Hamed Vafa Arani

Creating Shared Value

An Operations and Supply Chain Management Perspective

Creating Shared Value: An operations and supply chain management perspective

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Het creëren van gemeenschappelijke waarde: een operationeel en supply chain perspectief

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Rotterdam, 2023

Contents

1 Introduction

The conventional approach to value creation for businesses is to maximize short-term profits. However, there is now ample evidence that such an approach leads to a range of environmental (such as pollution and emissions), social (such as unequal resource and wealth distribution), and even economic (such as resource scarcity and depletion) issues. We refer to all such problems as social problems, as they negatively affect social welfare.

Corporate Social Responsibility (CSR) has become a common term used to describe a company's efforts to mitigate social problems (Holme & Watts, 1999). Companies that adopt CSR usually believe there is a trade-off between economic efficiency and social progress, and hence try to tackle social problems sometimes at the expense of their business (Porter & Kramer, 2011). CSR policies are often accounted for separately from profit maximization. Profit-maximizing companies often view CSR activities as expenses, rather than a separate objective. This approach certainly does not lead to permanent improvement in addressing social issues by such companies, i.e., this does not lead to improvement in sustainability of businesses.

In order to effectively address social problems, social responsibility must be integrated with profit maximization. To this end, Porter & Kramer (2011) introduced *creating shared value* (CSV) as an integrated approach to resolving social issues. They define CSV as "policies and operating practices that enhance the competitiveness of a company while simultaneously advancing the economic and social conditions in the communities in which it operates". In this definition, both social and environmental issues are framed as social conditions. The essence of CSV is to identify and expand the connection between societal and economic progress.

For example, in the context of waste management in the smartphone industry, a company that adopts a remanufacturing approach can both benefit from the economic returns of selling remanufactured products, and simultaneously reduce e-waste while increasing access to mobile communication for lower-income individuals. Porter & Kramer (2011) provide numerous other examples of issues that CSV can improve, including environmental impact, supplier access and viability, employee skills, employee safety, employee health, water use, and energy use.

The notion of CSV is closely related to the concept of *sustainability*, which is formally defined as "the process of change, in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations" (Keeble, 1988). Like sustainability, CSV also emphasizes the environmental and social aspects of business development. However, CSV emphasizes that profitability is a prerequisite for socially responsible or sustainable business development.

The concept of CSV is also utilized in the design of the United Nations Sustainable Development Goals (SDGs), which are a collection of 17 interrelated global goals that aim to create a sustainable and just future for all by 2030. The SDGs address a wide range of crucial issues, such as poverty and hunger eradication, promoting health and well-being, providing equal access to quality education and gender equality, building sustainable infrastructure and communities, and combating climate change and its impacts (United Nations, 2015). The SDGs prioritize both social progress and economic prosperity, emphasizing the need to protect peace, justice, and the planet for future generations.

Various stakeholders in society are also advocating for CSV to be at the core of strategic planning for businesses and governments. Some shareholders of businesses, who are directly impacted by their performance, also recognize the importance of CSV and acknowledge that social and environmental issues must be addressed for economic prosperity. This is evident in the increasing trend towards Environmental, Social, and Governance (ESG) investing (see e.g., Gelfand, 2022). Additionally, end consumers of products and services are increasingly demanding more sustainable options, as evidenced by consumer trends (Accenture, 2019). Governments, as policymakers, are also emphasizing the importance of CSV through regulations and public incentives for consumers and businesses. Governments have a responsibility to address social and environmental issues and adhere to international agreements such as the Paris Agreement, European Union regulations (e.g., Walls, 2006), and UN SDGs, as previously discussed. It is therefore logical for both the corporate sector and governments to prioritize CSV as the foundation of their business practices and policy-making. The purpose of this thesis is, therefore, to investigate how businesses and governments can leverage CSV to address social and environmental issues, and how this approach differs from the traditional focus on sustainability or pure profit maximization. By exploring the potential benefits of CSV, we aim to identify opportunities for businesses and governments to create shared value and promote sustainable development.

In this thesis, we define a sustainable business environment as one that pursues the goals of maximizing economic benefits (profit), protecting the planet by reducing environmental impacts (planet), and ensuring social welfare (people). Among all business practices, operations and supply chain management contributes substantially to businesses' environmental and social impact (Bové & Swartz, 2016). We thus focus mainly on the operations and supply chain management practices that can enable businesses to create shared value. We specifically study two topics: 1) servicizing business models, 2) drug shortages. The first primarily focuses on the environmental impact of businesses by adopting a business model, called servicizing, which facilitates circularity in the supply chain of businesses. The second focuses more on addressing a social issue by studying drug availability for the patients.

Both studies address the challenges that arise when prioritizing either profit, or social and environmental issues and explore how these challenges can be resolved. The first study aims to reduce emissions by designing business models that align with both profit and sustainability goals. More specifically, the first topic involves designing business offerings that satisfy the objectives of both planet and people while maximizing profits. The second study addresses the issue of drug shortages, a significant societal concern, by modifying public policies that balance the financial interests of businesses with the social need for affordable and available drugs. Despite differences in stakeholders involved, both topics ultimately focus on designing incentives that promote sustainable operations management. The following sections discuss how these two studies contribute to the creation of shared value through the design and modification of incentives.

1.1 Environment: Servicizing

The concept of a *circular economy* has been introduced by The Ellen MacArthur Foundation (EMF)[1]. EMF defines circular economy as a transformation of the current linear *take-make-dispose* industrial model into a circular one which regenerates and restores materials, products, and other resources (e.g., energy) by circulating them in a system (EMF, 2018e). EMF's mission is mainly motivating leading companies and businesses to adopt the circular economy approach to create shared value. To show the economic potential of circular economy, it is estimated that, in European Union alone, the investment level in circular economy initiatives will total to €320 billion until 2025, which are mainly in food, mobility, and built environment (EMF, 2018a).

EMF mentions three building blocks of a circular economy (EMF, 2018b): reverse flow, circular design, and circular business model. *Reverse flow* refers to creation of an industrial system to facilitate reuse, repair, remanufacturing, refurbishing, and recycling (Figure 1.1). This building block is closely related to the literature on closed-loop supply chains (Guide Jr & Van Wassenhove, 2009; Tang & Zhou, 2012; Govindan et al., 2015). EMF argues that products should be designed in such a way that they are durable, repairable, and recyclable (Agrawal et al., 2016).

A circular business model ensures that products and materials are efficiently and effectively acquired, recovered, and brought to the market. Service integration is one way of moving towards such circular business models. These business models are known as *servicizing* (or servitization). In a servicizing business model, a service provider (SP) sells a specific functionality served by a product, not merely the product itself. Such business models are

[1] See www.ellenmacarthurfoundation.org/about

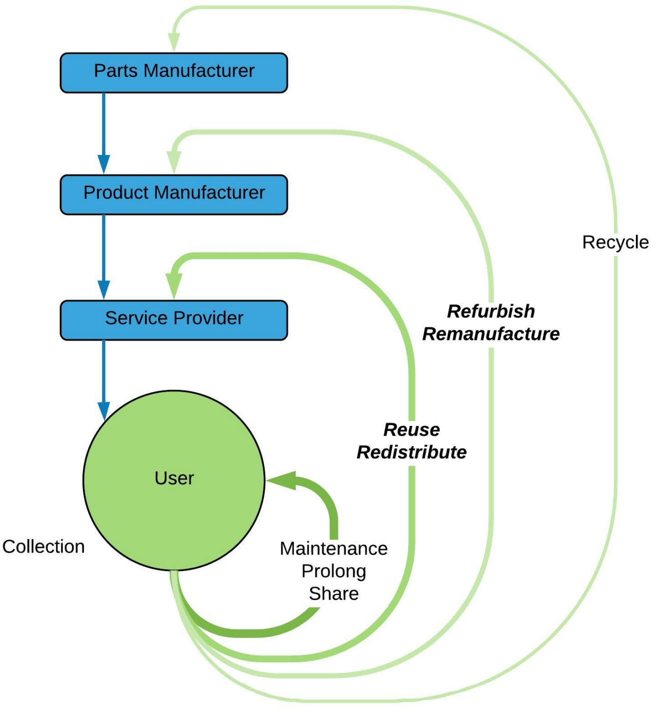


Figure 1.1: Circular Economy System Diagram

in general called product-service systems (PSS) since they integrate a service element to the product (Tukker, 2004). There are several examples of companies which already transited to a servicizing business model. Bundles is a Dutch company which has servicized washing machines. In their business model, customers purchase the service of washing instead of the washing machine. Their model reduces the production of new washing machines and also facilitates the collection of end-of-use machines (Agrawal et al., 2018). See EMF (2018c) for more details and other case studies and examples of innovative business models that facilitate the movement towards a more circular economy.

The increasing popularity of PSS is partly the result of advances in technology, e.g., Internet of Things applications, for measuring actual usage. A second driver is that PSS have significant potential environmental benefits (Tukker, 2004). First, they can reduce usage (Vafa Arani et al., 2023), which decreases the environmental impact in the usage phase. Second, PSS allow the SP to take the product back after use and remanufacture or recycle it. This reduces material use and the environmental impact in the disposal phase (Fu et al., 2022). Third, PSS incentivize SPs to design or choose durable products when they are responsible for maintenance. This can reduce the use of material. EMF estimates an annual material cost saving of up to €630 billion in Europe alone (Schulze, 2016).

Servicizing, thus, has potential to reduce the environmental impact of companies. Chapter 2 and Chapter 3 focus on creating shared value by prioritizing economic viability of such business models, but also reducing the environmental impact as much as possible, and if possible improving consumer welfare. In the next section, we provide research opportunities in servicizing and more specifically the research questions on which this thesis focuses on.

1.1.1 Research Focus: Servicizing

In spite of the potential environmental benefits, and the acknowledged economic advantages, which are witnessed by some companies, the transition to a circular business model is still not a widespread practice. This indicates that there are tactical and operational issues yet to be resolved (Agrawal et al., 2018). As a result, exploring research avenues in this area can pave the way to shift from linear to more circular business models. In this context, we focus on two specific sub-problems related to optimal design of servicizing business models.

Chapter 2 focuses on the choice of a pricing policy in servicizing business models. In the servicizing business model, product ownership remains with the SP while it guarantees a certain level of performance for a specified contract period. The SP incurs all investment and operating costs during the product lifecycle while should to be effectively priced-in for the overall service, not just the product. This pricing will influence consumer usage, which has implications for both SP costs and revenues.

Companies with a servicizing business model offer various price plans, usually either a pay-per-use or a pay-per-period scheme. In pay-per-use, also known as a two-part tariff, the SP charges a flat fee per period and a usage rate for each use of a product. One example is Bundles that provides home appliances such as washing machines as a service. Customers pay a monthly flat fee plus a fee per washing cycle (Bundles, 2020). Many other companies offer pay-per-use, such as Xerox's pay per page printed (Xerox, 2020) or Mobike's "pay as you go" service (Mobike, 2020). Pay-per-period, or subscription, schemes charge a flat fee regardless of usage. Swapfiets offers customers two types of bikes through a pay-per-month option (Reid, 2020). Other examples include Ahrend for office furniture (Ahrend, 2020), Gerrard Street for headphones (EMF, 2018d), and Philips' "light as a servic" (Phillips, 2020).

These two pricing models impact customer usage behavior. By setting an appropriate pay-per-use price, the SP can influence usage behavior and thus control operational costs. Still, customer use must be measured and controlled, and this incurs further SP costs in usage measurement and administration. On the sales side, price-per-use may discourage customer engagement, thus reducing revenue as customers perceive a loss in utility each time they pay after use. This perceived loss in utility is known in consumer behavior studies as the *ticking meter effect* (Sundararajan, 2004; Cachon & Feldman, 2011). In the pay-per-period scheme, however, payment is delinked from usage. This implies that the SP has limited influence on usage through the pricing mechanism. Here, pay-per-period usage may prove more intense, dissipating the SP's profit with rising operational costs. Yet, the pay-per-period scheme may still enjoy a cost efficiency advantage for SPs uncluttered by usage measuring devices and administration. Also, customers avoid any negative ticking meter effect since paying in advance decouples the payment from usage (Lambrecht & Skiera, 2006). Thus, in Chapter 2, we compare these two pricing schemes in terms of profitability, environmental impacts, and consumer welfare to find the best possible option. A pricing policy that maximizes the SP's profit and at the same time reduces the environmental impact and improves the consumer welfare is a unique opportunity to create shared value.

Chapter 3 goes beyond pricing schemes, and looks into further design elements of PSS, like minimum contract duration (MCD) on top of the price. Despite the popularity of PSS, many businesses have little experience and evidence on which they can base these choices (Vezzoli et al., 2015; Agrawal & Bellos, 2016). Many have a limited understanding of how the attributes of PSS affect consumer choices. Furthermore, it is unclear whether and how these PSS attributes affect the perception of product-related characteristics such as energy efficiency, selling price, and quality (Kreye & van Donk, 2021). For example, given that many PSS take responsibility for product maintenance, the utility customers derive from such a product's quality may differ from when they purchase the product. This lack of understanding could lead to businesses launching PSS that are weakly aligned with consumer preferences. Consumers may easily switch to convenient and easily accessible purchasing options. Therefore, businesses must understand which attributes strongly impact consumer choices, how changing the level of such attributes affects these choices, and how consumer characteristics drive those choices. This understanding helps businesses tailor their PSS to a market or focus on specific market segments.

This study contributes to creating shared value by assisting firms interested in adopting PSS in achieving economic viability in sustainable business models, resulting in potential reduced environmental impact as an inherent feature of such models.

1.2 Society: Drug Shortages

Drug shortages are a growing problem in many countries worldwide, including the US and European Union. In the US, drug shortages are considered a national security issue and a persistent problem (FDA, 2019; Acosta et al., 2019), while the European Commission sees it as a major issue for patient care (EC, 2021). The consequences of drug shortages are serious and can lead to increased mortality rates (Vail et al., 2017; Yurukoglu et al., 2017), medication errors (Fox & Tyler, 2003), and less effective treatment. Over half of US hospitals have reported using alternative or delayed care due to drug shortages, and almost 40% have had to reschedule or cancel procedures (Phuong et al., 2019). The economic impact of drug shortages is also significant, with pharmacies and wholesalers having to source from expensive small-scale local producers (EAHP, 2019) or provide more costly alternatives (Caulder et al., 2015). Moreover, handling shortages places a considerable burden on pharmacies, with Dutch pharmacies estimated to spend 17.5 person-hours per week and costing between €45 and €105 million per year to manage shortages (Ministerie van VWS, 2019a).

The causes of drug shortages can be categorized into two groups: manufacturing/ supply causes and economic causes (Economist, 2017). The former include quality issues (which can lead to recalls), disrupted supply of active pharmaceutical ingredients (APIs), disrupted transportation, or poor inventory management. Economic causes encompass regulations, policies, and practices making markets less attractive and/or affecting incentives to invest in supply resilience (Economist, 2017; Kanavos et al., 2009). The most heavily debated economic cause is the use of *tendering*. Tendering is a formal procedure to procure goods, work, or services – drugs in our case – using competitive bidding for a particular contract (Dranitsaris et al., 2017). In Europe, tenders are commonly used to procure drugs, with hospital pharmacies procuring 80-100% of drugs through tenders in almost all EU member states. Several countries, including Germany, Belgium, the Netherlands, Spain, Slovakia, and Denmark, use tendering to procure drugs for outpatient care (Medicines for Europe, 2022; Gawronski et al., 2022). Tenders can consider various criteria for awarding to authorized suppliers, and tendering can lead to multiple winners. Price is often the only factor, and winner-takes-all tenders dominate (EC, 2021).

Drug shortages in general are a side-effect of efforts to improve affordability by decreasing business profits. This is where we need to bring the CSV idea to the table. We argue that there is a need to create shared value by redesigning the tendering system in such a way that shortages are reduced, potentially at the expense of affordability – i.e., by enhancing business profits.

1.2.1 Research Focus: Drug shortages

Given the extent of the drug shortages problem, and also the severe social and economic consequences, we need to first identify the causes of drug shortages and then find ways to modify policies to ensure both profit and people objectives are satisfied. Currently, only few studies identify causes of drug shortages. Here we focus on tendering as a potential cause of drug shortages and the mechanisms involved.

Chapter 4 focuses on investigating the impact of tendering on market-wide drug shortages. Although tendering can lead to significant price reductions and improve affordability, it has been criticized for causing drug shortages through four mechanisms (Biedermann, 2022;

de Vries et al., 2021). First, it can *put suppliers' margins under pressure*, which can result in a decrease in inventories, offshore production, and reduced slack production capacity, leading to an increased risk of shortages (Besancon & Chaar, 2013; Jagtenberg et al., 2021). Low margins can cause suppliers to prioritize other countries over the tendering country during shortages (KNMP, 2020; VIG, 2023). Second, the uncertainty created by price-based, winner-takes-all tendering can *prompt suppliers to exit the market* (EC, 2021), resulting in fewer suppliers who can quickly fill shortages caused by other suppliers (Pauwels et al., 2014). Third, tendering *can lead to more concentrated markets*, with one or a few suppliers serving most patients. This leaves few suppliers with enough capacity to fill the shortages caused by a major supplier (EC, 2021). Last, it *induces switches in suppliers*, which can lead to additional risk of shortages. The former supplier might ramp down the supply chain too quickly, while the new supplier can face difficulties ramping up (Kanavos et al., 2009; EFPIA, 2022; Biedermann, 2022; Jagtenberg et al., 2021).

Despite these plausible mechanisms, no strong empirical evidence exists that tendering increases shortages (see Section 4.2). In fact, many doubt whether this effect exists or is substantial for several reasons. First, winning a tender leads to a relatively stable and predictable demand during the contract period, offering the tender winner the financial security needed to justify investments in production capacity and inventory (EC, 2021). Second, the prospect of serving a major share of the market also attracts *new suppliers*, often those who participate in tenders across multiple countries (Bruijnooge, 2021; Hordijk, 2019). They thereby expand the set of alternative suppliers available to jump in when a disruption occurs. Third, in markets that have become more concentrated (due to tendering), suppliers are believed to feel a stronger sense of responsibility to prevent shortages (See Francas et al., 2023). Last, many suppliers have a diverse portfolio of drugs, allowing them to hedge against uncertainty induced by tendering. This may limit the effect of tendering on market exit decisions (Bruijnooge, 2021).

The *net impact* of tendering on drug shortages is, hence, unknown and needs concrete evidence. Therefore, in Chapter 4, we zoom in on the impact of tendering on drug shortages and mechanisms that can influence this relationship.

1.3 Contribution and Thesis Outline

Chapter 2: How to Charge in Servicizing: Per Period or Per Use? [2]

In this chapter, we explore the choice of a pricing policy in servicizing business models. This includes the structure of the pricing schemes and the price itself. More specifically, we answer the following research question:

[2] Vafa Arani, H., Pourakbar, M., van der Laan, E., & de Koster, R. (2023). How to charge in servicizing: Per period or per use?. *European Journal of Operational Research*, 304(3), 981-996.

- Which pricing policy is superior in terms of profitability, environmental impact, and consumer welfare?

To answer this question, we model the problem as a dynamic game of incomplete information between the SP, offering a single product either through a pay-per-use or pay-per-period scheme, and the consumers, where consumers are divided to two segments of high- and low usage-valuation. Then, we also extend the model where the SP offers a line of products including one green and one regular product.

