2^{**} - R_u^{**})\frac{1}{m}Q_2^{**} \\
&= \left(1 - \frac{m(1-\tau Q_1)}{m+1} - \tau Q_1\right)\frac{1-\tau Q_1}{m+1} \\
&= \frac{(1-\tau Q_1)^2}{(m+1)^2}, \\
\pi_r^c &= (1-Q_2^{**} - R_u^{**})\frac{1}{n}R_u^{**} \\
&= \left(1 - c - \frac{m(1-\tau Q_1)}{m+1} - \tau Q_1\right)\frac{1}{n}\tau Q_1 \\
&= \frac{1-(m+1)c-\tau Q_1}{n(m+1)}\tau Q_1.
\end{aligned}$$

4

Pay-per-use as a win-win business model

For both the firm and the environment?

I use a simple stylized model to provide some insights on the conditions for PPU to be a sustainable business model: one that generates higher profits for the firm and lower aggregate use levels of the product at the same time. Indeed, the pay-per-use (PPU) pricing structure allows the firm to segment its customers without necessarily identifying their type, a capacity that is unavailable to the firm under selling. Yet, the firm may still earn lower profits under PPU if the gain from segmenting customers does not offset the loss from incurring a lower use level of its product or not wholly appropriating consumers' surplus when they encounter a high-utility instance of need. Furthermore, the profitability of PPU does not necessarily align with its potential to reduce the business' environmental impacts. While the per-use payment encourages some consumers to reduce their usage, it also allows more consumers to participate in the market. Consequently, the product's aggregate use levels may also be higher under PPU, causing more environmental impacts.

4.1 Introduction

The current proliferation of Industrial Internet-of-Things (IIoT) has created tailwinds for pay-per-use (*PPU*) business models. Under these models, the firm does not sell its product for a one-off payment but instead provides the product's functionality to its customers and charges them on a per-use basis. One of the textbook examples of *PPU* is Xeros' *document management service*, in which the firm takes care of the operational process and charges its customers a fee for each page printed.

PPU has attracted significant attention from both academics and practitioners for its potential to be more sustainable than *selling*. From the economic perspective, *PPU* allows the firm to segment its customers without necessarily identifying their types while this capacity is not available to the firm under *selling*. By having customers self-select according to their usage level, the firm under *PPU* can appropriate better the consumers' surplus and earn higher profits. From the environmental perspective, the per-use payment may incentivize customers to reduce their usage. Since the use phase is reported to harm the environment more critically than the production and disposal phases for many products,[1] reducing the product's aggregate use level will help reduce the business' environmental impacts significantly.

Nevertheless, many firms failed to adopt *PPU* profitably in reality. A typical example of failure is Better Place. The Israeli startup received almost $1 billion in funding to establish a network for electric cars and charging stations in Israel and Denmark. Better Place's customers can "rent" the cars' batteries and swap them at the stations when the batteries drain out under a *PPU* business model. However, the firm failed to grow and went bankrupt in 2013 (Noel and Sovacool, 2016). One primary reason is that consumers tend to use the car significantly less when they pay for every use than when they own it. Since lower use levels translate into lower revenues for the firm, Better Place did not generate enough profits to sustain.

Furthermore, *PPU*'s potential to reduce the business' environmental impacts is also ambiguous. While *PPU* can incentivize some customers to

[1] Costagliola, Prati, Mariani, Unich and Morrone (2015), Elijošiute and Varžinskas (2011) and Muthu (2015) use life-cycle analysis to study the environmental impacts of cars, refrigerators, and washing machines respectively. All three studies conclude that, among the three phases of production, usage, and disposal of a product's lifetime, the use phase is the most detrimental to the environment.

reduce their usage, it also gives access to new customers who would not be able to use the product under *selling*. Consequently, this leads to a larger number of customers adopting and using the product, increasing the aggregate use level and causing higher environmental impacts.

To contribute to the debate concerning *PPU*'s potential to be a sustainable business model, I use a simple stylized model to discuss the new business models' profitability, focusing on the changes in the operating profits when the firm transits from selling to *PPU*. Then, I focus on the changes in aggregate use levels of the product as proxies for its environmental impacts. Finally, I provide some insights on the conditions for *PPU* to be a sustainable business model, namely one that can benefit the firm and the environment at the same time.

Main intuitions. Consider a manufacturer facing two segments of customers identified by how often they use the product. Under *selling*, the customers pay in advance a fixed purchase price to own the product. Hence, without the capacity to price-discriminate its customers, the firm faces the classical tradeoff: set a high price and sell only to high-usage customers or set a low price and sell to both customer segments.

In contrast, because there is no (or insignificant) upfront payment under *PPU*, any customer can use the product at the instances of need that yield a utility higher than the per-use fee she pays to the firm. Consequently, even without the capacity to identify different types of customers, the firm under *PPU* can segment its customers by having them pay according to the use volume they incur.

Therefore, if the firm finds it optimal to focus only on the high-usage segment under *selling*, *PPU* allows the firm to extend the market to the low-usage segment without necessarily appropriating less surplus from high-usage customers. Alternatively, if the firm finds it optimal to cover the market with a low price under *selling*, *PPU* allows the firm to appropriate more efficiently the high-usage customers' surplus without giving up on the low-usage segment.

However, each time the product is used, it incurs an operating cost. Hence, under *selling*, a customer uses the product at the instances of need that yield a utility higher than the cost she has to pay. Meanwhile, under *PPU*, the firm takes care of this operating cost. As a result, the same customer uses the product only when she derives a utility higher than the fee she pays to the firm. Since the per-use fee under *PPU* must reasonably be higher than the operating cost,[2] the customer may use the product less under *PPU*. Consequently, *PPU* generates a negative impact on the firm's profits due to the reduction in customers' usage.

In contrast, if the operating cost is sufficiently low, the firm under *PPU* may find it optimal to set a low fee and serve all instances of need whether they yield low or high utility. However, at this fee, the firm leaves consumers a positive surplus when they experience a high-utility instance of need. Meanwhile, if a consumer buys the product under *selling*, the purchase price allows the firm to appropriate wholly the consumer's expected surplus over all instances of need. Consequently, *PPU* can generate another negative impact on the firm's profits for appropriating less consumer surplus than *selling*.

Therefore, the profitability of *PPU* compared to *selling* is ambiguous. The firm earns higher profits under *PPU* if and only if the gain from segmenting its customers can offset the two aforementioned negative impacts.

The impacts of the transition from *selling* to *PPU* on the product's aggregate use levels are also ambiguous. On the one hand, some customers may use the product less under *PPU*. But on the other hand, *PPU* also grants access to more customers, whose usage can offset the reduction aforementioned and result in a higher aggregate use level of the product.

Pay-per-use as a business model. Providing a bundle of goods and services in product-service-systems (PSS) is not a new concept. Firms have provided an integration of product and service rather than the product alone for a long time (Vandermerwe and Rada, 1988). The commoditization of products has left limited room for differentiation and made it harder for manufacturers to compete simply by making and selling high-quality products at competitive prices (Visnjic, Jovanovic, Neely and Engwall, 2017). Consequently, the firms have to adopt more innovative approaches by selling services, integrated solutions, experiences, and even results-based contracts to capture value throughout the value chain (Tukker, 2015).

Some of the PSS are simple bundles of services such as warranties and maintenance services sold along with durable products such as cars, household appliances, and computers. In other PSS, manufacturers sell services derived from the use of the products, treating the products as an intermediate good

[2] the operating cost is assumed to be symmetric under both business models to focus on the impacts on the demand side of *PPU*. A lower operating cost will make the firm better off and vice versa.

rather than the final product. This latter type of PSS, a "service-centric" rather than a "product-centric" business model, is hence referred to as "servitization" (Vandermerwe and Rada, 1988).

From the mid-1990s, servitization has become a popular subject for researchers engaged with sustainability and business models (Tukker, 2015). As servitization business models focus on final users' needs rather than the products, it is expected to reduce the environmental impacts of the business by triggering more sustainable behaviors from both the firms and individuals. With the emergence of the Circular Economy as a new concept for sustainability, servitization has been touted as disruptive business models that can cut growth and development from resource dependence and pollution (Lovins, Braungart and Ellen MacAthur Foundation Publishing, 2014).

This paper investigates a specific business model in the servitization family: the pay-per-use business model. Initially, the pay-per-use pricing structure was used in only a few industries like utilities and telecommunication due to the lack of affordable and reliable technologies to track and meter customers' usage. However, the recent proliferation of IIOT, with cheap sensors and connections that allow tracking, storing, and communicating data on how the products are used, has granted manufacturers of durable products the same capacity. As a result, *PPU* now infiltrates a broad range of industries that cover many perspectives of our life.

To date, *PPU* is still far more common in B2B than in B2C markets. The "document management program" of Xeros mentioned previously, for instance, only targets business customers. In another example, Philips provides to business customers in The Netherlands the "pay-per-lux" contract, in which the firm takes care of all the installation, operation, and maintenance of the lighting system then charges the customer a fee for each unit of lumix used. In the aviation industry, Rolls Royce also provides to aviation companies the TotalCare program. The firm leases jet engines to airlines, provides complete management of the engines throughout their life cycle, and charges the customers a fee for every flying hour.

Recently, *PPU* has finally landed in B2C markets with the emergence of carsharing firms such as Cambio, Zipcar, General Motors' Maven , and DriveNow of BMW and Daimler, to cite a few. Even though car-rental services have been around since the 1950s, it was too expensive and unreliable to organize in large scales a *PPU* business models for individual consumers. Nowadays, thanks to the development of communication technologies, particularly the Internet, smartphones, and GPS, consumers can easily rent a car and pay only for the minutes or kilometers they drive. At the same time, the insurance, gasoline, parking, and maintenance costs are taken care of by the firms.

Even though the market share is still minimal, *PPU* has extended to other products as well. One typical example is Bundles, a newly established firm in The Netherlands. The firm has provided to individual consumers various electric appliances such as washing machines, dishwashers, and even coffee machines under *PPU* since 2014.

It is important to distinguish *PPU* with *leasing*, also called subscription business models. Under subscription, the customers pay at a regular interval of time (monthly or annually) for the service, irrespective of how often they use it. Xeros, for instance, also rents out photocopy machines and receives monthly payments from its customers, independently of the usage rate. While sharing many common features with *PPU*, the subscription pricing structure does not tie the customers' payment to their usage of the product. Therefore, subscription does not have the feature that supports *PPU*'s superiority on profitability and environmental impacts compared to *selling*.

The rest of the paper is organized as follows. Section 2 presents the model. Section 3 compares the two business models *PPU* and *selling*. Section 4 discusses the literature and contribution of this paper. Section 5 concludes.

4.2 The model

Consider a durable-good monopolist that has the choice between *selling* and *PPU*. Under *selling*, consumers buy the product from the firm at price p. After purchasing, a consumer incurs an operating cost k every time she uses the product. Under *PPU*, the firm does not sell the product but serves its functionality to consumers on a per-use basis. For each use realized, the firm incurs the operating cost k and charges the consumer a fee f. Consumers pay nothing but the fee f each time they use the product. To focus on the fundamental changes on the demand side when the firm transits from *selling* into *PPU*, I assume no production cost, no changes in the operating cost under both business models, and no pooling capacity under *PPU*.

On the demand side, there are two segments of consumers identified by the frequencies that they need to use the product, namely the high-usage consumers with usage rate α_H and low-usage consumers with usage rate $\alpha_L < \alpha_H$. A usage rate close to zero characterizes a consumer who does not need to use the product at all. Meanwhile, a usage rate close to one characterizes a consumer that needs the product all the time. For simplicity, I assume that both segments have the same size equal one so that the valuation gap $\alpha \equiv \frac{\alpha_L}{\alpha_H}$ measure the heterogeneity degree of the consumer base: if α is close to zero, the consumer base is highly heterogeneous; and if α is close to one, the consumer base is mostly homogeneous.

At each instance of need, a consumer derives a random utility level V. For the sake of tractability, I assume that the utility can either be high v_H with probability $(1-\beta)$ or low v_L with probability β. The critical assumption is that a consumer does not know in advance the utility level generated at each instance of need. Consequently, a consumer under *selling* decides *ex-ante* whether to buy the product based on her expected utility from owning the product; she buys if her expected utility over time is larger than the purchase price and does not buy otherwise. On the contrary, the renting decision under *PPU* is made *ex-post*; that is, after the consumer learns the utility she obtains at each instance of need. Hence, she can use the product when she derives a utility higher than the fee f without a commitment in advance.

The manufacturer knows the distribution of the usage rate across consumers and the utility they derive from the instances of need but cannot directly observe the usage rate of a specific consumer or the utility level that the consumer derives at a specific instance. Hence, the manufacturer cannot apply third-degree price discrimination under both business models and sets one unique price p under *selling* or one unique per-use fee f under *PPU*.

This setting allows characterizing many durable products with which consumers derive utility not as a constant flow but as a series of specific instances of need, each associated with a different utility level. For instance, a citizen may derive a high utility from making a car trip in the suburbs, where public transport is meager. But when she has to commute to work during the week, she may obtain a much lower utility due to the heavy traffic and lack of parking slots. In addition, some consumers may need to use the product more often than do others. In the example above, not all people have the same need to repeatedly commute every day or go on a trip every weekend. Thus, cars and many other durable products deliver utility stochastically over time according to the realization of specific instances of need from consumers.