The model recommends pay-per-use as the best pricing policy when the operational cost is high for a single product. When high usage-valuation customers are the majority, the SP should exclude low usage-valuation customers by offering a pricing policy that appeals only to high usage-valuation customers. A hybrid policy can be optimal only when the operational costs are low enough and the high usage-valuation customers form a moderate fraction of the market. When offering a product line with regular and green options, the general findings hold while offering a regular product to both segments through a pay-per-period scheme is no longer optimal.

Pay-per-use is generally better for the environment than pay-per-period. In the single-product case, the best policy is to offer a pay-per-use scheme and exclude the low usage-valuation segment. However, when offering a product line with regular and green options, the results depend on environmental impact factors in different phases of the product life-cycle. If the usage phase impact is high, pay-per-use policies are superior. A menu of pay-per-period schemes can minimize environmental impact only when the use-phase impact is extremely low. Different pricing policies have varying effects on consumer welfare, but this only applies in the case of a single product. If two products are offered, consumer welfare stays constant across policies. For a single product, offering a pay-per-period policy to both segments maximizes consumer welfare. However, this doesn't align with minimizing environmental impact, which is only achieved by offering pay-per-use to high usage-valuation customers. Therefore, there are no win-win-win strategies.

Chapter 3: Design of a Servicizing Business Model [3]

There are few studies that explore how consumers make choices between PSS and traditional purchasing options. Companies that recognize the potential of PSS for creating shared value require robust insights to make well-informed decisions. Our study aims to bridge this gap by addressing the following research questions:

- How do PSS' attributes affect consumer choices?
- How do consumers' characteristics affect their choices?
- How should businesses set up PSS to maximize their market share?

[3] Vafa Arani, H., De Vries, H., & de Koster, R. (2023). Design of a Servicizing Business Model. *Second round of review in International Journal of Operations and production Management*

To answer our research questions, we conduct a choice experiment for washing machines among 298 Dutch adults. We specifically use a choice-based conjoint analysis (CBCA) to calculate the relative importance of the payment scheme (purchase, pay-per-use, and pay-per-period), price (low, medium, and high), MCD (one year, three, and five years), and energy efficiency (labels A and C). We use the Hierarchical Bayes (HB) method to analyze the data. Our follow-up survey measures participants' characteristics. These characteristics include the ticking meter effect, psychological ownership, and greenness. We also conduct a cluster analysis in which we find four segments with homogeneous choices in the market. The implications of our main findings are illustrated through simulation analysis. We specifically use the results of the conjoint choice experiment to predict consumers' choices and use these to simulate the impact of attribute-level choices on a company's market share.

Our results show that the payment scheme is the most important factor determining consumer preferences (32.2%), followed by price (22.9%), MCD (22.8%), and energy efficiency (22%). Our study also provides insight into the mechanisms that drive consumer decision-making, specifically in the choice of payment schemes. The ticking-meter effect, for instance, strongly affects the importance of price for consumers. We also find that consumers' psychological ownership greatly influences their preference for energy efficiency, while their greenness does not have a significant impact. Finally, our cluster analysis can assist service providers in understanding market segments and attribute preferences based on existing clusters.

Chapter 4: The Bitter Pill: The Impact of Tendering on Nationwide Drug Shortages [4]

Practitioners and academic literature suggest that tendering induces mechanisms that can both *trigger* shortages and *reduce* them. Scientific literature quantifying the *net impact* of tendering on shortages is lacking. Therefore, this study examines the following empirical research question:

- What is the impact of tendering on drug shortages?

We answer our research question using a panel data staggered difference-in-difference (DiD) framework, a state-of-the-art method in policy evaluation (Roth et al., 2023). This setup enables us to compare drugs affected by initiating a tendered contract (treatment group) to unaffected drugs (control group). Our data enables us to study shortages on the prescription cluster level – a cluster of identical articles except for the pack size and/or the supplier or manufacturer. It also allows for a holistic analysis of the impact of tendering – how it affects the capability of *the entire market* to ensure the availability of articles in a given prescription cluster. Our analyses cover both short-term and long-term impacts. Since it is key for policymakers to understand *under what conditions* tendering enhances shortages,

[4] Vafa Arani, H., De Vries, H., & Gutt, D. (2023). The Bitter Pill: The Impact of Tendering on Nationwide Drug Shortages. *Second round of review in Journal of Operations Management*

we also investigate three potential *moderators*: 1) the number of alternative suppliers in the prescription cluster, 2) the magnitude of change in the tendered market share, and 3) the market concentration within the prescription cluster.

We find tendering decreases prices and makes the market more concentrated. Also, there is a strong relationship between tendering and the market share in shortage. Shortages increase right after an insurance company initiates a tendered contract and peak three months after the tender to an 8.1 percentage point increase relative to one month before the initiation. This supports the hypothesized mechanism that supplier switches cause shortages. We observe the same results if we only consider extreme shortages, e.g., cases when more than 80% of the market for a given prescription cluster is affected by shortages. We also show that the impact of tendering sustains. Over a 48-month period, the market share in shortage increases by 11.5 percentage points on average after an insurance company initiates a tendered contract. We finally find that the effect on shortages is strong when (1) a large market share is allocated through the tender, (2) there are few alternative suppliers, and (3) the market is fairly concentrated. Conversely, tendering appears to have little to no impact when the market is fragmented and less than 20% of the market is granted through the tender. Our results prove consistent and reliable through several robustness checks.

These findings offer valuable insights for policymakers and organizations that use tenders to balance affordability and availability. To improve this balance, we suggest implementing the following modifications: 1) using a reliability score as a criterion in selecting the winning bid, 2) allowing for multiple winners or localizing tenders, 3) leaving enough time between the tender and the start of the contracted period, and 4) considering market conditions such as the number of suppliers, market concentration, and the potential impact of the tender on the the tendered market share. These changes have the potential to help policymakers and organizations more effectively use tenders to ensure both affordable and accessible medication.

Research Statement

This Ph.D. thesis has been written during the author's work at the Erasmus University Rotterdam. The author is solely responsible for formulating the research questions, building the analytical models, designing experiments, collecting the data, analyzing the results, and writing all the chapters of this thesis. While carrying out the research, the author received valuable and constructive feedback from the doctoral advisors and other doctoral committee members, which subsequently increased the quality of research. Chapters 2 is published. Chapter 3 is submitted to a scientific journal and is currently under the second round of review. Chapter 4 is also submitted to a scientific journal and is under review.

2 How to Charge in Servicizing: Per Period or Per Use?

2.1 Introduction

Many firms have realized that product innovation alone is not enough. They must also integrate services with their products to stay competitive. Service integration has spawned the emergence of a new business model known as servicizing (or servitization). In the servicizing business model, a service provider (SP) sells a specific functionality served by a product, not merely the product itself. Here, product ownership remains with the SP while it guarantees a certain level of performance for a specified contract period. The SP incurs all investment and operating costs during the product lifecycle needing to be effectively priced-in for the overall service, not just the product. This pricing will influence consumer usage patterns, which have implications for both SP costs and revenues.

Companies with a servicizing business model offer various price plans, usually either a pay-per-use or a pay-per-period scheme. In pay-per-use, also known as two-part tariff, the SP charges a flat fee per period and a usage rate for each use of a product. One example is Bundles who provides home appliances such as washing machines as a service. Customers pay a monthly flat fee plus a fee per washing cycle (Bundles, 2020). Many other companies offer pay-per-use, such as Xerox's pay per page printed (Xerox, 2020) or Mobike's "pay as you go" service (Mobike, 2020). Pay-per-period, or subscription, schemes charge a regular fee regardless of usage. Bedzzzy.com offers mattresses charging a periodic flat fee. At contract end, mattresses are collected, remanufactured and marketed as new (Bedzzzy.com, 2020). Swapfiets offers customers two types of bikes through a pay-per-month option (Reid 2020). Other examples include Ahrend for office furniture (Ahrend, 2020), Gerrard Street for headphones (EMF, 2018d), and Philips' "light as a service" (Phillips, 2020).

These two pricing models impact customer usage behavior. By setting an appropriate pay-per-use price, the SP can influence usage behavior and thus control operational costs. Such operational costs are assumed to be maintenance-related and contingent on usage. Still, customer use must be measured and controlled, and this incurs further SP costs in measurement gear and administration.

On the sales side, price-per-use may discourage customer engagement, thus reducing revenue as customers perceive a loss in utility each time they pay after use. This perceived loss in utility is known in consumer behavior studies as the *ticking meter effect* (Sundararajan, 2004; Cachon & Feldman, 2011). Customers who experience the ticking meter effect associate the disutility of paying for a service directly with the utility received from its consumption (Prelec & Loewenstein, 1998). In the pay-per-period scheme, however, payment is delinked from usage. This implies that the SP has limited influence on usage through the pricing mechanism. Here, pay-per-period usage may prove more intense, dissipating the SP's profit with rising operational costs. Yet, the pay-per-period scheme may still enjoy cost efficiency advantage for SPs uncluttered by usage measuring devices and administration. Also, customers avoid any negative ticking meter effect since paying in advance decouples the payment from usage Lambrecht & Skiera (2006).

We examine these two pricing schemes in terms of both SP profit and customer welfare (utility). In addition, we evaluate the effect of the pricing scheme on the environmental impact of the product during its production, usage, and disposal phases. Prior research has shown that when customers pay based on usage, they use the service more cautiously (Lambrecht & Skiera, 2006), which reduces the environmental impact during the usage phase. Given the differences between pricing schemes, our main research question in this study is: *Which pricing policy is superior in terms of profitability, environmental impact, and consumer welfare?*

To answer this question, we model the problem as a dynamic game of incomplete information between the SP offering a single product either through a pay-per-use or pay-per-period scheme. Its consumers are assumed to be heterogeneous in their usage utility. Some companies, like Homie (who offers home appliances as a service), distinguish heavy- and light-usage consumers to charge different prices in these segments (Homie, 2020). Our study mirrors this distinction between the high and low usage-valuation segment in the market. Consumers then choose their desired schemes and set their usage levels to maximize their utilities.

Our base case focuses on just a single product-service. We then extend our baseline model for two competing products: a green versus regular product. Per Accenture (2019) and Toluna (2019), we segment users into environmentally conscious (or green) versus regular customers where the green product not only trims environmental impact, but is also more cost efficient for its customers. This brings additional utility for environmentally conscious consumers. Bundles, for example, offers two such competing options: two types of wash dryers where one is more efficient in both water and electricity use (Bundles, 2020), thus making each use cycle cheaper, versus the regular product.

For a single-product case, our model favors the pay-per-use policy as economically optimal when the SP's operational cost is high. Moreover, when high usage-valuation customers dominate the market, the SP prefers to exclude low usage-valuation customers by offering a pricing policy that appeals only to high usage-valuation customers. Our results also show that this exclusion policy is economically optimal only when the ticking meter effect is sufficiently low. The SP can also offer different schemes to the segments through a hybrid policy. Such a hybrid policy can only be optimal when the operational costs are low enough and the high usage-valuation customers form a moderate fraction of the market.

The pay-per-use policy generally also performs better than pay-per-period for the environment. In the single-product case, the best policy offers a pay-per-use scheme and excludes the low usage-valuation segment. However, when offering a product line with regular and green options, results depend on environmental impact factors in different phases of the product life-cycle. If the usage phase impact is high, pay-per-use policies prove superior. Only where the use-phase impact is extremely low can a menu of pay-per-period schemes minimize environmental impact.

The effect of different policies on consumer welfare varies only when a single product is offered. When two products are offered, consumer welfare remains fixed under different policies. In the single-product case, results show that offering the pay-per-period policy to both segments results in the highest consumer welfare among all possible policies. Thus, given that offering a pay-per-use only to the high usage-valuation segment always minimizes the environmental impact, we show there will be no win-win-win strategies.

We extend the model to a situation where the SP can influence the size of the green segment by raising awareness about environmental benefits of servicizing business models. We find optimal consumers' awareness level for different pricing schemes. Then, we discuss a case where the SP is able to set the product greenness in two phases of the product life cycle, namely, a usage phase and a production/disposal phase. Our results reveal that, in this case, compared to the one-dimensional greenness, the SP charges a lower per-use fee and a higher flat fee and also sets a higher usage-phase greenness level.

The remainder of the paper is structured as follows. We first review the relevant literature in Section 2.2 and then formulate the model in Section 2.3. In Section 2.4, we first describe the equilibrium and then compare policies based on profitability, environmental impact, and consumer welfare. Section 2.5 extends the model to a dual-option product line, followed by analyzing two additional cases in Section 2.6. Finally, Section 2.7 offers concluding remarks.

2.2 Literature Review

Three streams of literature are relevant for this research: 1) product-service systems (PSS), 2) operations management of servicizing business models, and 3) pricing of services and information goods.

The first stream of literature categorizes the PSS conceptually and reveals evidence of how they perform economically and environmentally. For example, Tukker (2004) classified the PSS and then evaluated the different types from the tri-perspective of business, consumer, and environment. Toffel (2008) cast servicizing as the principal agent problem. He described servicizing as a way to align incentives of the SP with its consumers so that the business proves more environmentally friendly. In a qualitative study, Visnjic et al. (2012) investigated the effect of servicizing on the performance of the firm through two dimensions: service investment and market approaches. In a recent study, Agrawal et al. (2018) discuss specific cases of servicizing, leasing, and two-sided markets in terms of the different operational challenges they face and the way they promote a circular economy.

The stream of literature we mainly advance is the one that studies different operational aspects of servicizing. Avci et al. (2014) is the first study where an analytical approach assessed the impact of adopting a usage-based business model. In this paper, a servicizing business model for electric vehicle batteries was studied in the context of conventional electric versus fossil-fuel vehicles. Agrawal & Bellos (2016), however, researched servicizing in a general setting under the possibility of incorporating the pooling effect. Notably, servicizing without pooling has been seen to incur higher environmental impact from excess production versus traditional sales modes.

As the study most relevant to our work, Örsdemir et al. (2019) investigate the difference between servicizing and traditional selling in terms of profitability, environmental impact, and consumer welfare. Unlike Agrawal & Bellos (2016), Örsdemir et al. (2019) interestingly detected conditions where servicizing proves superior to sales in all three bottom lines absent any pooling effect. Durability of the product has also been endogenized where customers are offered a menu of contracts specifying both length of contract and the price. Another relevant paper Bellos et al. (2017) examined a car-sharing SP featuring various car options, levels of fuel efficiency and price to lure customers via pay-per-use schemes or traditional sales. Blaettchen et al. (2018) recently compared 1) basic sales, 2) sales with after-sales services, 3) servicizing, and 4) sharing business models in terms of profitability. What distinguishes this paper from others is its treatment of uncertainties in usage and product failure and their impacts on operational costs of durable goods. Results confirmed that the optimal business model strongly depends on the after-sales service costs for the OEM. Bhattacharya et al. (2019) compared selling and installed based management, in which the manufacturer leases the product to the customers. The lease contract includes maintenance and repair services. They draw conclusions on the equilibrium strategy in case of a monopoly and duopoly market. They show that offering installed based management outperforms selling in a duopoly case regardless of firms' offering identical or vertically differentiated products. However, in a monopoly situation selling is the superior strategy. They model competition, assuming a continuum of customers with known utilities.

In a different servicizing application, Agrawal et al. (2022) analyze non-ownership business models for solar panels where people may purchase the solar panel, lease, or pay per generated power. This study discovers the condition for each where the buy, lease, or pay-per-use models are economically and environmentally superior. The impacts of government subsidies or restrictions on these model outcomes are also investigated under the unique assumption that customers can also receive income from the extra power they generate.

Our paper contributes to the operations management literature of servicizing by comparing the performance of different pricing policies. In every above-cited paper, a servicizing business model has been compared to traditional sales without considering or even explicitly mentioning the varied pricing policies SPs can adopt. What also distinguishes this paper from others in this field is that we allow for discretionary usage by customers. This has not been considered in prior research, the exception being Agrawal & Bellos (2016).

Additionally, we capture the impact of the ticking meter effect and SP usage monitoring costs on its own and its users' decisions to generate useful insights. To obtain a good understanding of the ticking meter effect, we also review marketing that exhibits the existence of such a concept and its relevant settings. The ticking meter effect first appeared in Prelec & Loewenstein (1998) and was empirically proven in (Train et al., 1991; Lambrecht & Skiera, 2006). Lambrecht & Skiera (2006) studied empirically different biases customers show under flat rate versus pay-per-use schemes. They proved that customers incur a psychological cost when they pay per use, which they dubbed a *taxi meter* or *ticking meter* effect. Based on this empirical finding, other papers have enlisted this idea to model information goods pricing (Sundararajan, 2004; Balasubramanian et al., 2015) since information goods, such as on-demand video streaming or cloud services, can also be priced per usage or as a subscription (Fishburn & Odlyzko, 1999).

Therefore, the most salient feature of marketing literature regarding this paper is the pricing of information goods. As one of the first analytical studies, Sundararajan (2004) addressed the pricing problem of information goods when a firm could offer either a fixed-fee or usage-based scheme. This study also discussed the use of non-linear pricing in usage-based schemes and specified the optimality conditions for each scheme. In a duopoly setting, Choudhary (2010) investigated when it is optimal for the firm to offer various schemes to differentiate themselves from its competitor. Based on the findings, each firm should optimally offer multiple schemes when the goods are horizontally differentiated. In another study, Balasubramanian et al. (2015) compared buying to own, i.e., paying upfront, with pay-per-use offerings of information goods when customers differed in their usage frequency. As our study assumes, customers are influenced by the ticking meter effect when paying per use. It has been proven that a subdued ticking meter effect renders pay-per-use more profitable in monopoly. Remarkably, however, the same muffled ticking meter effect yields lower profits for both firms in a duopoly.

What distinguishes our work from the pricing literature on information goods is that we consider physical product handling as an added operational challenge. Distinct from information goods, physical-product servicizing makes the SP responsible for operational costs where a salient link between usage and environmental performance emerges. In contrast, usage level of information goods does not as nearly degrade the SP's environmental footprint.

2.3 The Model

We consider a monopolist SP offering customers access to a single product through a servicizing business model. It is also responsible for the installation, maintenance and possible replacement of the product. The SP may offer customers either a pay-per-use (two-part tariff) or pay-per-period (subscription) scheme, denoting the pay-per-period scheme by P and the pay-per-use scheme by U. An overview of notation used in this paper is presented in Table 2.1.

Table 2.1: Notation

Symbol	Definition
	Index
i	Consumer's usage valuation index, $i \in \{L, H\}$
	Parameters
γ	Fraction of high usage-valuation consumers in the market
v_i	Valuation of product usage by customer type i per use
f_i	Proportion of the i-type customers in the market; $f_H = \gamma$
δ	Ticking meter effect parameter
α	Customer depreciation sensitivity parameter
τ	Duration of the contract
c_f	Operational costs of the SP
c_m	Costs of measuring the usage of the consumer
	Decision Variables
θ_i	Level of usage by customer type i per period
F_i	The flat rate in the pay-per-use scheme per period for customer type i
p_i	The pay per use fee in the pay-per-use scheme for customer type i
S_i	Pay per period fee in the pay-per-period scheme for customer type i

The problem is modelled as a game between the SP and its customers. In this game, the SP first decides which policy and what price to offer to each customer segment. Then, customers choose pricing scheme and set usage level. We first model the consumers' problem. Next, the SP's problem will be discussed as an adverse selection problem (Bolton et al., 2005).