Moreover, by normalizing the utility of outside options to zero, the utility that a consumer derives from using the product represents the relative value that the firm's product brings to its consumers compared to outside options. A high utility level indicates that the product has few and/or low-quality substitutions, generating a high market power for the firm. In cities where public transports are poorly served, for instance, likely, people often find it relatively highly satisfied using cars. In contrast, in cities where public transports are well organized, the relative level of satisfaction of taking a car compared to taking public transport will be lower.

Selling. Under *selling*, consumers buy the product at price p and incur the operating cost k every time they use it. The operating cost k is assumed to be smaller than the high utility level v_H; otherwise, consumers will never use the product. Since a consumer only uses the product when the utility derived from the instance of need is higher than the operating cost, the expected utility from buying and using the product for a consumer with usage rate α_i $(i \in \{L, H\})$ is given by

$$U_p(\alpha_i) = \alpha_i E[\max\{(V - k), 0\}] - p.$$

Because the firm cannot distinguish the two types of consumer, its faces the classic price-quantity tradeoff when setting price: it can either set a high price and sell only to high-usage consumers or set a low price and sell to both segments. On the one hand, if the firm sets a high price, it can earn high margins from each product sold, but it will sell fewer products as low-usage consumers are unwilling to pay the high price. On the other hand, if the firm sets a low price, it can sell to all consumers, but it will earn lower margins from each product sold. Therefore, the firm sells to all consumers if the value of the low-usage segment is high enough and sells to high-usage consumers only otherwise.

Lemma 5. *Under selling, the firm finds it optimal to sell to all cosumers if $\alpha > \frac{1}{2}$. Otherwise, the firm finds it optimal to sell to high-usage consumers only.*

Proof. If the operating cost k is high such that $v_H > k > v_L$, consumers only use the product at high-utility instances of need. A consumer with usage rate α_i $(i \in \{L, H\})$ will then obtain the expected utility $U_p(\alpha_i) = \alpha_i(1 - \beta)(v_H - k) - p$ from purchasing the product. Consequently, if the firm sets a high price $p^h = \alpha_H(1 - \beta)(v_H - k) - p$, it sells only to high-usage consumers and earns a profit $\pi_p^h = \alpha_H(1-\beta)(v_H - k)$. Meanwhile, if the firm sets a low price $p^b = \alpha_L(1-\beta)(v_H - k)$, it sells to all consumers and earns a profit $\pi_p^b = 2\alpha_L(1-\beta)(v_H - k)$.

If the operating cost k is low such that $v_H > v_L > k$, consumers will use the product at all instances of need since they always derive a utility higher than the operating cost. A consumer with usage rate α_i ($i \in \{L, H\}$) will then obtain the expected utility $U_P(\alpha_i) = \alpha_i\big((1-\beta)(v_H - k) + \beta(v_L - k)\big) - p$ from purchasing the product. Consequently, if the firm sets a high price $p^h = \alpha_H\big((1-\beta)(v_H - k) + \beta(v_L - k)\big)$, it sells only to the high-usage segment and earns a profit $\pi_p^h = \alpha_H\big((1-\beta)(v_H - k) + \beta(v_L - k)\big)$. Meanwhile, if the firm sets a low price $p^b = \alpha_L\big((1-\beta)(v_H - k) + \beta(v_L - k)\big)$, it sells to both segments and earns a profit $\pi_p^b = 2\alpha_L\big((1-\beta)(v_H - k) + \beta(v_L - k)\big)$.

Hence, the firm sells to both segments of consumer if

$$
\begin{aligned}
& \pi_p^b - \pi_p^h > 0 \\
\iff & \begin{cases} \big(2\alpha_L - \alpha_H\big)(1-\beta)(v_H - k) > 0 & \text{if} \quad k > v_L \\ \big(2\alpha_L - \alpha_H\big)\big((1-\beta)(v_H - k) + \beta(v_L - k)\big) > 0 & \text{otherwise} \end{cases} \\
\iff & \frac{\alpha_L}{\alpha_H} > \frac{1}{2}.
\end{aligned}
$$

□

Pay-per-use. Under *PPU*, the firm incurs the operating cost k and charges a fee f each time a consumer uses the product. If $k > v_L$, the firm has no reason to charge $f < v_L$ as it will lose from each transaction. Hence, in this case, the firm sets $f = v_H$ and serves only the high-utility instances of need.

If $k < v_L$, the firm faces the tradeoff between two alternatives. If the firm sets a high fee, it earns a high margin from each use but only serves the high-utility instances of needs. Meanwhile, if the firm sets a low fee, it earns a low margin from each use, but it can serve all instances of needs and earns from the large number. Hence, if the margin from serving the low-utility usage instances is high enough, the firm will find it optimal to set a low fee and serve all instances of need. In contrast, if the margin from serving the low-utility usage instances is narrow, the firm will find it optimal to set a high fee and serve only the high-utility instances of need. This reasoning is recorded in the following lemma.

Lemma 6. *Under PPU, the firm will set a low per-use fee to serve all instances of need if the operating cost k is lower than a certain threshold $\tilde{k}$. Otherwise,* *it will set a high per-use fee to serve only the high-utility instances of need.*

Proof. A consumer of type α_i will use the product $(1-\beta)\alpha_i$ times if $f > v_L$ and α_i times otherwise. The aggregate use level of the product in the two cases is hence $AU_f^h = (\alpha_H + \alpha_L)(1-\beta)$ and $AU_f^b = \alpha_H + \alpha_L$ respectively.

If the operating cost is high such that $v_L < k \leq v_H$, the firm has no incentive to charge $f \leq v_L$. Hence, it sets $f = v_H$ to serve only the high-utility usage instances and earns a profit $\pi_f^h = AU_f^h(f-k) = (\alpha_H + \alpha_L)(1-\beta)(v_H - k)$.

If the operating cost is lower than v_L, the firm has two options: either set a low fee $f \leq v_L$ to serve all instances of need, or set a higher fee $v_L < f \leq v_H$ to serve high-utility instances of need only. To maximize its profits, the firm sets either $f_L = v_L$ or $f_H = v_H$ and earns the profit $\pi_f^b = AU_f^b(f-k) = (\alpha_H + \alpha_L)(v_L - k)$ or $\pi_f^h = AU_f^h(f-k) = (\alpha_H+\alpha_L)(1-\beta)(v_H-k)$, respectively. Hence, it is more profitable to serve all instances of need if

$$\begin{aligned} \pi_f^b - \pi_f^h > 0 \iff & (\alpha_H + \alpha_L)\big((v_L - k) - (\alpha_H + \alpha_L)(1-\beta)(v_H - k)\big) > 0 \\ \iff & k < v_L - \frac{1-\beta}{\beta}(v_H - v_L) \equiv \tilde{k}. \end{aligned}$$

□

We observe that, if $v_L < (1-\beta)v_H$, $\tilde{k} < 0$; that is, if the value generated by low-utility instances of need is insignificant relative to high-utility instances of need, it is not optimal for the firm to serve the former irrespective of the operating cost.

4.3 *Selling* vs. *PPU*

Having outlined the firm's choice under the two business models, I now compare the outcomes under *selling* and *PPU* to tease out the implications of *PPU* on profitability and the aggregate use levels.

4.3.1 Profitability

Under *selling*, because the firm cannot distinguish the two types of consumers, it faces a tradeoff between two alternatives: it can either set a high price to appropriate all high-usage consumers' expected surplus and drop the low-usage segment or set a low price to cover the market but give up on appropriating a part of high-usage consumers' expected surplus.

In contrast, the pricing structure under *PPU* allows the firm to segment the two types of consumers without necessarily identifying them. Since consumers do not pay the purchase price in advance but only a per-use fee, they use the product and pay according to their usage rate. Therefore, the firm does not face the same tradeoff as under *selling*: if the firm finds it optimal to sell only to high-usage consumers under *selling*, *PPU* allows the firm to expand to the low-usage segment without necessarily giving up appropriating totally high-usage consumers' surplus. Alternatively, if the firm finds it optimal to sell to all consumers under *selling*, *PPU* allows the firm to appropriate more efficiently high-usage consumers' surplus without giving up the low-usage segment.

Nonetheless, it does not means that *PPU* is always more profitable than *selling*. Consider a consumer who purchases the product under *selling*. Since she incurs an operating cost k each time the product is used, she will use the product at the instances of need that yield a utility higher than k. Meanwhile, the same consumer under *PPU* rents the product only at the instances of need that yield a utility larger than the fee f the consumer pays to the firm. Specifically, if $k \in (\tilde{k}, v_L)$, consumers who buy the product under *selling* will use it at all instances of need while the firm finds it optimal to charge $f = v_H$ and serve only the high-utility instances of need under *PPU*. Due to this choice of the firm, if a consumer is willing to buy the product under *selling*, she uses the product less often, and hence, has a smaller total willingness-to-pay for using the product under *PPU*. Therefore, in the present case, the firm is better off if and only if the gain from segmentation can offset the loss due to the lower use level of some consumers.

Alternatively, if $k < \tilde{k}$, the firm finds it optimal to charge $f = v_L$ and serve all instances of need under *PPU*. While this fee allows the firm to maintain the same use level at consumers who are active under *selling*, it also forces the firm to give up appropriating a part of consumers' surplus when they derive v_H from the instances of need. Therefore, in the present case, *PPU* is more profitable than *selling* if and only if the gain from segmentation can offset the loss due to the reduction in consumers' surplus appropriation at high-utility instances of need.

This result is recorded the following proposition:

Proposition 6. *PPU is more profitable than selling if and only if*

(1a) $k > v_L - \frac{\alpha(1-\beta)}{\beta-\alpha(1-\beta)}(v_H - v_L)$ *or (1b)* $k < v_L - \frac{1}{\alpha}(1-\beta)(v_H - v_L)$ *in case* $\alpha < \frac{1}{2}$

(2a) $k > v_L - \frac{(1-\alpha)(1-\beta)}{\alpha(1+\beta)-(1-\beta)}(v_H - v_L)$ *or (2b)* $k < v_L - \frac{2\alpha(1-\beta)}{1-\alpha}(v_H - v_L)$ *in case* $\alpha > \frac{1}{2}$

We observe that, if $k > v_L$, *PPU* is more profitable than *selling* for all valuation gap $\alpha \in [0, 1]$. This is because, in this case, consumers only use the product when they derive v_H from the instances of need under both business models. Hence, the firm can charge $f = v_H$ under *PPU* and benefits from the segmentation capacity without incurring any loss relative to *selling*.

Meanwhile, in case $k < v_L$, the firm's profits are not necessarily higher under *PPU*, depending on the balance between the gain from segmentation and the loss due to the reduction in either the use level of some consumers or the surplus appropriation at high-utility instances of need in each of the following cases:

(1) When *PPU* leads to market expansion

If $\alpha > \frac{1}{2}$, the firm finds it optimal to sell only to high-usage consumers under *selling*. In this case, *PPU* allows the firm to extend the market to low-usage consumers without necessarily giving up appropriating high-usage consumers' surplus. However, *PPU* also generates a negative impact on the firm's profits depending on the operating cost k as follows:

(1a) $\mathbf{k} \in (\tilde{\mathbf{k}}, \mathbf{v_L}]$. In the present case, high-usage consumers use the product less under *PPU*. Hence, the firm is better off under *PPU* if and only if the additional profit from market expansion can offset the loss due to the reduction in high-usage consumers' use level; that is,

$$
\begin{aligned}
& \pi_f^h - \pi_p^h > 0 \\
\Longleftrightarrow\ & (\alpha_H + \alpha_L)(1-\beta)(v_H - k) - \alpha_H\big((1-\beta)(v_H - k) + \beta(v_L - k)\big) > 0 \\
\Longleftrightarrow\ & \underbrace{\alpha_L(1-\beta)(v_H - k)}_{\text{gain from market expansion}} - \underbrace{\alpha_H\beta(v_L - k)}_{\text{loss due to lower use level}} > 0 \\
\Longleftrightarrow\ & k > v_L - \frac{\alpha_L(1-\beta)}{\alpha_H\beta - \alpha_L(1-\beta)}(v_H - v_L) \\
\Longleftrightarrow\ & k > v_L - \frac{\alpha(1-\beta)}{\beta - \alpha(1-\beta)}(v_H - v_L) \equiv \overline{k_e}.
\end{aligned}
$$

(1b) $\mathbf{k} < \tilde{\mathbf{k}}$. In the present case, the firm does not appropriate all the consumers' surplus when they encounter high-utility instances of need under *PPU*. Hence, *PPU* is more profitable than *selling* if and only if the gain from market expansion can offset the loss due to the reduction in surplus appropriation when high-usage consumers encounter high-utility instances of need; that is,

$$\begin{aligned}
&\pi_f^l - \pi_p^h > 0 \\
\Longleftrightarrow\ & (\alpha_H + \alpha_L)(v_L - k) - \alpha_H\big((1-\beta)(v_H - k) + \beta(v_L - k)\big) > 0 \\
\Longleftrightarrow\ & \underbrace{\alpha_L(v_L - k)}_{\text{gain from market expansion}} - \underbrace{\alpha_H(1-\beta)(v_H - v_L)}_{\text{loss due to lower surplus appropriation}} > 0 \\
\Longleftrightarrow\ & k < v_L - \frac{\alpha_H}{\alpha_L}(1-\beta)(v_H - v_L) \\
\Longleftrightarrow\ & k < v_L - \frac{1}{\alpha}(1-\beta)(v_H - v_L) \equiv \underline{k_e}.
\end{aligned}$$

(2) **When the market is already covered under *selling***

If $\alpha > \frac{1}{2}$; that is, if the valuation gap between the two segments is not too large, the firm finds it optimal to sell to both segments under *selling*, leaving a positive surplus to high-usage consumers. In this case, the segmentation capacity under *PPU* allows the firm to appropriate better the surplus of high-usage consumers and earn higher profits. However, similar to the previous case, *PPU* may reduce the firm's profits depending on the operating cost k as follows:

(2a) $\mathbf{k} \in (\tilde{\mathbf{k}}, \mathbf{v_L}]$. In the present case, the firm only serve the high-utility instances of need under *PPU*. Hence, the firm is better off under *PPU* if and only if the gain from segmentation can offset the loss due to the reduction in the use level of all consumers; that is,

$$\begin{aligned}
&\pi_f^h - \pi_p^b > 0 \\
\Longleftrightarrow\ & (\alpha_H + \alpha_L)(1-\beta)(v_H - k) - 2\alpha_L\big((1-\beta)(v_H - k) + \beta(v_L - k)\big) > 0 \\
\Longleftrightarrow\ & \underbrace{(\alpha_H - \alpha_L)(1-\beta)(v_H - k)}_{\text{gain from segmentation}} - \underbrace{\alpha_L\big((1-\beta)(v_H - k) - \beta(v_L - k)\big)}_{\text{loss due to lower use level}} > 0 \\
\Longleftrightarrow\ & k > v_L - \frac{(\alpha_H - \alpha_L)(1-\beta)}{\alpha_L(1+\beta) - \alpha_H(1-\beta)}(v_H - v_L) \\
\Longleftrightarrow\ & k > v_L - \frac{(1-\alpha)(1-\beta)}{\alpha(1+\beta) - 1 + \beta}(v_H - v_L) \equiv \overline{k_s}.
\end{aligned}$$

(2b) $\mathbf{k} < \tilde{\mathbf{k}}$. In the present case, the firm does not appropriate all consumers' surplus when they encounter high-utility instances of need under *PPU*. Hence,

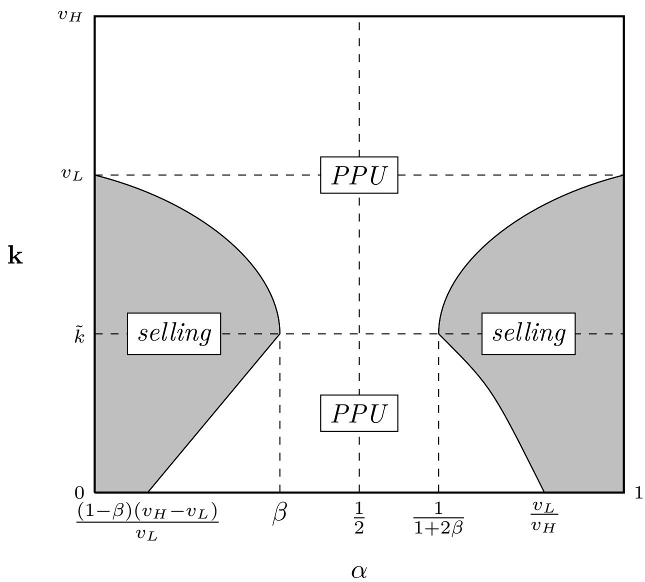


Figure 4.3.1.1. Optimal business model

the firm is better off under *PPU* if the gain from segmentation can offset the loss from the reduction of surplus appropriation when consumers of both types encounter high-utility instances of need; that is

$$\begin{aligned}
&\pi_f^l - \pi_p^b > 0 \\
\iff &(\alpha_H + \alpha_L)(v_L - k) - 2\alpha_L\big((1-\beta)(v_H - k) + \beta(v_L - k)\big) > 0 \\
\iff &\underbrace{(\alpha_H - \alpha_L)(v_L - k)}_{\text{gain from segmentation}} - \underbrace{2\alpha_L(1-\beta)(v_H - v_L)}_{\text{loss due to lower surplus appropriation}} > 0 \\
\iff &k < v_L - \frac{2\alpha_L(1-\beta)}{\alpha_H - \alpha_L}(v_H - v_L) \\
\iff &k < v_L - \frac{2\alpha(1-\beta)}{1-\alpha}(v_H - v_L) \equiv \underline{k_s}.
\end{aligned}$$

Corollary 5. *PPU is more likely to dominate selling if the marker is neither too homogeneous nor too heterogeneous and if the probability that consumers encounter high-utility instances of need is higher.*

As we can observe in Figure 4.3.1.1, $\overline{k_e}$ descreases in α, $\underline{k_e}$ increases in α, $\overline{k_s}$ increases in α, and $\underline{k_s}$ descreases in α. Thus, it is easier for *PPU* to be more profitable than *selling* if α is neither too high nor too low. Indeed, if the consumer base is highly homogeneous (α close to 1), the difference in surplus between the both types of consumers is insignificant. Hence, by selling to both types of consumers, the firms already appropriates all of low-usage consumers' surplus and most of high-usage consumers' surplus under *selling*. In contrast, if the consumer base is highly heterogeneous (α close to 1), the low-usage segment generates little value. Hence, the firm already captures most of the market's potential value by focusing on the high-usage segment under *selling*. In both cases, the additional profits brought about by the segmentation capacity are small and can be offset more easily by the loss due to the reduction in consumers' use level or the firm's surplus appropriation capacity.

From Figure 4.3.1.1, we can also observe that, for $k < v_L$, it is harder for *PPU* to be more profitable than *selling* if the two thresholds β and $\frac{1}{1+2\beta}$ are closer to each other. Since, the former increases and the latter decreases with β, the two threshold converge to each other when β increases. In other words, the higher the probability that a consumer derives a low utility level at the instances of need, the lower the chance for *PPU* to be more profitable than *selling*.

4.3.2 Aggregate use level

Having outlined the profitability of the transition from *selling* to *PPU*, I now compare the conditions under which *PPU* can generate a lower aggregate use level of the product. The result is formalized in Figure 4.3.2.1 and the following propositions.

Proposition 7. *(1) In case $\alpha < \frac{1}{2}$, PPU results in lower aggregate use levels if $k \in (\tilde{k}, v_L)$ and $\alpha < \beta$ and in higher aggregate use levels otherwise.*
(2) In case $\alpha > \frac{1}{2}$, PPU results in lower aggregate use levels if $k \in [\tilde{k}, v_L]$ and the same aggregate use levels as selling otherwise.

Similary to the analysis for probability, I establish the reasoning behind this result by checking the two cases: (1) when *PPU* leads to market expansion and (2) when *selling* already covers the market.