2.3.1 Consumers' problem

Customers are assumed heterogeneous in usage valuation, v_i, where $i \in L, H$. We also assume two separate customer segments in the market: high usage-valuation, v_H, and low usage-valuation, v_L, where $v_H > v_L$. Without loss of generality, we normalize the size of the market to one. High usage-valuation consumers form fraction γ of the market and the rest, i.e., low usage-valuation consumers, form fraction $(1 - \gamma)$. Here, the size of a customer segment does not depend on prices set by the SP. Similar assumptions have pervaded the literature (Bellos et al., 2017; Örsdemir et al., 2019). In case of washing machines, for example, there are evidences indicating that usage intensity, i.e., the number of wash cycles, mostly depends on the household size. This is observed studying consumers' actual usage in Germany, Austria, Switzerland, and the Netherlands (Pakula & Stamminger, 2010; Faille, 2021). This further justifies our assumption. A user's own valuation is private where the SP is not aware of any customer υ_i, while knowing the distribution of user types.

Customer utility is assumed to be concave with respect to usage level per time, θ, and length of service contract, τ. This assumption appears often in the literature (Örsdemir et al., 2019; Agrawal & Bellos, 2016; Avci et al., 2014; Lambrecht & Skiera, 2006). This also makes customers' decisions tractable. In some papers, usage level is set to 1. However, this fits only products lacking any discretionary usage, like carpet or furniture (Örsdemir et al., 2019). Others vary the usage level under a fixed duration of contract (Agrawal & Bellos, 2016). Consistent with the latter group of studies, we model the utility deterioration as a negative term $\alpha\frac{\tau^2\theta^2}{2}$ and fix the contract duration, τ. Parameter α captures the sensitivity of consumers to the age of the product, which may vary for different product categories. This implies that, with more product usage over time, the introduction of newer technologies and models may dissipate attractiveness and consequent consumer utility.

In the pay-per-use scheme, customers must pay each time they use the product. This may impact consumer utility. This is a recognized psychological cost, known as the *ticking meter* effect that reduces the utility of a customer each time she pays (for empirical studies related to this effect see Lambrecht & Skiera (2006); for analytical ones see Balasubramanian et al. (2015) and Sundararajan (2004) and the references therein). We capture this in our modeling framework as parameter δ. We can formulate the customer's utility when choosing a pay-per-period or pay-per-use scheme as follows:

$$U_i^P = \int_0^\tau (\upsilon_i\theta_i - S_i - \alpha t\theta_i^2)dt \tag{2.1}$$

$$U_i^U = \int_0^\tau ((\upsilon_i - p_i - \delta)\theta_i - F_i - \alpha t\theta_i^2)dt \tag{2.2}$$

A customer's utility is a function of price, usage level, usage valuation, and the depreciation term. We assume fully rational customers who choose their usage levels to maximize the utility function. Lemma 1 specifies the optimal usage levels of customers in each of the schemes.

Lemma 1. *The optimal usage level of customers of type i is $\theta_i^* = \frac{\upsilon_i - p_i - \delta}{\alpha\tau}$ if they choose the pay-per-use scheme and $\theta_i^* = \frac{\upsilon_i}{\alpha\tau}$ if they choose the pay-per-period scheme.*

Applying the first-order condition to Equations 2.1 and 2.2 knowing that the customer's utility function is concave, we prove the optimal usage levels. Also, given $\upsilon_i, \alpha\tau, p_i, \delta \geq 0$, it follows that the usage level is higher in the pay-per-period scheme than in pay-per-use.

Without loss of generality, we assume length of contract to remain the same for all contracts the SP offers set at $\tau = 1$[1].

2.3.2 Service Provider's problem

The SP aims to maximize profit through design of the pricing schemes. We consider two popular pricing schemes, namely, pay-per-period and pay-per-use. In a pay-per-period, customers pay S_i per period (e.g., per month) independent of usage level. In pay-per-use, customers pay a flat rate of F_i per period plus a rate, p_i, each time the product is used.

We denote pricing policy as a pair (H, L) where H represents the pricing scheme targeting the high usage-valuation segment and L as the scheme targeting the low usage-valuation segment. $H, L \in \{P, U, \varnothing\}$, where P, U and $\varnothing$ each denotes pay-per-period, pay-per-use, and exclusion schemes. Our initial analysis considers cases where the SP offers a pay-per-use scheme to both segments, i.e., (U, U) policy, a pay-per-period scheme to both segments, i.e., (P, P) policy, or a mix of a pay-per-period and pay-per-use policy, i.e., either (P, U) or (U, P). Note that it may not always be best practice to offer a menu of contracts. In other words, there might be cases where excluding a certain type of customer improves the profit of the SP. We call such policies exclusion policies, e.g., a $(U, \varnothing)$ policy representing a case where low usage-valuation consumers are excluded.

The SP also incurs operational costs per customer to keep the product in service. We assume a quadratic increasing cost as a function of usage level, formulated as $c_f \frac{\theta^2}{2}$. This reflects that the more the product is used, the more often repair is required, thus increasing SP operational costs by usage level disproportionately. Such a convex relation has been observed in practice, e.g., by Xerox when making inventory decisions for spare parts in their machines (Bacon, 2013). A similar assumption is made in the literature, by for example Agrawal & Bellos (2016); Örsdemir et al. (2019), and Avci et al. (2014). This is a proper assumption for durable products such as washing machines as they require less frequent maintenance, and their performance does not deteriorate significantly over time. Additionally, a company like Bundles conducts "smart maintenance" to ensure the appliance retains its initial performance throughout its use as well as its life cycle (Bundles, 2020).

The difference between pay-per-period and pay-per-use schemes is not limited to pricing format. In the case of pay-per-use, the SP also charges a fee per tracking the usage by each customer. For example, Bundles measures via internet the number of cycles a washing machine performs to charge the customer per use, to process data, and often to provide consumers with usage feedback (Bundles, 2020). This is also the case for servicized solar panels discussed in Agrawal et al. (2022). The cost of measuring usage in our model is represented by c_m.

[1] It is a common practice that companies offer a fixed length of service contract, e.g., one year, to the customers

In the next four sections, we model the SP's problem when offering specific pricing policies. Through profit comparison under the two policies, we find the optimal policy in various conditions.

2.3.2.1 Pay-per-use policy

First, we consider the case where the SP offers each segment a different pay-per-use scheme to discover the true customer type. We dub this policy (U, U). We face an adverse selection problem here as the SP aims at maximizing profit formulated next:

$$\max_{p_L, p_H, F_L, F_H} \quad \pi_{(U,U)} = \gamma[p_H \theta_H + F_H - c_f \frac{\theta_H^2}{2} - c_m] + (1-\gamma)[p_L \theta_L + F_L - c_f \frac{\theta_L^2}{2} - c_m] \tag{\textbf{P.1}}$$

S.t.

$$\begin{aligned}
IR_H: &\quad (v_H - p_H - \delta)\theta_H - F_H - \alpha\frac{\theta_H^2}{2} \geq 0 \\
IR_L: &\quad (v_L - p_L - \delta)\theta_L - F_L - \alpha\frac{\theta_L^2}{2} \geq 0 \\
IC_H: &\quad (v_H - p_H - \delta)\theta_H - F_H - \alpha\frac{\theta_H^2}{2} \geq (v_H - p_L - \delta)\theta'_L - F_L - \alpha\frac{\theta_L'^2}{2} \\
IC_L: &\quad (v_L - p_L - \delta)\theta_L - F_L - \alpha\frac{\theta_L^2}{2} \geq (v_L - p_H - \delta)\theta'_H - F_H - \alpha\frac{\theta_H'^2}{2}
\end{aligned}$$

where, $\theta'_L = \frac{v_H - p_L - \delta}{\alpha}$ and $\theta'_H = \frac{v_L - p_H - \delta}{\alpha}$. For each segment $i \in \{L, H\}$, the revenue generated consists of a flat fee F_i, charged per period plus a use-rate-dependent variable fee, p_i. The SP incurs both operational cost $c_f \frac{\theta_i^2}{2}$ and measuring cost c_m. Constraints (IR_H) and (IR_L) are individual rationality constraints for each type to ensure non-negative utility. Constraints (IC_H) and (IC_L) are incentive compatibility constraints. Arising from the revelation principle, they ensure that the utility a user gains by revealing her true type exceeds the utility obtained by pretending to be the other type.

2.3.3 Pay-per-period policy

In this (P, P) policy, the SP offers both segments a pay-per-period scheme, with a flat fee S, regardless of their type. Thus, the SP only optimizes one per-period fee as follows:

$$\max_{S} \quad \pi_{(P,P)} = \gamma[S - c_f \frac{\theta_H^2}{2}] + (1-\gamma)[S - c_f \frac{\theta_L^2}{2}] \tag{\textbf{P.2}}$$

S.t.

$$IR_H: \quad \upsilon_H \theta_H - S - \alpha \frac{\theta_H^2}{2} \geq 0$$
$$IR_L: \quad \upsilon_L \theta_L - S - \alpha \frac{\theta_L^2}{2} \geq 0$$

Two parts of the objective function are similar where the first terms show the revenue from the per-period fee and the second terms represent the operational costs. To satisfy both IR_H and IR_L, IR_L will be binding in the optimal solution since it is a tighter constraint.

2.3.3.1 Hybrid policy.

In order to reveal true customer types, the SP could offer different schemes to various segments. We investigate the following two possibilities: (P, U) that represents offering a pay-per-period to the high usage-valuation customers and a pay-per-use scheme to the low usage-valuation customers and, inversely, the (U, P) policy. The adverse selection problem for the hybrid strategy is as follows:

$$\max_{p,F,S} \quad \pi_{(U,P)/(P,U)} = f_i[S - c_f \frac{\theta_i^2}{2}] + (1 - f_i)[p\theta_{\bar{i}} + F - c_f \frac{\theta_{\bar{i}}^2}{2} - c_m] \qquad \forall i \in \{L, H\} \tag{P.3}$$

S.t.

$$IR_i: \quad \upsilon_i \theta_i - S - \alpha \frac{\theta_{\bar{i}}^2}{2} \geq 0$$
$$IR_{\bar{i}}: \quad (\upsilon_{\bar{i}} - p - \delta)\theta_{\bar{i}} - F - \alpha \frac{\theta_{\bar{i}}^2}{2} \geq 0$$
$$IC_i: \quad \upsilon_i \theta_i - S - \alpha \frac{\theta_i^2}{2} \geq (\upsilon_i - p - \delta)\theta'_{\bar{i}} - F - \alpha \frac{\theta'^2_{\bar{i}}}{2}$$
$$IC_{\bar{i}}: \quad (\upsilon_{\bar{i}} - p - \delta)\theta_{\bar{i}} - F - \alpha \frac{\theta_{\bar{i}}^2}{2} \geq \upsilon_{\bar{i}} \theta'_i - S - \alpha \frac{\theta'^2_i}{2}$$

where $\bar{i}$ is the complement of i and f_i represents the fraction of customers who are in segment i. This means $f_H = \gamma$, and $f_L = 1 - \gamma$. If $i = H$, it models a (P, U) policy. If $i = L$, a (U, P) policy applies. In the objective function, the first part is similar to Problem **P.2** and the second part is the same as the objective function in Problem **P.1**.

2.3.3.2 Exclusion Policies.

Homie and Bundles are SPs that offer either a pay-per-use or pay-per-period scheme to both segments. There are also companies, such as Coolblue (an online retailer) or Swapfiets, that offer only one scheme – implying that some consumer segments might be excluded

(Coolblue, 2020; Reid, 2020). We denote such policies as exclusion policies. It is well-known in mechanism design literature that, apart from merely providing customers a menu of contracts, the SP could also reach an efficient result by targeting only the more efficient type (Bolton et al., 2005). In this case, we do not apply the IC_i constraints since we target only one type of customers in the market. According to Lemma 1, high usage-valuation customers will consume more than low usage-valuation customers when offered the same scheme. In our case, more usage does not necessarily yield more profit for the SP since higher usage also raises operational costs. Therefore, the SP must decide which customer type should be excluded.

We denote the case where the SP offers a pay-per-use scheme to one customer type as either $(U, \varnothing)$ or $(\varnothing, U)$. Then, the SP's problem is formulated as follows:

$$\max_{p_i, F_i} \quad \pi_{(U,\varnothing)/(\varnothing,U)} = f_i[p_i\theta_i + F_i - c_f\frac{\theta_i^2}{2} - c_m] \qquad \forall i \in \{L, H\} \tag{\textbf{P.4}}$$

S.t.

$$IR_i: \quad (\upsilon_i - p_i - \delta)\theta_i - F_i - \alpha\frac{\theta_i^2}{2} \geq 0$$
$$IR_{\bar{i}}: \quad (\upsilon_{\bar{i}} - p_{\bar{i}} - \delta)\theta_{\bar{i}} - F_{\bar{i}} - \alpha\frac{\theta_{\bar{i}}^2}{2} \leq 0$$

where $IR_{\bar{i}}$ ensures that the excluded type will not participate. This model represents the case of the $(U, \varnothing)$ policy when $i = H$, and the $(\varnothing, U)$ policy when $i = L$.

If the SP offers only a pay-per-period scheme to one segment, we model the SP's problem similarly:

$$\max_{S} \quad \pi_{(P,\varnothing)/(\varnothing,P)} = f_i[S - c_f\frac{\theta_i^2}{2}] \qquad \forall i \in \{L, H\} \tag{\textbf{P.5}}$$

S.t.

$$IR_i: \quad \upsilon_i\theta_i - S - \alpha\frac{\theta_i^2}{2} \geq 0$$
$$IR_{\bar{i}}: \quad \upsilon_{\bar{i}}\theta_{\bar{i}} - S - \alpha\frac{\theta_{\bar{i}}^2}{2} \leq 0$$

when $i = H$, the model represents the $(P, \varnothing)$ policy case, and for $i = L$, the case of the $(\varnothing, P)$ policy.

2.4 Analysis of the Base Case: Single Product Model

In this section, we first characterize the equilibrium for each policy. Then, we compare different policies to find the optimal in terms of profitability, environmental impact and consumer welfare.

2.4.1 Equilibrium Specifications

Proposition 1 shows the optimal menu of contracts the SP offers customers in a (U, U) policy.

Proposition 1. *In a (U, U) policy:*

(i) Optimal pay-per-use prices are $p_H^{(U,U)^*} = \frac{c_f(\upsilon_H - \delta)}{\alpha + c_f}$ *and* $p_L^{(U,U)^*} = \frac{c_f(\upsilon_L - \delta)}{\alpha + c_f} + \alpha \frac{\gamma(\upsilon_H - \upsilon_L)}{(1-\gamma)(\alpha + c_f)}$.

(ii) Optimal flat fees are $F_H^{(U,U)^*} = \frac{(\upsilon_H - p_H^* - \delta)^2}{2\alpha} - \frac{(\upsilon_H - p_L^* - \delta)^2 - (\upsilon_L - p_L^* - \delta)^2}{2\alpha}$ *and* $F_L^{(U,U)^*} = \frac{(\upsilon_L - p_L^* - \delta)^2}{2\alpha}$,

(iii) $F_H^* > F_L^*$ *and* $p_H^* < p_L^*$.

Note that the cost of measuring usage, c_m, does not play a role in the pricing decision since it is a sunk cost for the SP. However, c_m does play a role in choosing the optimal policies where the SP needs the measuring device in a pay-per-use scheme, but not for a pay-per-period subscription offer.

The third part of Proposition 1 shows that the SP charges a higher flat fee and a consequent lower per-use fee to the high usage-valuation type[2]. The reasoning here is that high usage-valuation consumers use the product more as shown in Lemma 1. Thus, they tend to choose the scheme charging a lower per-use fee. However, if the SP also offers a lower flat fee to these customers, no consumer will choose the costlier option. Therefore, to reveal the true customer type, it is necessary to charge a higher flat fee and a lower per-use fee to the high usage-valuation consumers to extract the maximum possible information. A similar statement applies for low usage-valuation customers.

Now, we discuss the optimal solution for the (P, P) policy in Proposition 2.

Proposition 2. *In a (P, P) policy, the optimal per-period fee equals $S^{(P,P)^*} = \frac{\upsilon_L^2}{2\alpha}$, which depends only on the valuation of the low usage-valuation segment.*

This shows that the SP offers the price based on the valuation of the low usage-valuation customers. That is because if the SP prices the service based on the valuation of the high usage-valuation customers, the low usage-valuation customers would be excluded. As a result of setting the price based on the valuation of low-usage customers the consumer surplus of high usage-valuation segment increases (See Section 2.4.2.3).

Proposition 3 shows the equilibrium prices in the hybrid policy.

Proposition 3. *In a hybrid policy:*

[2]For example, Bundles offers the high usage-valuation type consumers a contract of €22.95 as the flat fee per month and €0.6 per use. However, they offer the low usage-valuation consumers a flat fee of €16.95 per month and a per-use fee of €1.

(i) the SP offers a pay-per-period scheme to the high usage-valuation, and a pay-per-use scheme to the low-usage valuation customers, i.e., (P,U) policy.

(ii) the optimal per-period fee for the high usage-valuation consumers is $S^{(P,U)^*} = \frac{\upsilon_H^2}{2\alpha} - \frac{(\upsilon_H - p^* - \delta)^2 - (\upsilon_L - p^* - \delta)^2}{2\alpha}$.

(iii) the optimal prices for the low usage-valuation consumers are $p^{(P,U)^*} = \frac{c_f(\upsilon_L - \delta)}{\alpha + c_f} + \alpha\frac{\gamma(\upsilon_H - \upsilon_L)}{(1-\gamma)(\alpha + c_f)}$ *and* $F^{(P,U)^*} = \frac{(\upsilon_L - p^* - \delta)^2}{2\alpha}$.

Intuitively, the high usage-valuation segment prefers to use the product more. We have also shown in Lemma 1 that, in the optimal solution, customers use more under a pay-per-period scheme. Therefore, high usage-valuation customers opt for the pay-per-period scheme and thus avoid the pay-per-use scheme where customers pay a fee per use that effectively hinders usage. This result infers a suboptimal restraint on high usage-valuation user tendency when offering a pay-per-use scheme. Thus, the SP is better off when featuring a pay-per-period scheme to high usage-valuation customers and a pay-per-use scheme to low usage-valuation customers.

The results for the exclusion policies are summarized next in Proposition 4.

Proposition 4. *In exclusion policies:*

(i) The SP always excludes the low usage-valuation consumers, which means it may only offer $(U,\varnothing)$ and $(P,\varnothing)$.

(ii) In a $(U,\varnothing)$ policy, the optimal prices are $p_H^{(U,\varnothing)^*} = \frac{c_f(\upsilon_H - \delta)}{\alpha + c_f}$ *and* $F_H^{(U,\varnothing)^*} = \frac{(\upsilon_H - p_H^* - \delta)^2}{2\alpha}$.

(iii) In a $(P,\varnothing)$ policy, the optimal pay-period fee is $S^{(P,\varnothing)^*} = \frac{\upsilon_H^2}{2\alpha}$.