(1) When ***PPU*** leads to market expansion

$\mathbf{k} \in (\tilde{\mathbf{k}}, \mathbf{v_L}]$. Under *selling*, the firm only sells to high-usage consumers, who use the product at all instances of need after purchasing. Meanwhile, under

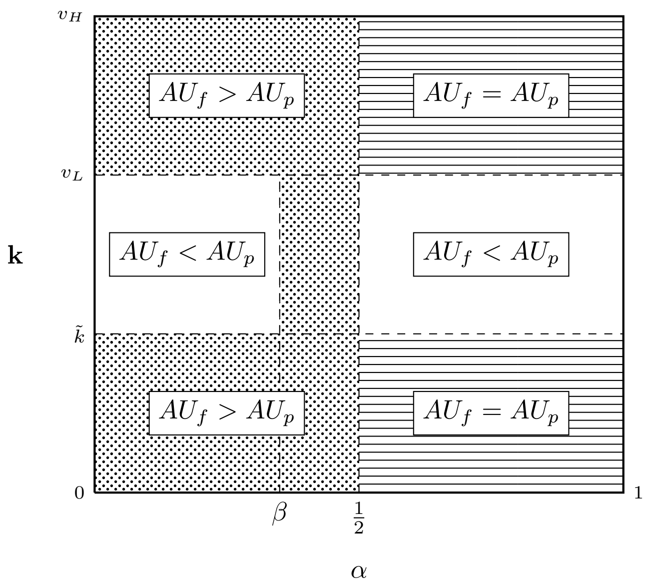


Figure 4.3.2.1. Aggregate use level of the product under the two business models

PPU, the firm serves both segments of consumers but only when they encounter high-utility instances of need. Thus, while *PPU* lowers the use level of high-usage consumers, it also generates more uses from low-usage consumers by allowing them to participate in the market. Therefore, *PPU* results in a lower aggregate use level if and only if the low-usage segment is not too large; that is, $\alpha < \beta$.

$\mathbf{k} > \mathbf{v_L}$ **or** $\mathbf{k} < \tilde{\mathbf{k}}$. In the present cases, actives consumers have the same use pattern under both business models: they use the product only at high-utility instances of need or at all instances of need, respectively. Since, *PPU* allows the firm to serve also low-usage consumers while *selling* does not, *PPU* necessarily results in a higher aggregate use level relative to *selling*.

(2) **When the market is already covered under *selling***

$\mathbf{k} \in (\tilde{\mathbf{k}}, \mathbf{v_L}]$. In the present case, the firm sells to both segments of consumers, who use the product at all instances of need after purchasing under *selling*. Meanwhile, under *PPU*, the firm serves both segments of consumers only at high-utility instances of need. Thus, *PPU* results in a lower aggregate use level.

$\mathbf{k > v_L}$ **or** $\mathbf{k < \tilde{k}}$. In the present case, since all consumers have the same use pattern and the firm covers the market under both business models, *PPU* results in the same aggregate use level as *selling*.

We observe that *PPU* is more likely to reduce the aggregate use level when it does not lead to market expansion. This is easily understandable: expanding the market brings about more active consumers, and hence, more use. Therefore, if leading to market expansion, *PPU* generates lower aggregate use levels if and only if the use volume added by low-usage consumers does not offset the reduction in high-usage consumers' use volume.

4.3.3 *PPU* as win-win business model

Combining the results from the propositions above, the conditions for *PPU* to be a win-win business model that can yield both higher profits for the firm and lower aggregate use levels of the products at the same time are presented in Figure 4.3.3.1.

We observe that the profitability of *PPU* is not aligned with its potential to be more environmentally friendly than *selling*. Indeed, when *PPU* is more profitable than *selling*, the necessary condition for *PPU* to reduce the aggregate use level is that $k \in (\tilde{k}, v_L)$. In this case, a consumer who buys the product under *selling* uses it at all instances of needs while the same consumer under *PPU* only uses the product at high-utility instances of need because the firm charge $f = v_H$. Even so, if *PPU* leads to market expansion, the additional uses incurred by low-usage consumers may offset the reduction of high-usage consumers' use volume. In this case, the sufficient condition for *PPU* to be a win-win business model requires that $\alpha < \beta$; that is, the use level of low-usage consumers is small enough so that the additional use volume is sufficiently small.

Corollary 6. *The probability that PPU is a win-win business model is decreasing in* β

Proof. The probability that *PPU* is a win-win business model is the total

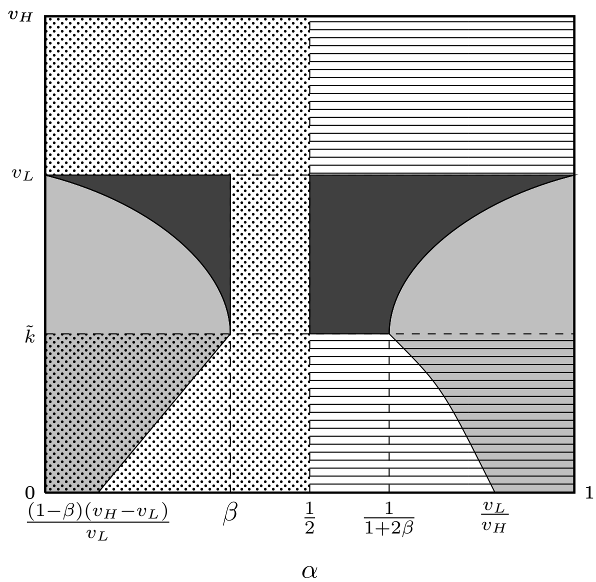


Figure 4.3.3.1. Profitability and aggregate use of the two business models, the win-win regions are colored in dark gray

surface of the purple zone in Figure 4.3.3.1 and is computed as follows:

$$Pr(w-w) = (v_L - \tilde{k})\Big(\beta - \int_0^\beta (\overline{k_e} - \tilde{k})d\alpha + \big(1 - \frac{1}{1+2\beta}\big) - \int_{\frac{1}{1+2\beta}}^1 (\overline{k_s} - \tilde{k})d\alpha\Big)$$

$$= \frac{\big(\beta^2 - \beta\log(\beta) - \beta\big)(v_H - v_L)}{1-\beta}$$

$$+ \frac{\left(4\beta^2\log(2\beta) - 4\beta^2\log\left(\frac{2\beta^2}{2\beta+1}\right) - 3\beta^2 - 2\beta + 1\right)(1-\beta)(v_H - v_L)}{2(1+\beta)^2\beta}.$$

We can prove that this probability decreases in β for all $v_H > v_L > 0$. □

Recall that β represents the probability of occurrence of low-utility instances of need, an increase in β affects negatively the probability of *PPU* to be a win-win business model via two effects. On the one hand, when β increases, $\tilde{k}$ increases; that is, the firm may find it optimal to serve all instances of need under *PPU* at higher operating cost. Hence, the probability that *PPU* reduce the aggregate use level decreases with β. On the other hand, if the firm still finds it more profitable to serve only the high-utility instance of need, an increase in β emphasizes the loss of *PPU* compared *selling* by increasing the profits that low-utility instances of need bring about under *selling*. Hence, the probability that *PPU* is more profitable than *selling* also decreases with β.