As the results indicate, it is never possible to exclude the high usage-valuation consumer. Intuitively, if the SP offers the product only to the low usage-valuation type, the price will be lower than what a high usage-valuation consumer is willing to pay. Thus, the high usage-valuation type will also take the offer. The question that next arises is how the SP sets the price in pay-per-use and pay-per-period policies in an exclusion versus non-exclusion policy. To make the assessment meaningful, we compare the prices offered in the exclusion policy to prices set for high usage-valuation consumers in the corresponding non-exclusion policies. Corollary 2.4.0.1 describes the results.

Corollary 2.4.0.1. *When comparing prices, we have:*

(i) The flat fee in a $(U,\varnothing)$ policy is higher than the flat fee for the high usage-valuation customers in a (U,U) policy, i.e., $F^{(U,\varnothing)^*} > F_H^{(U,U)^*}$.

(ii) The per-use fee in a $(U,\varnothing)$ policy is equal to the per-use fee the high usage-valuation customers in a (U,U) policy, i.e., $p^{(U,\varnothing)^*} = p_H^{(U,U)^*}$.

(iii) *The per-period fee in a* $(P, \varnothing)$ *policy is higher than the per-period fee for the high usage-valuation in a* (P, U) *policy, i.e.,* $S^{(P,\varnothing)^*} > S^{(P,U)^*}$.

(iv) *The per-period fee in a* $(P, \varnothing)$ *policy is higher than the per-period fee in a* (P, P) *policy, i.e.,* $S^{(P,\varnothing)^*} > S_i^{(P,P)^*}$ *for all* $i \in \{L, H\}$.

Results show that the SP charges higher flat fees in the exclusion policies. Intuitively, the SP tries to offset the lower income from excluding low usage-valuation consumers by charging higher flat fees to high usage-valuation users. Note that the per-use fee remains the same in pay-per-use policies since higher per-use fees increase direct revenue while being offset by a reduced usage level. Still, a higher flat fee will not impact usage level. Therefore, the SP prefers to increase only the flat fee.

The impact of the ticking meter effect seems critical in decisions by both consumers and the SP. In the following corollary, we show how the results change with a variable ticking meter effect. Note that since $(P, \varnothing)$ and (P, P) are decoupled from the ticking meter effect, they are excluded.

Corollary 2.4.0.2. *(i) Flat fees and per-use fees in pay-per-use schemes are decreasing in* δ.

(ii) The per-period fee in (P, U) *is increasing in* δ.

(iii) The profit of the SP is decreasing in the ticking meter effect, δ.

According to this result, we conclude that, in the pay-per-use scheme, the SP must decrease both the flat fee and per-use prices when the ticking meter effect rises. This decrease in pricing can also explain the drop in profits across all policies where customers are more sensitive to paying per use. In the alternative hybrid policy (P, U), the SP charges a higher per-period fee to counter a higher level ticking meter effect. Here, the SP tries to offset loss of revenue in the pay-per-use scheme offered to low usage-valuation types by increasing the per-period fee in the pay-per-period scheme offered to high usage-valuation users. Yet, part *(iii)* of the corollary shows the SP is unable to compensate all losses. This means that a higher ticking meter effect will also lower the profit from a (P, U) policy despite charging a higher per-period fee to high usage-valuation consumers.

2.4.2 Comparing Different Policies

In this section, we compare pay-per-period, pay-per-use, and hybrid policies in terms of profitability, environmental, and consumer surplus implications. Although companies make their decisions primarily based on profit maximization, they also have concerns about environmental and welfare implications of their decisions. Per the concept of *shared value* introduced by Porter & Kramer (2019), we first find the best policies to maximize profit. Then, we seek profit-maximizing policies that are also either environmentally friendly, welfare-improving, or both. If companies can find a policy that is more profitable and environmentally friendly at the same time, it would be a win-win situation for the company and the environment. If that policy also favors consumer welfare, it then elevates to a win-win-win strategy, the third win posting in consumer surplus.

2.4.2.1 Profitability

In this part, we compare policy options in terms of profitability. Proposition 5 characterizes the conditions under which each policy is most profitable.

Proposition 5. *There exists unique thresholds* c_m^1, c_m^2, c_f^1,c_f^2, c_f^3, c_f^4, γ^1, γ^2, γ^3, γ^4, *and* γ^5 *such that:*

(i) the (P, P) *policy is optimal in either of the following cases:*

- $\gamma \leq \gamma^1$ *when* $c_m \leq c_m^1$ *and* $c_f \leq c_f^1$ *or when* $c_m^1 \leq c_m \leq c_m^2$ *and* $c_f^2 \leq c_f \leq c_f^1$.
- $\gamma \leq \gamma^2$ *when* $c_m^1 \leq c_m \leq c_m^2$ *and* $c_f \leq c_f^2$ *or when* $c_m \geq c_m^2$ *and* $c_f \leq c_f^1$.
- $\gamma \leq \gamma^4$ *when* $c_m \leq c_m^2$ *and* $c_f^1 \leq c_f \leq c_f^4$ *or when* $c_m \geq c_m^2$ *and* $c_f^3 \leq c_f \leq c_f^4$,
- $\gamma \leq \gamma^5$ *when* $c_m \geq c_m^2$ *and* $c_f^1 \leq c_f \leq c_f^3$.

(ii) the (P, U) *policy is optimal in the following cases:*

- $\gamma^1 \leq \gamma \leq \gamma^3$ *when* $c_m \leq c_m^1$ *and* $c_f \leq c_f^1$ *or when* $c_m^1 \leq c_m \leq c_m^2$ *and* $c_f^2 \leq c_f \leq c_f^1$

(iii) the $(P, \varnothing)$ *policy is optimal in either of the following cases:*

- $\gamma \geq \gamma^3$ *when* $c_m \leq c_m^1$ *and* $c_f \leq c_f^1$ *or when* $c_m^1 \leq c_m \leq c_m^2$ *and* $c_f^2 \leq c_f \leq c_f^1$.
- $\gamma \geq \gamma^2$ *when* $c_m^1 \leq c_m \leq c_m^2$ *and* $c_f \leq c_f^2$ *or when* $c_m \geq c_m^2$ *and* $c_f \leq c_f^1$

(iv) the (U, U) *policy is optimal in either of the following cases:*

- $\gamma^4 \leq \gamma \leq \gamma^3$ *when* $c_m \leq c_m^2$ *and* $c_f^1 \leq c_f \leq c_f^4$ *or when* $c_m \geq c_m^2$ *and* $c_f^3 \leq c_f \leq c_f^4$.
- $\gamma \leq \gamma^3$ *when* $c_f \geq c_f^4$.

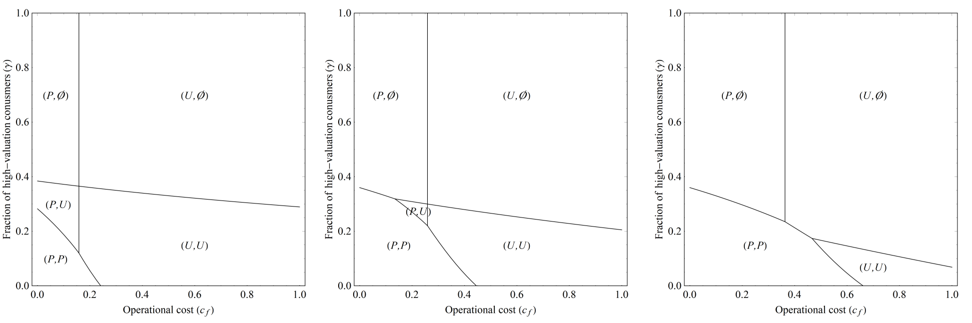
(v) the $(U, \varnothing)$ *policy is optimal in either of the following cases:*

- $\gamma \geq \gamma^5$ *when* $c_m \geq c_m^2$ *and* $c_f^1 \leq c_f \leq c_f^3$.
- $\gamma \geq \gamma^3$ *when* $c_m \leq c_m^2$ *and* $c_f \geq c_f^1$ *or when* $c_m \geq c_m^2$ *and* $c_f \geq c_f^3$.

Results show that the SP has incentive to induce customers to use the product less by offering the pay-per-use policy when the unit operational cost of the SP, c_f, exceeds a certain threshold (See Figure 2.1), since less usage means reduced maintenance, replacement operations and SP operational costs.

Within each category of policies, i.e., pay-per-use policies including (U, U) and $(U, \varnothing)$ and pay-per-period policies including (P, P), (P, U) and $(P, \varnothing)$, the proportion of high usage-valuation consumers, γ, is a crucial parameter. When these consumers form a relatively large portion of the market, the SP is better off excluding low usage-valuation customers in maximizing profit. This phenomenon can be explained using contract theory where the SP pays an information rent to the high usage-valuation consumers to reveal their true type by an offer of non-exclusion policies. However, information rent vanishes when excluding one type. When the information rent exceeds the profit from low usage-valuation consumers, the SP will be better off to exclude them. With higher-level c_f, the exclusion threshold is further lowered. When operational cost rises, then the SP can exclude low usage-valuation customers at relatively lower levels of γ. Figure 2.1 illustrates this. Among the non-exclusion pay-per-period policies, the (P, P) policy is optimal when γ is sufficiently small, while the (P, U) policy is optimal when it is moderate (See the bottom left corner of Figure 2.1a and Figure 2.1b). This is because, implementing the (P, P) policy, the high usage-valuation segment does not bring much profit for the SP since it has to offer a single price to both segments based on the valuation of the low usage-valuation customers. Thus, a lower fraction of low usage-valuation customers increases the profitability of this policy.

Another important parameter in deciding the optimal policy is the measuring costs, c_m. As intuition dictates and it is observed in Figure 2.1a, Figure 2.1b, and Figure 2.1c, the higher the c_m is, the less profitable a pay-per-use policy becomes. This improves the attractiveness of a pay-per-period scheme as the payment is not contingent on the usage level.



(a) Small c_m **(b)** Medium c_m **(c)** Large c_m

Figure 2.1: Optimal policy in terms of profitability (γ and c_f)

Now, consider Figure 2.2 where the optimal policies have been depicted in terms of δ, and, c_f. Here, a lower c_f improves the profit of a pay-per-period scheme making it optimal. However, among the pay-per-period policies, (P, P) is optimal in sufficiently small values of c_f, whereas $(P, \varnothing)$ is optimal in moderate levels. This happens because the (P, P) leads to a higher total usage by customers than what $(P, \varnothing)$ allows. Higher usage increases the operational costs of the SP thus policies implying higher usage become more attractive when operational costs are low.

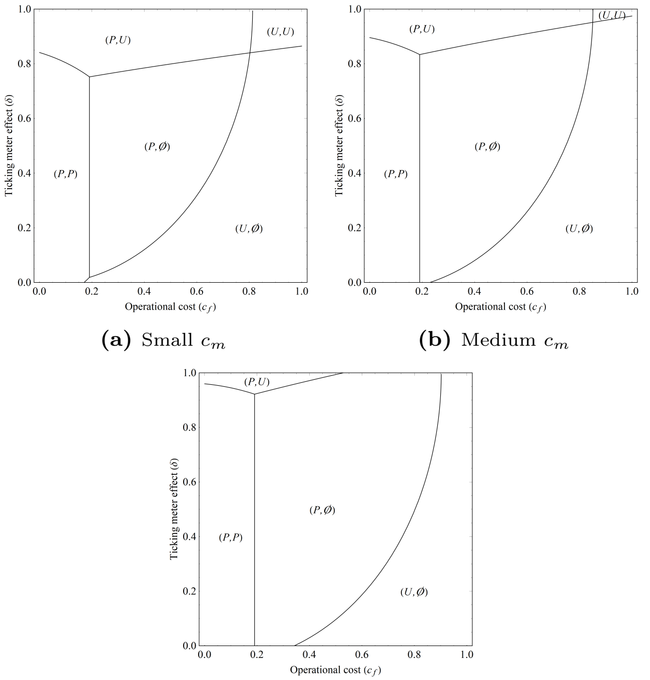
When the operational costs are sufficiently high, the ticking meter effect exerts an inverse impact on the exclusion decision versus the fraction of high usage-valuation customers, γ. This means that if the ticking meter effect is sufficiently high, the SP does not exclude the low usage-valuation customers since its heightened level already depresses usage. Lower usage decreases the operational costs and per-use revenue of the SP. However, the flat fee revenue remains intact regardless of usage. This clearly favors the SP. When the ticking meter effect is high enough, the additional profit from low usage-valuation customers exceeds the information rent that the SP must pay to the high usage-valuation segment in case of a non-exclusion policy. Therefore, the SP decides to offer the service also to low usage-valuation customers.

If c_f is sufficiently low then the SP would be better off not to exclude low usage-valuation customers. Hence, the SP has to decide either to offer (P, P) or (P, U). In low values of δ, (P, P) outperforms (P, U). However, this reverses as δ increases. This is because, when δ increases then usage level of the low usage-valuation segment, and accordingly, revenue decreases. This also leads to a decrease in operational costs such that it is sufficient to offset the decrease in revenue. This makes (P, U) outperform (P, P).

Parameter α captures how consumer utility using the product decays over time due to product age or obsolescence. Compared to Figure 2.2b (where $\alpha = 0.7$), Figure 2.3a and Figure 2.3b show the impact of lower and higher α, respectively. We note that lower values of α make pay-per-use policies more appealing to the SP since customers less sensitive to product obsolescence use the product more per Lemma 1. Here, a pay-per-use scheme allows the SP to drive down usage and operational costs accordingly. Thus, when α is low, a pay-per-use policy performs better in terms of profitability versus a pay-per-period policy.

2.4.2.2 Environmental Impact

The environmental impact of a product can be divided into three phases, namely production, usage, and disposal. Different options must thus be compared based on aggregate performance over all these phases. For the following reasons we regard the usage phase, and thus the usage level of customers under different pricing policies, causing the most relevant environmental impact. First, empirical evidences suggest that for products such as washing machines the environmental impact during the disposal phase is almost negligible compared to the impact during the use phase (Yuan et al., 2016). Secondly, these are usually durable products, and in some cases SPs may order customized products from OEMs intended to improve durability, and with the maintenance expertise and efforts of the SP, they retain a desirable quality throughout their life cycle regardless of the business model under which they are providing service to customers. These limit the impact of the business models



(a) Small c_m **(b)** Medium c_m

(c) Large c_m

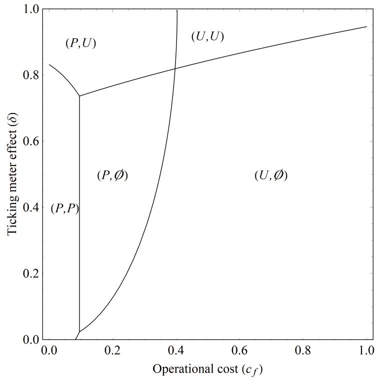
Figure 2.2: Optimal policy in terms of profitability (δ and c_f)

on the disposal phase. Hence, to capture the environmental impact of pricing schemes, we assume that the production and disposal phase impacts are fixed regardless of the pricing scheme given fixed product and contract length. However, different pricing policies ensue usage levels varying the use phase impact.

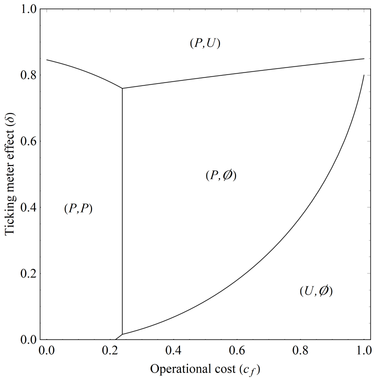
Following the papers by Örsdemir et al. (2019) and Agrawal & Bellos (2016), we formulate the usage phase impact as a convex function of usage level: with a higher level of usage, the product wears out and energy consumption rises disproportionally. Thus, the total environmental impact of the product is:

$$EI = \gamma[e_u \theta_H^2 + e_{pd}] + (1-\gamma)[e_u \theta_L^2 + e_{pd}] \tag{2.3}$$

where e_u is the environmental impact resulting from each usage, and e_{pd} is the aggregate impact during production and disposal phases. Please note that in exclusion policies, i.e., $(U, \varnothing)$ and $(P, \varnothing)$, the second term will disappear since the low usage-valuation segment will not be present. As a result, there will not be any production and disposal impact either. Proposition 6 shows the best policy in terms of environmental impact assuming the SP maximizes profit and the customers maximize their utilities.



(a) $\alpha = 0.4$



(b) $\alpha = 1$

Figure 2.3: The profitability regions by varying the customers' sensitivity to obsolescence, α

Proposition 6. *In terms of environmental impact:*

(i) Pay-per-use policies outperform pay-per-period policies,

(ii) $(U, \varnothing)$ *is always the best policy.*

According to Lemma 1, the usage level is always higher in pay-per-period policies. Since environmental impact is an increasing function of usage level, it is logical to conclude that pay-per-use always outperforms pay-per-period policies. However, the main conclusion is that $(U, \varnothing)$ incurs the least environmental impact since excluding one entire market segment reduces total usage.

A win-win strategy is one superior in terms of both profitability and environmental impact. Corollary 2.4.0.3 next characterizes the conditions under which the SP can achieve a win-win strategy:

Corollary 2.4.0.3. *The win-win situation happens if* $(U, \varnothing)$ *maximizes profit, which happens in either of the following cases:*

- $\gamma \geq \gamma^5$ *when* $c_m \geq c_m^2$ *and* $c_f^1 \leq c_f \leq c_f^3$.
- $\gamma \geq \gamma^3$ *when* $c_m \leq c_m^2$ *and* $c_f \geq c_f^1$ *or when* $c_m \geq c_m^2$ *and* $c_f \geq c_f^3$.

We know that the $(U, \varnothing)$ policy always outperforms other policies environmentally. When it is also more profitable than others, then it is a win-win strategy. Given the characterization specified in Proposition 5, when the level of operational cost, c_f, is relatively high, and the proportion of the high usage-valuation consumers is also high (or the level of the ticking meter effect is low), the SP will select a win-win strategy. Figure 2.4 shades the conditions where $(U, \varnothing)$ leads to a win-win situation.

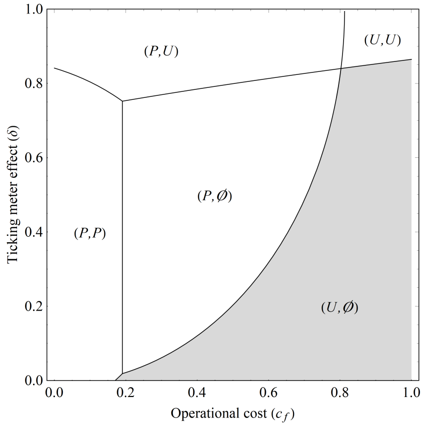


Figure 2.4: The win-win strategy in the single-product case

2.4.2.3 Consumer Surplus

We measure the welfare implications of pricing policies through the lens of consumer surplus. Given the utility functions presented in Equations (2.2) and (2.1), the consumer surplus can be calculated as follows:

$$CS(U,U) = \gamma U_H^{U*} + (1-\gamma)U_L^{U*} \tag{2.4}$$
$$CS(P,P) = \gamma U_H^{P*} + (1-\gamma)U_L^{P*} \tag{2.5}$$
$$CS(P,U) = \gamma U_H^{P*} + (1-\gamma)U_L^{U*} \tag{2.6}$$

The following proposition characterizes the best policies in terms of consumer surplus.