4.4 Related literature and contribution of this paper

This paper is closely related to the strand of literature on leasing durable goods. The profitability of *leasing* has been studied from different perspectives, such as the effect of product depreciation rate (Desai and Purohit, 1998), competition (Desai and Purohit, 1999), and the presence of a complementary product (Bhaskaran and Gilbert, 2015).[3] To tackle the sustainability of *leasing*, Agrawal, Ferguson, Toktay and Thomas (2012) compare this business model with *selling* and find that *leasing* can be environmentally worse than *selling* because the firm can remove the product from the market earlier to avoid cannibalization problems. However, as mentioned above, *leasing*, or subscription-based business models, does not tie consumers' payment with their usage. Consequently, this strand of literature typically assumes that the utility consumers obtain from using the product is constant over time. By relaxing this assumption, I show that the randomness of the utility obtained by using the product plays an essential role in studying business models such as *PPU*.

Also related to the per-use payment is the strand of literature on the pricing decision of digital-good providers. Jiang, Chen and Mukhopadhyay (2008), for instance, study the profitability of adopting per-use pricing for a digital good relative to a one-time purchase pricing. The authors show that the possibility of piracy favors per-use over the one-time price structure even when pay-per-use incurs an inconvenience cost over the consumer. Using the same framework, Gurnani and Karlapalem (2001) and Gilbert, Randhawa and Sun (2014) both conclude that a hybrid business model, namely adding per-use pricing to the one-time pricing business model, is more profitable than adopting each single pricing structure. In a more recent paper, Balasubramanian, Bhattacharya and Viswanathan (2015) compare per-use vs. one-time pricing when usage on a per-use pricing basis invokes a psychological cost to consumers, showing

[3] see Waldman (2003) for a comprehensive literature review covering various topics related to durable goods

that per-use pricing is more profitable if the psychological cost is low enough. These studies, however, rely on the assumption that consumers' use level and marginal utility from usage are uniformly distributed. As I will show in this paper, this is a strong assumption since the profitability of per-use pricing is highly sensitive to the distribution of these two variables. Furthermore, with the focus on digital products, this strand of literature does not tackle either the environmental impacts of different pricing structures or the operating cost of products, which play an important role in studying business models for physical products.

This paper contributes to the surprisingly few analytical studies on *PPU* business models.[4] In existing papers, the key properties of *PPU* are the potential to serve more customers with fewer products (Agrawal and Bellos, 2017), the advantage of the firm in operating the product at a lower cost than consumers (Örsdemir, Deshpande and Parlaktürk, 2019) and the logistic costs to divide the product into small portions to rent to consumers (Ladas, Kavadias and Loch, 2020). All three studies find ambiguous impacts of *PPU* on the firm's profitability, depending on the advantage in distributing and operating the product granted by the new business model.

In line with this paper, Agrawal and Bellos (2017) and Örsdemir et al. (2019) also investigate the environmental benefit of *PPU*. They identify that the business' environment impacts depend on the firm's pooling capacity and operating efficiency under *PPU*, making a win-win situation for both the firm and the environment not always feasible. Nevertheless, as I will argue in this paper, their specific setting on the demand side imposes that *PPU* and *selling* yield the same profits if the firm does not have any advantages in producing and operating the product under *PPU*. While their setting is helpful to look at the impact of *PPU* on the production side, it is reasonable to expect that *PPU* affects the firm's demand as well. Hence, this paper aims to contribute to the discussion by focusing only on how the different pricing structures (one-time purchase price vs. per-use fee) affect consumers' demand and the firm's operating profits without any distortions on the production side.

The abovementioned papers also rely on the assumption of a psychological cost associated with consumers' behavior under *PPU*. Yet it is unclear whether consumers incur higher psychological under *PPU* than under *selling*. Renting a car, for instance, reduces the time to find a parking slot and the efforts to

[4]Most of this strand of literature is conceptual and case studies conducted by researchers in management science. See Tukker (2015) for a review of these studies.

maintain the car and insurance coverage. Hence, it may result in a higher level of convenience than buying a car. This assumption is even stronger for business customers. For firms, the products at stake might be used as intermediate inputs to produce other final goods or services. Consequently, the utility (or productivity) of that unit of output should remain unchanged across the two business models. Furthermore, in B2B context, direct users of the product are employees of the firms. They do not feel the per-use fee as much as individual consumers in the context of carsharing, where the "taximeter effect" is detected (Lambrecht and Skiera, 2006). Not surprisingly, the empirical studies on this topic have yielded mixed results. While some (Kridel, Lehman and Weisman, 1993; Miravete, 2003; Dowling, Manchanda and Spann, 2018) observe a "pay-per-use bias", others (Kridel et al., 1993; DellaVigna and Malmendier, 2006; Lambrecht and Skiera, 2006; Krämer and Wiewiorra, 2012) observe a "flat-rate bias." For this reason, I assume that the utility level that the consumer obtains are identical under the two business models to provide a benchmark case for the comparison. The introduction of asymmetric utility will only make the result biased in the expected direction: higher utility level (psychological benefits) makes *PPU* more profitable and vice versa.

In brief, this paper contributes to the literature with a focus on the demand side to complement the supply-side focus of Agrawal and Bellos (2017) and Örsdemir et al. (2019), aiming to elaborate the fundamental mechanisms for *PPU* to be more profitable than *selling*, keeping all costs constant across the two business models. To do so, I propose a framework in which a monopoly faces two segments of consumers with high and low usage rates, respectively. For each instance that a consumer needs to use the product, she derives a random utility level that is either high or low. This utility is revealed only at each instance of need and independent of the firm's business model. Every time the product is used, it incurs an operating cost. This cost is paid by the consumer under *selling* and by the firm under *PPU*. To focus on the impacts of changes on the demand side, I also assume that operating cost is identical under both business models.

Using this specific setting, this paper also complements to the existing literature by relaxing the assumptions on a specific form of the demand function in other papers. In Agrawal and Bellos (2015) and Örsdemir et al. (2019), the concavity of utility function imposes that, without other distortions in the operating and production costs, *PPU* and *selling* yield the same profitability. In their setting, *PPU* always leads to a market expansion thank to the absence of the purchase cost. However, the consumer with the highest valuation for the product pays the same price under both business models while all other consumers pay less under *PPU* than under *selling*. With this restriction, the loss due to the lower use level of all consumers offsets perfectly the gain from market expansion (except the one with the highest valuation for the product). Due to this mechanism, Örsdemir et al. (2019) conclude that the advantage in operating the product (so that the operating cost is lower) is necessary for *PPU* to the more profitable. For the same reason, Agrawal and Bellos (2015) focus on the pooling capacity of the product as a driver for the profitability of *PPU*. In both cases, *PPU* is more profitable for lowering the cost of operating/producing the product rather than increasing revenue.

The setting used in Balasubramanian et al. (2015) and Postmus, Wijngaard and Wortmann (2009) can be considered special cases of this paper. In their settings, since the utility derived from the instances of need is constant, consumers maintain the same use level under both *selling* and *PPU*. Here, the loss due to lower use levels or lower surplus appropriation does not exist. Consequently, *PPU* is always more profitable than *selling* in their setting.