Proposition 7. *In terms of consumer surplus:*

(i) the (U,U) policy results in exactly the same consumer surplus as (P,U). The same holds for $(U,\varnothing)$ and $(P,\varnothing)$.

(ii) the (P,P) policy is always the best policy in terms of consumer surplus.

What makes exclusion and non-exclusion policies different in terms of consumer surplus is that exclusion policies can extract all the surplus. When a policy excludes low usage-valuation users, only one type of consumer receives the service. This allows the SP to know exactly what type of consumer it is facing. In non-exclusion policies, the SP extracts the full surplus of the low usage-valuation consumers, but at least part of the surplus of the high usage-valuation customers. Therefore, the consumers receive a higher surplus under non-exclusion policies regardless of the type of scheme they choose. Furthermore, although consumers use more under a pay-per-period scheme, the surplus they receive does not exceed pay-per-use surplus. True, customers are using more under pay-per-period, but they are also being charged more relative to their higher usage level.

A (P, P) policy generates the highest consumer surplus. It is because in this case both consumer segments are offered the same subscription fee. Thus a high usage valuation customer can enjoy the low price that is offered to attract a low usage-valuation consumer.

Corollary 2.4.0.4. *There is no win-win-win strategy.*

Per result of Corollary 2.4.0.4 , neither pay-per-use nor pay-per-period will optimize all three criteria of profit, environmental impact, and consumer surplus. That is because the $(U, \varnothing)$ policy always minimizes the environmental impact whereas it is the (P, P) policy that always maximizes the consumer surplus.

2.5 Product Line: Green and Regular Products

The base model assumed that the SP offers only one product. However, companies may offer multiple products in a servicizing business model. For example, Bundles offers two types of dryers and two types of dishwashers (Bundles, 2020); Swapfiets offers more than two bike types (Reid, 2020). These products may vary in several aspects to cater to different customer needs. In this section, we analyze a case where the product line consists of one regular and green product. The green product performs better in terms of environmental impact not only during the use phase, but also during the production and disposal phases. Superior environmental performance during the use phase is captured by product energy efficiency. For example, dryers offered by Bundles are different in their energy efficiency labels (Bundles, 2020). The greener the product, the less costly it is for customers given a similar per use price. The green product also incurs less energy cost during the usage phase, thus favoring more usage. A greener product also satisfies the environmental utility of consumers.

2.5.1 Consumers' and SP's problem

We assume two market segments based on how consumers value the greenness of the product. *Green* consumers, denoted by G, receive extra utility, μ, by choosing the greener product. This aligns with studies observing a considerable group of customers in the market who value green products more than regular ones and are willing to pay extra for them (Accenture, 2019; Toluna, 2019; Souza, 2013). However, regular customers, indicated by R, are indifferent between a regular and green product, i.e., $\mu = 0$ for them. We also assume that green customers form λ portion of the customers in the market with the rest, $1-\lambda$, being regular customers [3].

The SP must now choose the greenness level, g, of the green product in addition to the pricing. Note that the greenness level here primarily comprises product energy efficiency. It also conveys how production and disposal phases of the green product have proved environmentally friendly. Offering a green product can also incur purchasing costs for the SP. This cost is assumed convex in greenness level, $c_p g^2$. Similar cost structure for dual product options has appeared in prior work (See e.g., Bellos et al. (2017), Murali et al. (2019), and Chen (2001)).

The SP can now offer several combinations of schemes and products to customers since each product type can be offered through two pricing options. However, we observe that real-world companies apply only one scheme per product type. For example, Bundles offers two types of dishwashers and dryers where each type charges only one pricing scheme (EMF, 2019). In addition, offering multiple combinations of product types and pricing schemes can lead to consumer's confusion because of information overload, which can eventually result in poor decision making (See (Malhotra, 1982)). Therefore, in this section, we consider cases only where the SP offers one pricing scheme per product type. This ensures a simple presentation of results but the analysis can be easily extended to cases where two schemes are offered per product type. Some instances of this problem where four segments are allocated to different product-scheme types are presented in the Appendix.

Here, the pricing policy of the SP is represented by $((H^G, L^G), (H^R, L^R))$ for the menu of contracts offered to the green and regular segments, respectively. The SP excludes low usage-valuation customers and offers either pay-per-use for both products to the high usage-valuation segment, i.e., $((U, \varnothing), (U, \varnothing))$, pay-per-period for both products, i.e., $((P, \varnothing), (P, \varnothing))$ policy, or a hybrid policy, i.e., either $((P, \varnothing), (U, \varnothing))$ or $((U, \varnothing), (P, \varnothing))$. We will compare these policies with the exclusion policies from the baseline model, i.e., $(U, \varnothing)$ and $(P, \varnothing)$ whose characteristics were summarized in Proposition 4.

Note that since we have excluded low usage-valuation customers, the remaining market can be divided into green and regular customers. Thus, the index i formerly used to show usage-valuation now denotes greenness of customers, i.e., $i \in \{G, R\}$. Now, utility functions for the green segment need reformulation to reflect new assumptions. $U_G^U = \int_0^\tau((\upsilon_i - p_i - \delta + g)\theta_i - F_i - \alpha t\theta_i^2 + \mu g)dt$ is the green consumer utility in a pay-per-use scheme, and $U_G^P = \int_0^\tau((\upsilon_i + g)\theta_i - S_i - \alpha t\theta_i^2 + \mu g)dt$ captures green consumer utility in a pay-per-period scheme. There are two differences between these and the base model utility functions, i.e., Equations (2.1) and (2.2). Since g mainly reflects the energy efficiency of the green product, its customers will save an amount of g per use. In total, each customer receives $g\theta_i$ cost

[3] There are thus four segments of customers in the market based on their usage utility υ_i and green utility μ. However, we exclude low usage-valuation customers to isolate just two segments of green versus regular customers in the market.

savings using the green product. Green customers also receive extra environmental utility using the green product, increasing in g and formulated as μg.

These new assumptions yield optimal usage levels different from the single-product case for high usage-valuation consumers. Now, we have optimal usage levels of $\theta_G^* = \frac{\upsilon_H - \delta - p_i + g}{\alpha}$ for the pay-per-use and $\theta_G^* = \frac{\upsilon_H + g}{\alpha}$ for the pay-per-period schemes. Given the optimal usage level of the customers, the following model formulates the SP's problem when offering the pay-per-use scheme for two products that differ in terms of greenness:

$$\max_{p_i, F_i, g, i \in \{G,R\}} \quad \pi^E_{((U,\varnothing),(U,\varnothing))} = \gamma\lambda[p_G\theta_G + F_G - c_f\frac{\theta_G^2}{2} - c_m - c_p g^2] + \gamma(1-\lambda)[p_R\theta_R + F_R - c_f\frac{\theta_R^2}{2} - c_m] \qquad \textbf{(P.6)}$$

s.t.

$$IR_G : (\upsilon_H - p_G - \delta + g)\theta_G - F_G - \alpha\frac{\theta_G^2}{2} + \mu g \geq 0$$
$$IR_R : (\upsilon_H - p_R - \delta)\theta_R - F_R - \alpha\frac{\theta_R^2}{2} \geq 0$$
$$IC_G : (\upsilon_H - p_G - \delta + g)\theta_G - F_G - \alpha\frac{\theta_G^2}{2} + \mu g \geq (\upsilon_H - p_R - \delta)\theta'_R - F_R - \alpha\frac{\theta'_R 2}{2}$$
$$IC_R : (\upsilon_H - p_R - \delta)\theta_R - F_R - \alpha\frac{\theta_R^2}{2} \geq (\upsilon_H - p_G - \delta + g)\theta'_G - F_G - \alpha\frac{\theta'^2_G}{2}$$

Interested readers can find the SP's problem for other policies as well as the characterization of equilibrium prices in the Appendix. For sake of brevity, we present only the comparison between green versus regular policies. To evaluate this model comprehensively from the perspective of the triple bottom lines of profit, environment and welfare, we redefine the environmental impact to fit this situation. In the single-product base case, the impact during the production and disposal phases did not play a role being the same for all policies. Here, we assume that regular versus green products differ in their production and disposal phases of environmental impact. Still, the model can be easily adjusted where this is not the case. We define the environmental impact as follows:

$$EI = \gamma\lambda(e_u\theta_G^2 + e_{pd}(1-g)) + \gamma(1-\lambda)(e_u\theta_R^2 + e_{pd}) \qquad (2.7)$$

In the following section, different policies are compared with respect to the triple bottom lines.

2.5.2 Comparing policies

In this part, we specify under which conditions either a pay-per-use or a pay-per-period scheme is optimal. Additionally, we show when it is optimal to offer a product line instead of a single product. The following Lemma characterises the equilibrium, and specifies which policies are never optimal when offering a product line.

Here, we specify the conditions where either a pay-per-use or pay-per-period scheme is optimal. We also show when it is optimal to offer a product line beyond the single product case. Lemma 2 characterizes the equilibrium and specifies which policies are suboptimal under product line offers.

Lemma 2. *In case of a product line with a green product:*

(i) The $((P,\varnothing),(P,\varnothing))$ *policy dominates* $(P,\varnothing)$*.*

(ii) Hybrid policies, i.e., $((P,\varnothing),(U,\varnothing))$ *and* $((U,\varnothing),(P,\varnothing))$*, are never optimal.*

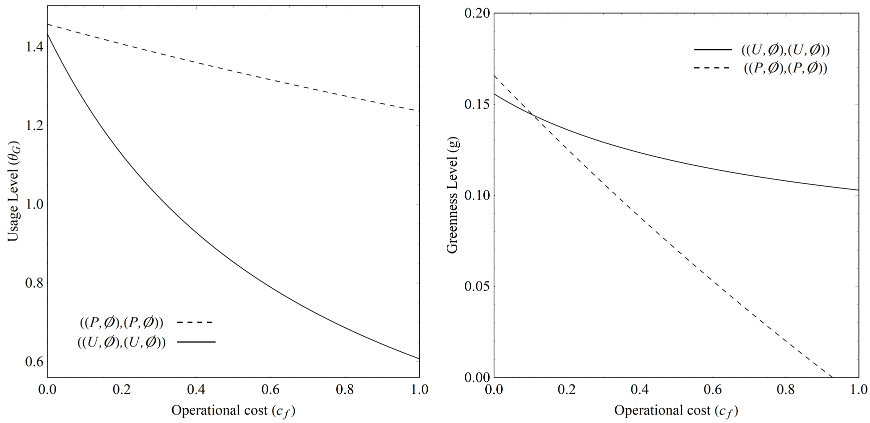
(iii) The optimal greenness levels are $g^*_{((U,\varnothing),(U,\varnothing))} = \frac{\alpha^2(1-\delta)+\alpha^2(\alpha-c_f)}{-\alpha^2+2c_p(\alpha+c_f)}$ *and* $g^*_{((P,\varnothing),(P,\varnothing))} = \frac{\upsilon_H(\alpha-c_f)+\alpha^2\mu}{2c_p\alpha^2-(\alpha-c_f)}$.

Per Lemma 2, the single-product policy $(P,\varnothing)$ is always dominated by $((P,\varnothing),(P,\varnothing))$ since offering a green product allows the SP to influence consumer usage apart from the single product. This is achieved by means of setting greenness level, g, to attain better control over usage and thus improve profit. This improvement is shown to cover the additional cost of offering a green product in this case. Being capable of reducing usage, $((P,\varnothing),(P,\varnothing))$ always dominates single-product $(P,\varnothing)$.

A departure from the single-product model is that hybrid policies are no longer optimal. Essentially, a hybrid policy here is an average mix of two pure policies, which would be dominated by either of the two pure policies (See Proposition 8 for explanation).

As previously mentioned, beyond the single-product case, the green product enables the SP to influence customer usage by means of the greenness level, even under a pay-per-period scheme. Figure 2.5a shows that the SP can reduce usage level in both pay-per-period (dashed line) and pay-per-use (solid line) policies as operational costs increase. Figure 2.5b depicts the greenness level as a function of operational cost. At low cost, we observe greenness level set higher in the pay-per-period policy before dropping below the pay-per-use policy g-level as operational cost exceeds a certain level. Although greenness level is the only tool the SP has to control usage in pay-per-period, a pay-per-use policy also features the per-use fee that exploits the high ticking meter effect to reduce usage and incurred operational cost. Another reason why the SP decreases greenness more sharply in the pay-per-period policy is that higher usage increases only its cost while more use boosts both revenue and cost in case of pay-per-use. Therefore, the SP is better off reducing usage more in the pay-per-period policy.

Next, Proposition 8 summarizes results based on both profitability and environmental impact.



(a) Usage levels **(b)** Greenness Levels

Figure 2.5: Optimal usage and greenness levels

Proposition 8. *There exists unique* $\bar{c}_f^E$ *such that:*

(a) ***Profitability:***

- *If* $c_f \leq \bar{c}_f^E$*:*

  (i) $((U,\varnothing),(U,\varnothing))$ *policy is optimal if and only if* $\delta \leq \hat{\delta}$*,*

  (ii) $((P,\varnothing),(P,\varnothing))$ *policy is optimal if and if* $\delta \geq \hat{\delta}$*.*

- *If* $c_f \geq \bar{c}_f^E$*:*

  (i) $((U,\varnothing),(U,\varnothing))$ *policy is optimal if and only if* $\delta \leq \underline{\delta}$*.*

  (ii) $(U,\varnothing)$ *policy is optimal if and if* $\underline{\delta} \leq \delta \leq \bar{\delta}$*.*

  (iii) $((P,\varnothing),(P,\varnothing))$ *policy is optimal if and if* $\delta \geq \bar{\delta}$*.*

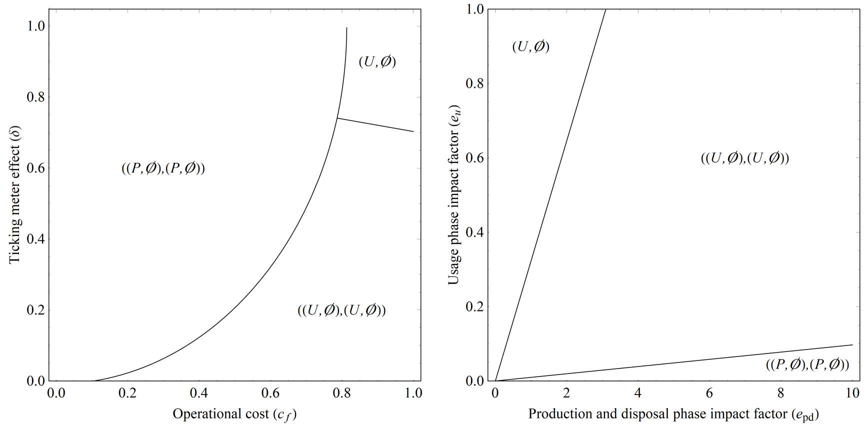
(b) ***Environmental Impact:***

(i) $((P,\varnothing),(P,\varnothing))$ *policy is the most environmental friendly policy if and only if* $e_u \leq \underline{e}_u$*.*

(ii) $((U,\varnothing),(U,\varnothing))$ *policy is the most environmental friendly policy if and only if* $\underline{e}_u \leq e_u \leq \bar{e}_u$*.*

(iii) $(U,\varnothing)$ *policy is the most environmental friendly policy if and only if* $e_u \geq \bar{e}_u$*.*

Proposition 8 is an analytical guide for the SP on how to choose the optimal policy under different conditions. As concluded in the single-product case, a higher operational cost under green-regular option also makes a pay-per-use policy more profitable (See Figure 2.6a).



(a) Profitability **(b)** Environmental impact

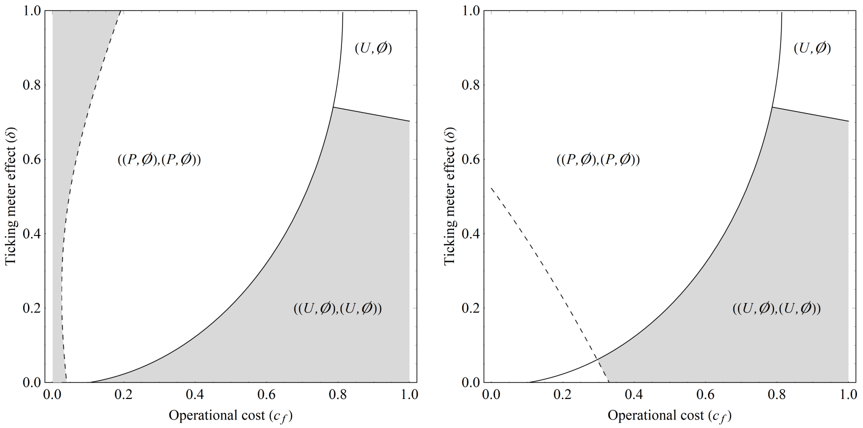
Figure 2.6: Optimal policy in terms of profit and environmental impact

Comparing Figure 2.6a and Figure 2.2a shows a similar segmentation between pay-per-period and pay-per-use policies. Where operational cost, c_f, is sufficiently high with lower levels of the ticking meter effect, δ, $((U, \varnothing), (U, \varnothing))$ offering the green option proves optimal. For relatively higher values of the ticking meter effect and operational cost, i.e., the top-right corner of the graph, $(U, \varnothing)$ single product-only becomes optimal. Offering a green product gives the SP another tool beyond the per-use fee to reduce usage where lower usage proves more profitable. Recall that the ticking meter effect also discourages use. Here, a sufficiently high ticking meter effect may overshadow the impact of greenness on usage reduction. Given the extra cost the SP incurs to offer a green product, high levels of the ticking meter effect limit the benefits of offering a green product that cannot cover its costs. Here, the SP offers only the regular product to both segments.

Figure 2.6b portrays how the profit-maximizing policies perform in terms of environmental impact based on the usage-phase, e_u, versus production-and-disposal-phase impact factor, e_{pd}. Three policies considered here perform differently in the usage versus production and disposal phases. $(U, \varnothing)$ restricts usage most effectively. However, since it offers no green product, it performs worst in the production-disposal phase. $((U, \varnothing), (U, \varnothing))$ performs moderately in limiting the usage level via per-use pricing merged with the ticking meter effect while it increases usage by offering a greener product to the high usage-valuation segment. Nevertheless, this policy yields higher performance in reducing production-disposal phase impact under the more efficient product it offers. Finally, $((P, \varnothing), (P, \varnothing))$ improves performance as does $((U, \varnothing), (U, \varnothing))$ in the production and disposal phase. However, pay-per-period also induces the highest usage level, which is also amplified by greenness. This emerges as the worst policy in terms of usage-phase environmental impact. Therefore, this policy is environmentally superior only where the usage impact factor is ultra-low.

2.5.3 Win-Win Strategies

Now, we explore policies where profitability is maximized with minimal environmental impact.



(a) Win-win strategy when $\frac{e_{pd}}{e_u}$ is large **(b)** Win-win strategy when $\frac{e_{pd}}{e_u}$ is small

Figure 2.7: Win-win strategies for a product line

A combination of Figure 2.6a and Figure 2.6b reveals win-win policies in this case. As seen in Figure 2.6b, environmental superiority depends strongly on the ratio of the production-disposal phase impact, e_{pd}, to that from the usage phase, e_u, i.e., $\frac{e_{pd}}{e_u}$. We present two situations: where the $\frac{e_{pd}}{e_u}$ ratio is large versus small. Figure 2.7a and Figure 2.7b shade the win-win strategies.

For large $\frac{e_p d}{e_u}$ as seen in Figure 2.7a, $((P, \varnothing), (P, \varnothing))$ might be environmentally superior. Although a pay-per-period policy always incurs a higher usage level and consequent higher use-phase environmental impact versus pay-per-use, $((P, \varnothing), (P, \varnothing))$ can reduce the impact in the production and disposal phases by offering a product with an elevated greenness level, g, as depicted in Figure 2.5. Here, this production and disposal impact reduction is sufficient to offset the increase in use-phase environmental impact. The shaded area in Figure 2.7a shows that this can happen when operational cost is sufficiently low. Interestingly, environmental superiority prevails in the same region where $((P, \varnothing), (P, \varnothing))$ is also most profitable. Therefore, when operational cost is sufficiently low, the win-win strategy is to offer a pay-per-period policy. However, when operational cost rises, the pay-per-use policy proves environmentally superior as it curbs usage more efficiently than the pay-per-period policy, thus reducing overall environmental impact. An alternative win-win strategy at higher operational cost and lower levels of the ticking meter effect is $((U, \varnothing), (U, \varnothing))$ where the shaded area on the right of Figure 2.7a represents this policy.

A second situation in Figure 2.7b, shows where $\frac{e_p d}{e_u}$ is small and both $((U, \varnothing), (U, \varnothing))$ and $(U, \varnothing)$ can minimize the total environmental impact. The difference in these two policies lies in the type of product offer. $((U, \varnothing), (U, \varnothing))$ will always outperform environmentally in the production and disposal phases since it offers a superior product to green customers. However, this policy does not necessarily perform better in terms of usage-phase impact. More specifically, sufficiently low ticking meter effect and operational costs allow $((U, \varnothing), (U, \varnothing))$ to offer a highly green product (See Figure 2.5b). This drives excessive usage behavior and its consequent rise in usage-phase environmental impact. Here, green pay-per-use consumption may offset the accrued advantage in production-disposal phase environmental impact, leading to $(U, \varnothing)$ environmental superiority. However, we observe that $(U, \varnothing)$ cannot lead to a win-win situation when c_f and δ are sufficiently low as it underperforms in profitability. Still, a $((U, \varnothing), (U, \varnothing))$ policy creates a win-win in almost the same $c_f - \delta$ area highlighted in the first situation.

Our third bottom line concerns consumer welfare. As mentioned before, the SP is able to extract all consumer surplus when it offers multiple products. This also holds for $(U, \varnothing)$ and $(P, \varnothing)$ policies since they deal with only one type of consumer. Here, the choice of pricing policy does not influence the consumer surplus, thus elevating a win-win strategy into a win-win-win strategy.

2.6 Other Cases

2.6.1 Increasing consumers' environmental awareness

In all models presented so far, we assumed the market has a fixed segmentation. In other words, the SP's decisions do not change the size of the segments, including green and non-green consumers. However, sustainability is at the core of servicizing business models. Therefore, SPs may be able to increase consumer awareness on environmental advantages of these models, through for example advertising campaigns. Increased environmental awareness may lead to an increased size of the green consumer segment. Motivated by this, we present a model in which λ is a decision of the SP. The SP can initiate an environmental awareness campaign, incurring a cost of $c_g \lambda^2$, to set the green segment of consumers in the market. In this case, we can show the following results when we have a product line including green and regular products:

Proposition 9. *There are unique optimal green segment sizes for* $((U,\varnothing),(U,\varnothing))$ *and* $((P,\varnothing),(P,\varnothing))$ *schemes expressed, respectively, as* $\lambda^*_{((U,\varnothing),(U,\varnothing))} = \frac{\gamma}{2c_g}[p^*_G\theta^*_G + F^*_G - c_f\frac{(\theta^*_G)^2}{2} - c_p g^{*2} - p^*_R\theta^*_R - F^*_R + c_f\frac{(\theta^*_R)^2}{2}]$ *and* $\lambda^*_{((P,\varnothing),(P,\varnothing))} = \frac{\gamma(\mu\alpha^2+\alpha v_H - c_f v_H)^2}{4\alpha^2 c_g(-\alpha+2\alpha^2 c_p + c_f)}$*. Additionally, both are increasing in* μ *and decreasing in* c_p*.*

Proposition 9 shows that, as intuition dictates, the more consumers are willing to pay for a green product the higher the SP should set λ. A higher μ allows the SP to charge a higher price for the green product offsetting the additional cost of increasing the green segment size. However, if the cost of producing green product, c_p increases, the SP should lower λ.

2.6.2 Two-dimensional greenness

In Section 2.5, greenness, denoted by g, was defined as energy efficiency and was only considered in the usage phase. However, a product's greenness is not only determined by its environmental impact in the use phase, but also by impacts in the production phase, e.g., by the use of materials and components, and decisions at the disposal phase. A main benefit of servicizing is that the SP retains the ownership of the product. Thus, an SP has a strong incentive to implement a closed-loop supply chain and to enable product remanufacturing. This incentivizes the SP to design a green product which reduces the environmental impact at the disposal phase.

In this section, we extend the results of Section 2.5 to a case where a product is considered green in two dimensions, namely i) the usage phase, and ii) the production/disposal phase. Greenness in the production/disposal phase encompasses design features of a product. Examples of these features are modular and durable designs and products that are easily repairable or recyclable. For example, a company like Bundles, features products that are more durable and easily repair-able to extend the life cycle of products (Arriola, 2019; Nahar, 2019). Extended durability is achieved through, for example, replacing wearable plastic parts with metal ones. Xerox also follows this strategy (de Kwant, 2021). Xerox uses a modular product architecture to improve repairability, allowing product remanufacturing (King et al., 2007; Bacon, 2013). Such design changes enable the company to reduce the environmental footprint in the production and disposal phase by extending the product life cycle through repair and remanufacturing. Gerrard Street, as another example, offers modular headphones through a subscription-based scheme. This product modularity makes repair and remanufacturing more cost efficient, and extends the product lifecycle. (EMF, 2018d).

Denote variables g_1 and g_2 as use and production/disposal greenness, respectively. Then, the profit function of the SP in case of a $((U,\varnothing),(U,\varnothing))$ can be formulated as follows:

$$\max_{p_i,F_i,g_1,g_2,i\in\{G,R\}} \quad \pi^E_{((U,\varnothing),(U,\varnothing))} = \gamma\lambda[p_G\theta_G + F_G - (1-g_2)c_f\frac{\theta_G^2}{2} - c_m - c_p^u {g_1}^2 - c_p^p {g_2}^2] + \gamma(1-\lambda)[p_R\theta_R + F_R - c_f\frac{\theta_R^2}{2} - c_m] \tag{P.7}$$

Repairability not only reduces the environmental impact but it may also bring additional benefits through reducing operational costs. If a product is modular or easily repairable it can make the repair process more cost efficient. To capture this aspect, we assume that a green product is designed such that the operational cost of the SP reduces with a factor $(1-g_2)$. Designing a product that is green in the production and disposal phase requires investment. This cost is formulated as $c_p^p {g_2}^2$.

For the green segment of the market, the consumer's utility function of using a green product becomes $U_G^U = \int_0^\tau ((v_i - p_i - \delta + g_1)\theta_i - F_i - \alpha t\theta_i^2 + \mu(g_1+g_2))dt$, if a pay-per-use scheme is offered, and $U_G^P = \int_0^\tau ((v_i + g_1)\theta_i - S_i - \alpha t\theta_i^2 + \mu(g_1+g_2))dt$ in case of a pay-per-period scheme.

The following proposition compares the results of the one-dimensional greenness, as developed in Section 2.5, with two-dimensional greenness.

Proposition 10. *Comparing the one-dimensional and two-dimensional greenness cases, we have the following:*

(a) ***In case of a*** $((U,\varnothing),(U,\varnothing))$ ***policy:***

- *The SP charges a lower per-use fee in case of two-dimensional greenness.*
- *The SP chooses a higher flat rate in case of two-dimensional greenness.*
- *The SP chooses a higher usage-phase greenness in case of two-dimensional greenness.*
- *The prices charged for the regular customers remain the same in both cases.*

(b) ***In case of a*** $((P,\varnothing),(P,\varnothing))$ ***policy:***

- *The SP chooses a higher usage-phase greenness in case of two-dimensional greenness.*
- *The SP charges a higher pay-per-period fee in case of two-dimensional greenness.*
- *The pay-per-period fee charged for the regular customers remains the same in both cases.*

(c) *Servicizing a product that is green in both dimensions improves the SP's profit and environmental impact compared to a product that is green in only usage phase when the environmental impact is only experienced during the usage.*

Proposition 10 shows that in a $((U, \varnothing), (U, \varnothing))$ scheme the SP charges a lower per-use fee when the product is considered green in both usage and production/disposal phases. This is because, thanks to the design of product, the operational cost is reduced allowing the SP to lower the price such that consumers can enjoy more frequent usage. The SP increases the usage phase greenness, i.e., energy efficiency, to stimulate a higher usage, which is now less costly for the SP. Setting the production/disposal greenness, g_2, the SP has to incur an additional cost $c_p^p g_2^2$. To compensate this cost, the SP sets a higher flat fee compared to one-dimensional greenness case. We can explain the results for a $((P, \varnothing), (P, \varnothing))$ scheme in a similar fashion.

2.7 Concluding Remarks

This study addresses the problem of designing a pricing policy for a service provider (SP) using a servicizing business model. The SP offers a single product-service through either a pay-per-use or pay-per-period scheme to two customer segments: high and low usage-valuation users. The challenge for the SP is which of these schemes to offer and at what price. Our analysis reveals that the optimal profit policy depends mainly on the SP's cost structure and consumer characteristics.

The pricing policy exerts significant impact on both the SP's revenue and operational costs related to providing the service. In contrast to a pay-per-period scheme, a pay-per-use pricing can regulate and lower the customer usage level. We show that a pay-per-period policy leads to a higher usage level. Therefore, when the SP's operational costs are relatively high because of, for example, the small scale of its operations, SPs should try to constrain customer usage. A pay-per-use pricing scheme discourages usage through the so-called 'ticking meter' effect and the per-use fee.

If operational costs are sufficiently high, when the ticking meter effect is high, the SP no longer needs to reduce the customer usage level since it will already be low, and the SP may offer the pay-per-period scheme. Low usage decreases the operational cost of the SP and its per-use revenue, but the fixed-fee revenue remains. Thus, a lower usage increases the profit sufficiently such that the SP can offer a scheme to both segments. Offering service to two customer segments requires paying an information rent to reveal the true high usage-valuation customer type. In this case, the SP covers the information rent with the extra profit from serving the low-usage valuation customers. At sufficiently low levels of the operational cost, however, exclusion is no longer optimal. In this case, the SP always offers a pay-per-period scheme to the high usage-valuation segment, but the SP should decide whether to offer a pay-per-use or a pay-per-period scheme to the low usage-valuation customers. Our results show that offering a pay-per-use scheme to the low segment is optimal when the ticking meter effect is sufficiently high.

The size of the high-end customer segment also shapes the schemes offered. A higher fraction of high usage-valuation customers motivates the SP to offer the service exclusively to these customers. The reason is that when low usage-valuation customers do not form a considerable market fraction, the profit they generate is too small to offset the information rent the SP pays to identify the high usage-valuation customers. Thus, the SP simply excludes the low usage-valuation customers. When offering a pay-per-period scheme to the high usage-valuation customers, the choice of the scheme to offer to the low usage-valuation segment also depends on the size of the high usage-valuation segment in the market. If the high usage-valuation segment size is sufficiently small, it is optimal to offer a pay-per-period scheme to the low usage-valuation customers as well.

The choice of pricing scheme impacts customer use level and therefore the environmental impact. Given a profit-maximizing SP, there appears to be only one dominant strategy: offering a pay-per-use scheme only to high usage-valuation customers. This always incurs the least environmental impact. Moreover, SPs with sufficiently high operational costs can realize a win-win strategy when offering a pay-per-use option to high usage-valuation customers if they form a sufficiently large majority of the market. Additionally, offering a pay-per-period scheme to all customers always maximizes the consumer surplus. This implies that when offering a single product, there is no win-win-win strategy possible meeting the triple bottom line objectives of "profit-planet-people."

If the SP begins offering "green" customers an alternative eco-friendly version of its product, this will cause a higher usage level by discounting usage costs in the user mindset. Here, results mirror the single-product case where pay-per-use policies are optimal at higher levels of operational cost. However, offering a single product through a pay-per-period scheme no longer proves optimal. Moreover, offering a single product through a pay-per-use scheme is optimal only when the ticking meter effect is sufficiently high.

When offering two products, though, no single dominant policy exists for profit-maximizing SPs. In this case, even the pay-per-period policy might generate the least environmental impact when this impact is extremely low during the usage phase. Finally, consumer welfare does not depend on the pricing policy when offering a product line.

The SP may be able to influence the segment sizes, by raising environmental awareness among the consumers when offering a product line with green and regular products. For this situation, we show the optimal size of the green segment is increasing in the greenness valuation of the consumers and decreasing in the cost of raising awareness. Also, if we assume two different dimensions for greenness, one concerning the usage phase, e.g., energy efficiency, and the other one concerning the production/disposal phase, e.g., product modularity, the SP would charge a lower per-use fee and a higher flat fee compared to the case with one-dimensional greenness. The SP will also increase the usage-phase greenness to allow a higher usage, which is less costly thanks to the production/disposal phase greenness.

Our study can be used to explain the pricing behavior of SP companies as well as to indicate which policies they should apply to maximize profit, consumer welfare, and environmental benefits. Our models may explain recent changes in the pricing policy of Bundles (SP of washing machines). Bundles formerly offered a hybrid menu of contracts for its best-selling washing machine before it recently abandoned the pay-per-period scheme. It now offers only pay-per-use (Bundles, 2020). Based on our results, such a move may be explained as a result of simultaneous rises in operational costs and the size of high usage-valuation consumer segment in the market. Bundles is a start-up that may well have underestimated its cost of supporting the product in the user's home. Also, it may have learned over time to segment the consumer market. Finally, the ticking meter effect may have also played a role, likely being lower than what the company expected.

There are several further OM related research opportunities in the servicizing industry. In addition to the pricing, the contract between the SP and the customers includes termination clauses and conditions. Some companies offer lenient cancellation terms (EMF, 2018d) to avoid keeping customers captive whereas other companies may offer a waiver or discount the deposit in turn for a minimum length of contracts (Bundles, 2020; Reid, 2020). These may have implications for consumer purchase behaviour as well as the revenue of companies. It seems relevant to explore the suitability of cancellation mechanisms depending on the product, consumer and company characteristics.

Additionally, many of these companies have limited capacity (inventory) of products offered to consumers because of the large investment required. This may require dynamic pricing and capacity(inventory) decisions to respond to evolving consumer demand behaviours (Özdemir-Akyıldırım et al., 2014). More specifically, SPs have to decide how to allocate the limited capacity to different consumer segments and how to update the price to match the demand and supply more effectively. This becomes more relevant and interesting in a multi-period setting where capacity/inventory decisions at one period have operational implications for the subsequent periods. To follow a circular economy approach, SPs also often offer refurbished products (see for example (Bundles, 2021)). This is another dimension of dynamic capacity that should be decided jointly with the pricing decisions of services considering the possible impact they have on consumer behaviour.

Furthermore, with growing number of servicizing companies, another interesting extension of the current model is taking competition into account. It would require a different modelling framework such that the market shares depend on the prices offered by service providers. Competition models could generate valuable insights on how optimal pricing schemes should change under competition and what are the consequent impacts of competition on the triple bottom-line of people, planet and profit.

2.8 Appendix

2.8.1 Appendix A

Proof. **Proof of Proposition 1**. Consider the problem (**P.1**). First, we have to substitute optimal values of θ_i in the problem. Doing so, we can rewrite the problem as follows:

$$\max_{p_L,p_H,F_L,F_H} \pi_{(U,U)} = \gamma[p_H \frac{\upsilon_H - p_H - \delta}{\alpha} + F_H - c_f \frac{(\upsilon_H - p_H - \delta)^2}{2\alpha^2}] + \\ (1-\gamma)[p_L \frac{\upsilon_L - p_L - \delta}{\alpha} + F_L - c_f \frac{(\upsilon_L - p_L - \delta)^2}{2\alpha^2}] - c_m \quad (2.8)$$

$$\textbf{S.t.} \quad (2.9)$$

$$(IR_H): \frac{(\upsilon_H - p_H - \delta)^2}{2\alpha} - F_H \geq 0 \quad (2.10)$$

$$(IR_L): \frac{(\upsilon_L - p_L - \delta)^2}{2\alpha} - F_L \geq 0 \quad (2.11)$$

$$(IC_H): \frac{(\upsilon_H - p_H - \delta)^2}{2\alpha} - F_H \geq (\frac{(\upsilon_H - p_L - \delta)^2}{2\alpha} - F_L \quad (2.12)$$

$$(IC_L): \frac{(\upsilon_L - p_L - \delta)^2}{2\alpha} - F_L \geq \frac{(\upsilon_L - p_H - \delta)^2}{2\alpha} - F_H \quad (2.13)$$

As can be seen the objective function is strictly increasing in F_i since $F_i \geq 0$. Therefore, the optimal values of F_is are smallest upper limits of them according to the constraints. We have from (2.12) that $\frac{(\upsilon_H - p_H - \delta)^2}{2\alpha} - F_H \geq (\frac{(\upsilon_H - p_L - \delta)^2}{2\alpha} - F_L$. Also, since $\upsilon_h > \upsilon_L$ by definition, we can write $\frac{(\upsilon_H - p_L - \delta)^2}{2\alpha} - F_L \geq \frac{(\upsilon_L - p_L - \delta)^2}{2\alpha} - F_L \geq 0$, where the last inequality comes from (2.11). Thus, we conclude that $\frac{(\upsilon_H - p_H - \delta)^2}{2\alpha} - F_H > 0$, which means Constraint (2.10) would become slack in optimal, therefore we can ignore it. Now, we claim that Constraint (2.11) is binding. If it is not biding in optimal, the SP can increase his profit through increasing both F_H and F_L without violating any constraints given we have them in both sides of (2.12)-(2.13). Therefore, it is a contradiction, thus we claim (2.11) is binding. Now we can claim $F_L^{(U,U)*} = \frac{(\upsilon_L - p_L^* - \delta)^2}{2\alpha}$.

For now, we ignore Constraint (2.13), then we will show in optimal that it is slack. Now, there is only one upper limit for F_H left which comes from Equation (2.12), or IC_H. Given we have already proved the IR_H is slack, we conclude that $F_H^{(U,U)*} = \frac{(\upsilon_H - p_H^* - \delta)^2}{2\alpha} - \frac{(\upsilon_H - p_L^* - \delta)^2 - (\upsilon_L - p_L^* - \delta)^2}{2\alpha}$.

Now, If we replace the F_H^* and F_L^* to Equation (2.13), with some algebra we will end up to the following feasibility condition: $(p_L - p_H)(\upsilon_H - \upsilon_L) \geq 0$. This boils down more to $p_H \leq p_L$, which is easy to show that it is equal to $F_H \geq F_L$. We will see in optimal this condition holds.