4.5 Discussion and concluding remarks

This paper contributes to the discussion on the profitability and environmental benefits of *PPU* relative to *selling* by focusing on the changes on the demand side following the transition of the firm from *selling* to *PPU*. For this purpose, I propose a simple model in which the firm faces two consumer segments identified by their usage rate. Assuming that using the product delivers utility stochastically such that consumers do not know in advance, under *selling*, consumers decide whether to purchase the product based on the expected utility they obtain in the future. Meanwhile, under *PPU*, they can learn about the utility delivered before deciding whether to rent the product for each specific instance of need. Also, each time the product is used, it incurs an operating cost. This operating cost is paid by consumers under *selling* and by the firm under *PPU*.

The analysis shows that, even without any advantage from the production side, such as the pooling capacity or the firm's advantages when operating the product, the firm can still benefit from *PPU* with a capacity to segment its customers without the need to observe their type. However, *PPU* does not necessarily generate higher profits for the firm. Due to the pricing structure, *PPU* may lead to either a reduction in consumers' use level or in the firm's appropriation of consumers' surplus when they encounter high-utility instances of need. Therefore, *PPU* only generates higher profits for the firm if the gain from the segmentation capacity can offset the loss from the lower use level and surplus appropriation. Notably, it is harder for *PPU* to be more profitable when the firm's consumer base is too heterogeneous or too homogeneous. In either case, the gain from segmentation is limited and has little chance to offset the loss caused by the lower aggregate use level.

The model also sheds light on changes in the product's aggregate use levels as a proxy for the environmental impacts of the firm's business. *PPU* is arguably more friendly to the environment for its capacity to reduce consumer's usage of the product. However, since *PPU* allows more people to access the product, it may increase the aggregate use level. Furthermore, a reduction in use level might lead to a smaller profit for the firm and hence, reduce the firm's motivation to adopt *PPU*. Therefore, *PPU* can only be a win-win business model if it results in a lower aggregate use level, but the firm's loss due to this reduction does not offset its gain from segmentation.

It is vital to highlight one limit of this paper. Due to the assumption of stochastic demand, the model is simplified significantly for the sake of tractability. When assuming other distributions for the two variables at stake, the setting loses its tractability, cannot be solved or is unclear to shed light on the primary mechanism behind the results. Thus, the robustness check for this model is left for further research.

Another research direction worth exploiting is the competition between firms adopting new and old business models. All the existing studies have focused on a monopoly's choice between *selling* and *PPU*. However, it is also important to shed light on the competition mechanism between firms with different business models. Whether the two business models can co-exist in the industry or disruption is unavoidable is, without doubt, a critical matter to firms' managers in many industries nowadays.

5

General conclusion

In this thesis, I study three business models for the circular economy, focusing on the interaction between the new business models, the incumbents, and consumers in the market by using the Industrial Organization toolbox. More specifically, Chapter 1 studies the interaction between a manufacturer of a product and a platform that organizes the peer-to-peer sharing of that product. The chapter emphasizes that improving the sharing market by reducing the underlying costs does not necessarily lead to a sustainable improvement for both the environment and consumers due to the manufacturer's reaction. Chapter 2 then exploits the classical two-period Cournot competition model to prove that improving the recycling process does not necessarily reduce the primary production quantity. This is also due to the manufacturer's reaction to control the input stream for the recycling sector. Finally, Chapter 3 proposes a simple stylized model in which one firm faces stochastic demand from consumers to demonstrate that *pay-per-use* is not necessarily superior to *selling* concerning both the firm's profitability and environmental benefits, depending on the product's nature and the characteristics of the customer base.

In a broader sense, the thesis contributes to the discussion on the circular economy by stressing two essential messages: *systems thinking* and *flexible policy*. As for systems thinking, this thesis provides proofs to highlight that the ability to understand how the parts of a system interact to produce the behavior of the whole is critical when investigating the potential of the circular economy. Chapter 1, for instance, shows that, while a cost reduction on the P2P market should mean to benefit the platform and consumers participating in the sharing market, different reactions of the manufacturer when confronting different types of cost reduction results in different outcomes. Indeed, a cost reduction that is proportional to consumers' preferences for private ownership triggers reactions from the manufacturer to mitigate the platform's advantage: by selling more products, the manufacturer lowers the owners' preference for ownership and reduces the benefits that the cost reduction brings to the platform. In contrast, a cost reduction that is constant across suppliers does not trigger the same reaction from the manufacturer; since the benefits brought about by the cost reduction is independent of the owners' characteristics, the manufacturer cannot mitigate the platform's advantage in the same way. As a result, while all cost reductions improve the platform's position in the competition with the manufacturer, it is the manufacturer's reaction that decides whether the peer-to-peer market is larger or smaller following the change. Chapter 2, in its turn, shows that the impact of improving the recycling process does not depend on the recyclers but the cost/benefit balance of the other agent in the market - the manufacturer. Indeed, even though improving the collection rate always favors the recyclers' scales when they enter the market, it is the manufacturer's decision prior to the recyclers' entry that decides the global impact on the system, and thus, the optimal collection rate for recycling.

As of flexible policy, the thesis stresses that the new business models are not necessarily better than *selling* and that there is no one-size-fits-all policy to correct the new business models' failures to deliver the desired outcomes. Chapter 1 proves that, in the context of the peer-to-peer renting business model, not all cost reductions can sustainably improve the economy. Thus, policymakers have to pay attention and make the policy flexible enough to target the correct cost reduction. Chapter 2, in its turn, suggests that the optimal policy for the environment depends on the market structure (the number of manufacturers and recyclers in the market). The analysis also reminds us that governments need to consider the conflict of interest between the environment and different economic agents when deciding their policies. Finally, Chapter 3 shows that the benefit of *pay-per-use* depends on the product's nature and the characteristics of the consumer base: each type of product in each different market results in a different comparison between *pay-per-use* and the legacy *selling* business models. Together, the three chapters underline that the authorities' policies must be flexible enough to consider different factors in specific contexts to target the correct sustainable improvement.

To conclude, the thesis shows that creating new business models that are good on their own is not sufficient to improve the sustainability of the economy. These business models also need to fit in and sustainably improve the current market via their interaction with other parts of the system. In this sense, the studies on the topic should exploit more and enlarge the concept of “coopetition” between firms (Brandenburger and Nalebuff, 1996); that is, new entries with creative business models should also look for the sustainable value they create *together* with the incumbents beyond the competition they impose on the latter. Particularly, since the circular economy focuses on establishing the links between different agents to close the loop of and add values to the material flows, the coopetition viewpoint can open valuable perspectives for the discussion on the topic and help advance more disruptive approaches, practices, as well as government’s policies to improve the circularity of the economy.

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