Now, to find the optimal values of p_i, we need to check first and second order derivatives of the objective function. Substituting F_i^*, we can easily derive the optimal values of p_is using FOC, as follows: $p_H^{(U,U)*} = \frac{c_f(\upsilon_H-\delta)}{\alpha+c_f}$ and $p_L^{(U,U)*} = \frac{c_f(\upsilon_L-\delta)}{\alpha+c_f} + \alpha\frac{\gamma(\upsilon_H-\upsilon_L)}{(1-\gamma)(\alpha+c_f)}$. A negative second-order derivative suffices to show that these numbers are optimal. We have $\frac{\partial^2\pi(U,U)}{\partial p_H^2} = \frac{-\gamma(\alpha+c_f)}{\alpha^2} < 0$ and $\frac{\partial^2\pi(U,U)}{\partial p_L^2} = \frac{-(1-\gamma)(\alpha+c_f)}{\alpha^2} < 0$, given $\alpha > 0$, $c_f > 0$, and $0 < \gamma < 1$.

Now, we only have to show that Constraint (2.13) is slack in optimal. If we compare p_H^* and p_L^*, the only condition we need to have $p_H^{(U,U)*} < p_L^{(U,U)*}$ is $c_f < \frac{\alpha\gamma}{1-\gamma}$. Otherwise, the solution would be infeasible. Please note that the optimal usage levels of each segment is as follows: $\theta_H^{(U,U)*} = \frac{\upsilon_H-\delta}{\alpha+c_f} > 0$ and $\theta_L^{(U,U)*} = \frac{\upsilon_L-\gamma\upsilon_H-\delta(1-\gamma)}{(1-\gamma)(\alpha+c_f)}$. Obviously, θ_H^* is positive always, otherwise, p_H^* would be negative as well. However, we have to put a triviality conditions up front to avoid negative usage levels for the L-type customers (i.e., $\theta_L^* > 0$), which implies $\upsilon_L \geq \gamma\upsilon_H + \delta(1-\gamma)$.

□ □

Proof. **Proof of Proposition 2.** If we replace the optimal usage levels into Problem **P.2**, the SP's problem in this case is as follows:

$$\max_S \quad \pi_{(P,U)} = \gamma[S - c_f\frac{\upsilon_H^2}{2\alpha^2}] + (1-\gamma)[S - c_f\frac{\upsilon_L^2}{2\alpha^2}] \tag{2.14}$$

$$\textbf{S.t.} \tag{2.15}$$

$$(IR_H): \frac{\upsilon_H^2}{2\alpha} - S \geq 0 \tag{2.16}$$

$$(IR_L): \frac{\upsilon_H^2}{2\alpha} - S \geq 0 \tag{2.17}$$

This is straightforward to show that the objective is always increasing in terms of S. Thus, the smallest upper bound of S based on the constraints would be the optimal value. This upper bound is either $\frac{\upsilon_H^2}{2\alpha}$ or $\frac{\upsilon_L^2}{2\alpha}$. Since the later one is smaller, $S^* = \frac{\upsilon_L^2}{2\alpha}$. The results follow.

□ □

Proof. **Proof of Proposition 3.** First, we characterise the equilibrium for (P,U) policy and then, we will show that (U,P) doe not have any equilibrium. This will prove the first part of the proposition which says the SP has to assign the pay-per-period scheme to the high type and the pay-per-use to the low type.

(P,U) **policy.** The proof is similar to the proof for (U,U) policy. we can skip some steps of the proof. First, if we replace optimal usage values, θ_i from Lemma 1 to problem (**P.3**), we can rewrite the problem as follows:

$$\max_{p,F,S} \quad \pi_{(P,U)} = \gamma[S - c_f \frac{\upsilon_H^2}{2\alpha^2}] + (1-\gamma)[p\frac{\upsilon_L - p - \delta}{\alpha} + F - c_f \frac{(\upsilon_L - p - \delta)^2}{2\alpha^2} - c_m] \tag{2.18}$$

$$\textbf{S.t.} \tag{2.19}$$

$$(IR_H): \frac{\upsilon_H^2}{2\alpha} - S \geq 0 \tag{2.20}$$

$$(IR_L): \frac{(\upsilon_L - p - \delta)^2}{2\alpha} - F \geq 0 \tag{2.21}$$

$$(IC_H): \frac{\upsilon_H^2}{2\alpha} - S \geq \frac{(\upsilon_H - p - \delta)^2}{2\alpha} - F \tag{2.22}$$

$$(IC_L): \frac{(\upsilon_L - p - \delta)^2}{2\alpha} - F \geq \frac{\upsilon_L^2}{2\alpha} - S \tag{2.23}$$

Since the objective function is strictly increasing in F and S, to find the optimal values we have to find the upper bound for them. Similar reasoning to what mentioned in proof of (U, U) implies that IR_H is slack and IR_L is binding in optimal. Therefore, optimal value of F would be $F^{(P,U)*} = \frac{(\upsilon_L - p^* - \delta)^2}{2\alpha}$.

To find the optimal value of S, for now, we ignore IC_L, but we show later it will be slack in optimal. Therefore, the only upper bound for S would be IC_H. This implies that IC_H is binding and the optimal value of S is $S^{(P,U)*} = \frac{\upsilon_H^2}{2\alpha} - \frac{(\upsilon_H - p^* - \delta)^2 - (\upsilon_L - p^* - \delta)^2}{2\alpha}$.

To find the optimal solution, we have to show that the objective function is concave in p and then easily find the optimal value. The second order derivative of the objective is $\frac{\partial^2 \pi_{(P,U)}}{\partial p^2} = -\frac{(1-\gamma)(\alpha + c_f)}{\alpha^2}$, which is always negative since $0 < \gamma < 1$. To find the optimal value of p, we have to put the first-order derivative equal to zero. The first derivative of the objective function with respect to p is $\frac{\partial \pi_{(P,U)}}{\partial p} = \frac{-(1-\gamma)\delta c_f - (1-\gamma)\alpha p + (1-\gamma)c_f(\upsilon_L - p) + \alpha\gamma(\upsilon_H - \upsilon_L)}{\alpha^2}$. Putting this function to zero, we prove the optimal value of p is $p^{(P,U)*} = \frac{c_f(\upsilon_L - \delta)}{\alpha + c_f} + \alpha\frac{\gamma(\upsilon_H - \upsilon_L)}{(1-\gamma)(\alpha + c_f)}$.

Replacing F^*, S^*, and p^* into IC_L, we can rewrite it with some algebra as:

$$\frac{-2(\upsilon_H - \upsilon_L)\big(\alpha\delta(1-\gamma) + c_f\upsilon_L(1-\gamma) + \alpha\gamma((\upsilon_H - \upsilon_L))\big)}{\alpha^2(1-\gamma)(\alpha + c_f)} \leq 0$$

This condition always holds since we have $0 < \gamma < 1$ and $\upsilon_H > \upsilon_L$. Therefore, the optimal solution presented also satisfies IC_L.

Similar to the (U, U) policy, the only condition which makes sure that the usage level of the L-type is non-negative is $\upsilon_L > \gamma\upsilon_H + \delta(1-\gamma)$. $\square$

(U,P) **policy.** Now, we do the same process for (U,P). First, we have to rewrite the model after substituting the optimal usage values, as follows:

$$\max_{p,F,S} \quad \pi_{(U,P)} = \gamma[p\frac{\upsilon_H - p - \delta}{\alpha} + F - c_f\frac{(\upsilon_H - p - \delta)^2}{2\alpha^2} - c_m] + (1-\gamma)[S - c_f\frac{\upsilon_L^2}{2\alpha^2}] \tag{2.24}$$

$$\textbf{S.t.} \tag{2.25}$$

$$(IR_H): \frac{(\upsilon_H - p - \delta)^2}{2\alpha} - F \geq 0 \tag{2.26}$$

$$(IR_L): \frac{\upsilon_L^2}{2\alpha} - S \geq 0 \tag{2.27}$$

$$(IC_H): \frac{(\upsilon_H - p - \delta)^2}{2\alpha} - F \geq \frac{\upsilon_H^2}{2\alpha} - S \tag{2.28}$$

$$(IC_L): \frac{\upsilon_L^2}{2\alpha} - S \geq \frac{(\upsilon_L - p - \delta)^2}{2\alpha} - F \tag{2.29}$$

As described before, IR_L is always binding and IR_H is slack. Thus, we could imply that $S^{(U,P)^*} = \frac{\upsilon_L^2}{2\alpha}$. Similarly to the first part of the proof, as the objective is increasing in F, its optimal value would be its upper bound. As we have proved that IR_H is slack, the only upper bound available is IC_H. Therefore, we could easily calculate optimal flat fee for the low type as $F^{(U,P)^*} = \frac{(\upsilon_H - p - \delta)^2}{2\alpha} - \frac{\upsilon_H^2}{2\alpha} + \frac{\upsilon_L^2}{2\alpha}$.

Now, we also have to show that IC_H is slack in optimal. Substituting optimal value of F and S to IC_L, we have $\frac{(\upsilon_L - p - \delta)^2}{2\alpha} - \frac{(\upsilon_H - p - \delta)^2}{2\alpha} + \frac{\upsilon_H^2}{2\alpha} - \frac{\upsilon_L^2}{2\alpha} \leq 0$. With some algebra, it is rather simple to show that, this inequality is equivalent to $(\upsilon_H - \upsilon_L)(p + \delta) \leq 0$. As we have, $\upsilon_H > \upsilon_L$ and p and δ are non-negative, the inequality will never be true. Therefore, the feasible region for the problem is proved to be empty. Thus, the (U,P) policy does not have an equilibrium. This proves the first part of the proposition which mentions that in a hybrid policy, the SP could only assign the pay-per-period scheme to the high type and the pay-per-use to the low type.

□ □

Proof. **Proof of Proposition 4.** In the exclusion policies, we have four possibilities: $(U,\varnothing)$, $(\varnothing,U)$, $(P,\varnothing)$, and $(\varnothing,P)$. The equilibrium is characterized for each possibility.

$(U,\varnothing)$ **policy.** First, we investigate the pay-per-use policies. In this case, if the SP offers the pay-per-use scheme to the high-type consumers, i.e., $(U,\varnothing)$ policy, we can rewrite the

SP's problem as follows:

$$\max_{p_H, F_H} \quad \pi_{(U,\varnothing)} = \gamma[p_H \frac{\upsilon_H - p_H - \delta}{\alpha} + F_H - c_f \frac{(\upsilon_H - p_H - \delta)^2}{2\alpha^2} - c_m] \tag{2.30}$$

$$\textbf{S.t.} \tag{2.31}$$

$$(IR_H) : \frac{(\upsilon_H - p_H - \delta)^2}{2\alpha} - F_H \geq 0 \tag{2.32}$$

$$(IR_L) : \frac{(\upsilon_L - p_H - \delta)^2}{2\alpha} - F_H \leq 0 \tag{2.33}$$

Because the objective is strictly increasing in F_H, only an upper bound from constraints ensures the optimally. There is only one upper bound, which comes from IR_H. Thus, $F_H^{(U,\varnothing)*} = \frac{(\upsilon_H - p_H - \delta)^2}{2\alpha}$. To see whether IR_L is also satisfied, we replace F_H^* in IR_L, which gives $\frac{(\upsilon_L - p_H - \delta)^2}{2\alpha} - \frac{(\upsilon_H - p_H - \delta)^2}{2\alpha}$. This term is obviously negative since $\upsilon_L < \upsilon_H$. This proves that IR_L is slack in optimal.

To acquire the optimal value of p_H, first we have to replace F_H^* into the objective. Then, taking a first-order derivative with respect to p gives us $\frac{\partial \pi_{(U,\varnothing)}}{\partial p_H} = \frac{c_f(\upsilon_H - p_H - \delta) - \alpha p_H}{\alpha}$. Putting this equal to zero, we get the optimal value as $p_H^{(U,\varnothing)*} = \frac{c_f(\upsilon_H - \delta)}{\alpha + c_f}$. To make sure this value is optimal and unique, we need also to show that the objective is concave with respect to p_H. To do so, we take the second-order derivative of the objective with respect to p_H as $\frac{\partial^2 \pi(U,\varnothing)}{\partial p_H^2} = \frac{-(c_f + \alpha)}{\alpha}$, which is obviously negative. Thus, the objective is concave and the given prices are proved to be optimal.

$(\varnothing, U)$ **policy.** First, we need to rewrite the model after replacing the optimal usage levels as follows:

$$\max_{p_L, F_L} \quad \pi_{(\varnothing,U)} = (1-\gamma)[p_L \frac{\upsilon_L - p_L - \delta}{\alpha} + F_L - c_f \frac{(\upsilon_L - p_L - \delta)^2}{2\alpha^2} - c_m] \tag{2.34}$$

$$\textbf{S.t.} \tag{2.35}$$

$$(IR_H) : \frac{(\upsilon_H - p_L - \delta)^2}{2\alpha} - F_L \leq 0 \tag{2.36}$$

$$(IR_L) : \frac{(\upsilon_L - p_L - \delta)^2}{2\alpha} - F_L \geq 0 \tag{2.37}$$

The IR_L is binding here because of the same reason as before. Thus, the optimal value of the flat fee is $F_L^{(\varnothing,U)*} = \frac{(\upsilon_L - p_L - \delta)^2}{2\alpha}$. To make sure that IR_H is also satisfied, we replace the optimal price to it, which results in $\frac{(\upsilon_H - p_L - \delta)^2}{2\alpha} - \frac{(\upsilon_L - p_L - \delta)^2}{2\alpha} - F_L \leq 0$. Given $\upsilon_H > \upsilon_L$, this constraint will never be met. Therefore, we can conclude the model is infeasible, which means there is no equilibrium for $(\varnothing, U)$ policy.

$(P, \varnothing)$ **policy.** Now, if the SP offers a pay-per-period scheme to the consumers, there are gain to possibilities. If the scheme is offered to the high type, after replacing the optimal usage levels, the model in this case will be rewritten as follows:

$$\max_{S} \quad \pi_{(P,\varnothing)} = \gamma[S - c_f \frac{\upsilon_H^2}{2\alpha^2}] \tag{2.38}$$

$$\textbf{S.t.} \tag{2.39}$$

$$(IR_H): \frac{\upsilon_H^2}{2\alpha} - S \geq 0 \tag{2.40}$$

$$(IR_L): \frac{\upsilon_L^2}{2\alpha} - S \leq 0 \tag{2.41}$$

Given that the objective is strictly increasing in S, the optimal value is its upper bound resulting from IR_H, i.e., $S^{(P,\varnothing)*} = \frac{\upsilon_H^2}{2\alpha}$. By substituting this optimal value into IR_L, we have $\frac{\upsilon_L^2}{2\alpha} - \frac{\upsilon_H^2}{2\alpha} \leq 0$. This inequality is always true since $\upsilon_L < \upsilon_H$. The proof is complete since the objective function is strictly increasing in S, thus it is concave and the mentioned S^* is optimal.

$(\varnothing, P)$ **policy.** The decision model if the SP offers s pay-per-period scheme to the low-type consumers can be rewritten as follows:

$$\max_{S} \quad \pi_{(\varnothing,P)} = (1-\gamma)[S - c_f \frac{\upsilon_L^2}{2\alpha^2}] \tag{2.42}$$

$$\textbf{S.t.} \tag{2.43}$$

$$(IR_H): \frac{\upsilon_H^2}{2\alpha} - S \leq 0 \tag{2.44}$$

$$(IR_L): \frac{\upsilon_L^2}{2\alpha} - S \geq 0 \tag{2.45}$$

The similar reasoning implies that $S^{(\varnothing,P)*} = \frac{\upsilon_L^2}{2\alpha}$. To make sure that IR_H is also satisfied in optimal, we substitute S^* in the constraint. Resulting inequality is $\frac{\upsilon_H^2}{2\alpha} - \frac{\upsilon_L^2}{2\alpha} \leq 0$, which cannot be true because $\upsilon_H > \upsilon_L$. Therefore, the feasible region is empty and $(\varnothing, P)$ policy does not have any equilibrium.

What we can conclude from this four different exclusion policies is that if the SP wants to exclude one type, it has to be the low-type consumers. In other words, the SP could offer either $(U, \varnothing)$ or $(P, \varnothing)$. this fact proves the first part of proposition. □ □

Proof. **Proof of Corollary 2.4.0.1.** To prove this result, first, we present following equations as the difference between flat fees:

$$F_H^{(U,U)*} - F^{(U,\varnothing)*} = S^{(P,U)*} - S^{(P,\varnothing)*} = \frac{-(\upsilon_H - \upsilon_L)[\alpha(\upsilon_H + \upsilon_L - 2\delta - 3\gamma\upsilon_H + \gamma\upsilon_L + 2\delta\gamma) + (\upsilon_H - \upsilon_L)(1-\gamma)c_f]}{2\alpha(1-\gamma)(\alpha + c_f)} \tag{2.46}$$

If we show that these equations are negative, the results will follow. The denominator is positive since $\gamma \leq 1$. In the numerator if we show that $[\alpha(\upsilon_H + \upsilon_L - 2\delta - 3\gamma\upsilon_H + \gamma\upsilon_L +$

$2\delta\gamma) + (\upsilon_H - \upsilon_L)(1-\gamma)c_f]$ is positive the whole fraction is negative since $-(\upsilon_H - \upsilon_L) < 0$. With some algebra, we can rewrite this equation as $[\alpha((\upsilon_H - \upsilon_L)(1-\gamma) + 2\upsilon_L - 2\delta(1-\gamma) - 2\delta) + 2\upsilon_L + (\upsilon_H - \upsilon_L)(1-\gamma)c_f]$. Given the condition mentioned in Proposition 1, we have $\upsilon_L > \delta(1-\gamma) + \gamma\upsilon_H$, we can say this equation is positive. This means that the whole fraction is negative and the results follow.

To show the last part of the corollary, we need to compare the per-period fees for $(P, \varnothing)$ and (P, P). According to Proposition 2, we have $S_H^{(P,P)^*} = S_L^{(P,P)^*} = \frac{\upsilon_L^2}{2\alpha}$ and according to Proposition 4, we have $S^{(P,\varnothing)^*} = \frac{\upsilon_H^2}{2\alpha}$. Since we have $\upsilon_H \geq \upsilon_L$, it simply follows that $S_i^{(P,P)^*} \leq S^{(P,\varnothing)^*}$ for all $i \in \{L, H\}$.

□ □

Proof. **Proof of Corollary 2.4.0.2.** If we take first-order derivative of the prices with respect to δ, we have:

$$\frac{\partial F_H^{(U,U)^*}}{\partial \delta} = \frac{-\alpha(\upsilon_L - \delta) + c_f(\upsilon_H - \upsilon_L)}{(\alpha + c_f)^2} \tag{2.47}$$

$$\frac{\partial F_L^{(U,U)^*}}{\partial \delta} = \frac{\partial F^{(P,U)^*}}{\partial \delta} = \frac{-\alpha(\upsilon_L - \delta(1-\gamma) - \gamma\upsilon_H)}{(1-\gamma)(\alpha + c_f)^2} \tag{2.48}$$

$$\frac{\partial S^{(P,U)^*}}{\partial \delta} = \frac{\upsilon_H - \upsilon_L}{\alpha + c_f} \tag{2.49}$$

$$\frac{\partial F^{(U,\varnothing)^*}}{\partial \delta} = \frac{-\alpha(\upsilon_H - \delta)}{(\alpha + c_f)^2} \tag{2.50}$$

$$\frac{\partial p_H^{(U,U)^*}}{\partial \delta} = \frac{\partial p_L^{(U,U)^*}}{\partial \delta} = \frac{\partial p^{(P,U)^*}}{\partial \delta} = \frac{\partial p^{(U,\varnothing)^*}}{\partial \delta} = \frac{-c_f}{\alpha + c_f} \tag{2.51}$$

If one look at the first equation, the condition for it to be negative is that $c_f < \frac{\alpha(\upsilon_L - \delta)}{\upsilon_H - \upsilon_L}$. We have a condition on c_f from Proposition 1, that $c_f < \frac{\alpha\gamma}{1-\gamma}$. If we show $\frac{\alpha(\upsilon_L - \delta)}{\upsilon_H - \upsilon_L} < \frac{\alpha\gamma}{1-\gamma}$, the results will follow since the model's condition will satisfy automatically our condition here. With some algebra, we can rewrite the comparison as $\upsilon_L > \delta(1-\gamma) + \gamma\upsilon_H$. This condition is also always satisfied because the model enforce that upfront according to Proposition 1. Therefore, $\frac{\partial F_L^{(U,U)^*}}{\partial \delta} < 0$.

Now, given $\upsilon_L > \delta(1-\gamma) + \gamma\upsilon_H$ from Proposition 1, it is straightforward that $\frac{\partial F_L^{(U,U)^*}}{\partial \delta} = \frac{\partial F^{(P,U)^*}}{\partial \delta} < 0$. Also, since $\upsilon_L \leq \upsilon_H$, $\frac{\partial S^{(P,U)^*}}{\partial \delta} > 0$. Other derivatives are also negative based on parameter specifications, therefore, we skip the explanation.

To show the part *(iii)*, we need to take first-order derivative of the profit functions with respect to δ as follows:

$$\frac{\partial \pi^*_{(U,U)}}{\partial \delta} = \frac{-(\upsilon_L - \delta)}{\alpha + c_f} \tag{2.52}$$

$$\frac{\partial \pi^*_{(P,U)}}{\partial \delta} = \frac{-\upsilon_L + \delta(1-\gamma) + \gamma \upsilon_H}{\alpha + c_f} \tag{2.53}$$

$$\frac{\partial \pi^*_{(U,\varnothing)}}{\partial \delta} = \frac{-(\upsilon_H - \delta)\gamma}{\alpha + c_f} \tag{2.54}$$

The first equation is always negative because $\delta < \upsilon_L$, otherwise usage levels would be negative. The second equation is negative given the condition $\upsilon_L > \delta(1-\gamma) + \gamma \upsilon_H$ in Proposition 1. Finally, the last equation is negative simply because $\delta < 1$. Therefore, results follow that all the policies' profits are decreasing in δ.

□ □

Proof. **Proof of Proposition 5** We have already shown in proof of Proposition 1 that we have $\pi^*_{(U,U)} - \pi^*_{(P,U)} = \pi^*_{(U,\varnothing)} - \pi^*_{(P,\varnothing)}$. From this equation, we can conclude that whenever $\pi^*_{(U,U)} \geq \pi^*_{(P,U)}$, it also holds that $\pi^*_{(U,\varnothing)} \geq \pi^*_{(P,\varnothing)}$. This way we have two situation in which either $\pi^*_{(U,U)}$ and $\pi^*_{(U,\varnothing)}$ are higher or $\pi^*_{(P,U)}$ and $\pi^*_{(P,\varnothing)}$ are higher. Since, the difference between them is the same, we have to show that the difference is monotone and there is only one crossing point between them in the feasible range of parameters.

First we compare (U,U) and (P,U). From proof of Proposition 1, you can find optimal profit functions $\pi^*_{(U,U)}$ and $\pi^*(P,U)$. The difference between them is as follows:

$$\pi^*_{(U,U)} - \pi^*_{(P,U)} = \frac{\gamma(-2\alpha^3 c_m + c_f^2 \upsilon_H^2 + \alpha^2(-2\delta \upsilon_H + \delta^2 - 2c_m c_f))}{2\alpha^2(\alpha + c_f)} \tag{2.55}$$

Taking the first-order derivative w.r.t. c_f, we have:

$$\frac{\partial[\pi^*_{(U,U)} - \pi^*_{(P,U)}]}{\partial c_f} = \frac{\gamma(\alpha^2(2\upsilon_H - \delta)\delta + 2\alpha c_f \upsilon_H^2 + c_f^2 \upsilon_H^2)}{2\alpha^2(\alpha + c_f)^2}$$

which is positive in our range since we have $0 < \delta < 1$, $0 < \upsilon_H < 1$, $0 < \alpha < 1$, and $0 < c_f < 1$. this shows that the difference function is an increasing function in c_f. Now, if we show that only one root of the difference function lies between the allowed range of c_f, we are done.

The equation $\pi^*_{(U,U)} - \pi^*_{(P,U)} = 0$ has two roots of $\underline{c}_f = \frac{\alpha^2 c_m - \alpha\sqrt{2\alpha c_m \upsilon_H^2 + \alpha^2 c_m^2 + \delta(2\upsilon_H - \delta)\upsilon_H^2}}{\upsilon_H^2}$ and $\bar{c}_f = \frac{\alpha^2 c_m + \alpha\sqrt{2\alpha c_m \upsilon_H^2 + \alpha^2 c_m^2 + \delta(2\upsilon_H - \delta)\upsilon_H^2}}{\upsilon_H^2}$. With some algebra, one can easily show that $\underline{c}_f < 0$, which is in conflict with $c_f > 0$. Therefore, the only possible point that the difference function would change sign is $\bar{c}_f$, which from now on we call it c_f^1. The first-order derivative being positive shows that before this point c_f^1, (P,U) is better and after this point (U,U) dominates.

Now, in the second stage we have to compare (U,U) and $(U,\varnothing)$, or equivalently, we have to compare (P,U) and $(P,\varnothing)$. The difference function is as follows:

$$\pi^*_{(U,U)} - \pi^*_{(U,\varnothing)} = \tag{2.56}$$
$$\left[\frac{\begin{array}{l} 2\alpha(\alpha+c_f)c_m(1-\gamma)^2 + (1-\gamma) \\ \quad \alpha\gamma(v_H-\delta)^2 + \alpha\Big((\delta-v_L)^2(1-\gamma) + \gamma^2(v_H-v_L)^2\Big) - \gamma c_f(1-\gamma)(v_H-v_L)^2 \end{array}}{2\alpha(1-\gamma)(\alpha+c_f)} \right]$$

If we take the first-order derivative w.r.t. γ, with some algebra, it will boils down to $\frac{\partial[\pi^*_{(U,U)} - \pi^*_{(U,\varnothing)}]}{\partial\gamma} = \frac{\alpha(v_H-v_L)^2 - (1-\gamma)^2\Big((v_H-v_L)^2(\alpha+c_f) + \alpha(v_H-\delta)^2 - 2\alpha c_m(\alpha+c_f)\Big)}{2\alpha(\alpha+c_f)(1-\gamma)^2}$. Since the denominator is always positive, we need to check the sign of the numerator in the feasible range of parameter γ. The derivative is a quadratic function of γ with two fallowing roots: $\gamma = 1 \pm \frac{(v_H-v_L)\sqrt{\alpha}}{\sqrt{(v_H-v_L)^2(\alpha+c_f) + \alpha(v_H-\delta)^2 - 2\alpha c_m(\alpha+c_f)}}$.

The derivative is negative if γ is bigger than the bigger root or less than the smaller root. It is obvious that the bigger root is higher than 1, which is out of the feasible range of $\gamma < 1$. From feasibility conditions derived in proof of Proposition 1, we have the feasible range of γ as follows: $\frac{c_f}{\alpha+c_f} \leq \gamma \leq \frac{v_L-\delta}{v_H-\delta}$. To make sure that the derivative is always negative in the feasible range, we need to show the other root is also not in the range. In other words, we have to show, $1 - \frac{(v_H-v_L)\sqrt{\alpha}}{\sqrt{(v_H-v_L)^2(\alpha+c_f) + \alpha(v_H-\delta)^2 - 2\alpha c_m(\alpha+c_f)}} > \frac{v_L-\delta}{v_H-\delta}$. With simple algebra, one can easily show that the necessary condition for this to be hold is $c_m \leq \frac{(v_H-v_L)^2}{2\alpha}$. This condition seems quite reasonable, thus, we will satisfy this condition in our results. Satisfying this additional condition, we can surely say that the difference function is decreasing in the feasible range.

Now, we are sure that the the difference function (2.56) can only change sign at at most one point. This function has two roots of:

$$\left[\frac{\begin{array}{r} 4\alpha^2 c_m - \alpha(v_H^2 + v_L^2 - 2\delta(v_H+v_L) + 2\delta^2 - 4c_m c_f) - c_f v_H(v_H-v_L)^2 \pm (v_H-v_L) \\ \sqrt{\alpha+c_f}\sqrt{8\alpha^2 c_m^2 + \alpha(v_H-v_L)(v_H+3v_L-4\delta) + c_f(v_H-v_L)^2} \end{array}}{4\alpha^2 c_m - 2\alpha((v_H-\delta)^2 + (v_H-v_L)^2 - 2c_m c_f) - 2c_f(v_H-v_L)^2} \right]$$

Now we need to show which one is the switching point of the policies. First, we show that the function is always convex in the feasible range. We have $\frac{\partial^2[\pi^*_{(U,U)} - \pi^*_{(U,\varnothing)}]}{\partial\gamma^2} = \frac{(v_H-v_L)^2}{(1-\gamma)^3(\alpha+c_f)}$, which is positive since $\gamma < 1$. Given that function (2.56) is decreasing, smaller root is our switching point which is:

$$\bar{\gamma} = \left[\frac{\begin{matrix} 4\alpha^2 c_m - \alpha(\upsilon_H^2 + \upsilon_L^2 - 2\delta(\upsilon_H + \upsilon_L) + 2\delta^2 - 4c_m c_f) - c_f \upsilon_H(\upsilon_H - \upsilon_L)^2 \\ \overline{(\upsilon_H - \upsilon_L)\sqrt{\alpha + c_f}\sqrt{8\alpha^2 c_m^2 + \alpha(\upsilon_H - \upsilon_L)(\upsilon_H + 3\upsilon_L - 4\delta) + c_f(\upsilon_H - \upsilon_L)^2}} \end{matrix}}{4\alpha^2 c_m - 2\alpha((\upsilon_H - \delta)^2 + (\upsilon_H - \upsilon_L)^2 - 2c_m c_f) - 2c_f(\upsilon_H - \upsilon_L)^2} \right] \tag{2.57}$$

We call $\bar{\gamma}$, γ^3 from now on. Since we have shown that the difference function (2.56) is decreasing, we can say that for $\gamma \leq \gamma^3$, (U, U) is optimal and for $\gamma \geq \gamma^3$, $(U, \varnothing)$ policy is optimal.

The next step would be to compare (P, P) policy to the other policies to find the optimal region for that policy. Following equations show the difference between four first policies with (P, P) policy:

$$\begin{aligned}
\pi^*_{(P,U)} - \pi^*_{(P,P)} =& \frac{1}{2\alpha^2(1-\gamma)(\alpha + c_f)}\big(- 2\alpha^3 c_m(1-\gamma)^2 + \alpha^2(\delta^2(1-\gamma)^2 - \\
& 2c_m c_f(1-\gamma)^2 + \gamma^2(\upsilon_H - \upsilon_L)^2 + 2\delta(1-\gamma)(\gamma\upsilon_H - \upsilon_L)) + \\
& 2\alpha\gamma(1-\gamma)(\upsilon_H - \upsilon_L)\upsilon_L + (1-\gamma)^2 c_f^2 \upsilon_L^2\big) && (2.58) \\
\pi^*_{(P,\varnothing)} - \pi^*_{(P,P)} =& \frac{(1-\gamma)c_f \upsilon_L^2 + \alpha(\gamma\upsilon_H^2 - \upsilon_L^2)}{2\alpha^2} && (2.59) \\
\pi^*_{(U,U} - \pi^*_{(P,P)} =& -\frac{1}{2\alpha^2(1-\gamma)(\alpha + c_f)}\big(2\alpha^3 c_m(1-\gamma) - 2\alpha(1-\gamma)\gamma c_f(\upsilon_H - \upsilon_L)\upsilon_L + \\
& \alpha^2(-\delta^2(1-\gamma) + 2c_m c_f(1-\gamma) - \gamma^2(\upsilon_H - \upsilon_L)^2 + 2\delta(1-\gamma)\upsilon_L) \\
& - (1-\gamma)c_f^2(\upsilon_L^2 + \gamma(\upsilon_H^2 - \upsilon_L^2))\big) && (2.60) \\
\pi^*_{(U,\varnothing)} - \pi^*_{(P,P)} =& \frac{\gamma(\upsilon_H - \delta)^2}{2(\alpha + c_f)} + \frac{(-\alpha + c_f)\upsilon_L^2 + \gamma c_f(\upsilon_H^2 - \upsilon_L^2)}{2\alpha^2} - \gamma c_m && (2.61)
\end{aligned}$$

First, we need to make sure that all these difference functions are monotone in the feasible range. Thus, we take the first-order derivative w.r.t. to γ to see if they are monotone. From (2.58), we have $\frac{\partial(\pi^*_{(P,U)} - \pi^*_{(P,P)})}{\partial\gamma} = \frac{2c_m(\alpha+c_f) - \delta^2 + 2\delta\upsilon_H + \frac{(2-\gamma)\gamma(\upsilon_H - \upsilon_L)^2}{(1-\gamma)^2} + \frac{2c_f(\upsilon_H - \upsilon_L)\upsilon_L}{\alpha} - \frac{c_f^2\upsilon_L^2}{\alpha^2}}{2(\alpha+c_f)}$. Consider the numerator of this fraction. We have two negative terms. The first one is $-\delta^2$. As we have $\upsilon_H \geq \delta$, we can conclude that $\upsilon_H\delta \geq \delta^2$ and consequently $2\upsilon_H\delta \geq \delta^2$, which implies the first negative term is strictly smaller than a positive term. Now, if we consider the last two terms, to show the whole equation is positive, it is sufficient to show that $\frac{2c_f(\upsilon_H - \upsilon_L)\upsilon_L}{\alpha} \geq \frac{c_f^2\upsilon_L^2}{\alpha^2}$. So, we need to have $\upsilon_L \leq \frac{2\alpha(\upsilon_H - \upsilon_L)}{c_f}$. In the next paragraph, we assumed $\frac{\alpha}{c_f} \geq 1$. Thus, if we assume this fraction is equal to its lower bound, i.e., $\frac{\alpha}{c_f} = 1$, we have $\upsilon_L \leq 2(\upsilon_H - \upsilon_L)$, this implies $\frac{\upsilon_L}{\upsilon_H} \leq \frac{2}{3}$. This is already a reasonable assumption. To keep the problem tractable, we need to make this additional assumption. Note that when

$\frac{\alpha}{c_f}$ gets bigger and bigger, it is easy to show that the upper bound for $\frac{\upsilon_L}{\upsilon_H}$ will approach 1. In that case, the constraint would be trivial.

For (2.59), we have $\frac{\partial(\pi^*_{(P,\varnothing)} - \pi^*_{(P,P)})}{\partial\gamma} = \frac{\alpha\upsilon_H^2 - c_f\upsilon_L^2}{2\alpha^2}$. A sufficient condition for this function to be positive is $\frac{\alpha}{c_f} \geq \frac{\upsilon_L^2}{\upsilon_H^2}$. We could also go a step further and simply say $\frac{\alpha}{c_f} \geq 1$, which will also satisfy the sufficient condition since $\upsilon_L \leq \upsilon_H$.

For (2.60), we have

$$\frac{\partial(\pi^*_{(U,U)} - \pi^*_{(P,P)})}{\partial\gamma} = \frac{(\upsilon_H - \upsilon_L)(\alpha^2(2-\gamma)\gamma(\upsilon_H - \upsilon_L) + 2\alpha c_f(1-\gamma)^2\upsilon_L + (1-\gamma)^2 c_f^2(\upsilon_H + \upsilon_L))}{2\alpha^2(1-\gamma)^2(\alpha + c_f)}$$

This equation is always positive since we have $\upsilon_H \geq \upsilon_L$, $\gamma \leq 1$, and $\alpha, c_f \geq 0$. So, the difference between optimal profit of (U,U) and (P,P) is always upward sloping in terms of γ.

And finally, from (2.61), we have $\frac{\partial(\pi^*_{(U,\varnothing)} - \pi^*_{(P,P)})}{\partial\gamma} = \frac{(\upsilon_H - \delta)^2}{2(\alpha + c_f)} + \frac{c_f(\upsilon_H^2 - \upsilon_L^2)}{2\alpha^2} - c_m$. In this equation, the first two terms are positive and the last one is negative. Consider the first and the third term. If we show $c_m \leq \frac{(\upsilon_H - \delta)^2}{2(\alpha + c_f)}$, then the whole equation would be positive. Before in this proof, we made the assumption of $c_m \leq \frac{(\upsilon_H - \upsilon_L)^2}{2\alpha}$, which is reasonable given tiny measuring costs. Now, we have:

$$c_m \leq \frac{(\upsilon_H - \upsilon_L)^2}{2\alpha} \leq \frac{(\upsilon_H - \delta)^2}{2\alpha} \leq \frac{(\upsilon_H - \delta)^2}{2(\alpha + c_f)}$$

where the first inequality follows from $\delta \leq \upsilon_L$. Then, based on this, we can say the derivative of $\pi^*_{(U,\varnothing)} - \pi^*_{(P,P)}$ is positive in terms of γ. All differences, therefore, are monotone and upward sloping, which shows they will cross only in one point in the feasible range. This also shows that the (P,P) policy is optimal only and only if γ is less than the thresholds which solve these differences in terms of γ.

Now, if we define $\gamma^1 \doteq \{\gamma : \pi^*_{(P,U)} - \pi^*_{(P,P)}) = 0\}$, $\gamma^2 \doteq \{\gamma : \pi^*_{(P,\varnothing)} - \pi^*_{(P,P)} = 0\}$, $\gamma^4 \doteq \{\gamma : \pi^*_{(U,U)} - \pi^*_{(P,P)} = 0\}$, $\gamma^5 \doteq \{\gamma : \pi^*_{(U,\varnothing)} - \pi^*_{(P,P)} = 0\}$. Also, we can define $c_f^2 \doteq \{c_f : \gamma^1 - \gamma^2 = 0\}$, $c_f^3 \doteq \{c_f : \gamma^4 - \gamma^5 = 0\}$, and $c_f^4 \doteq \{c_f : \gamma^4 = 0\}$. Finally, we define $c_m^1 \doteq \{c_m : c_f^2 = 0\}$, and $c_m^2 \doteq \{c_m : c_f^3 - c_f^1 = 0\}$. It is straightforward to show all these thresholds are positive and in the feasible range. It has been done for γ^3 and c_f^1.

We had $\gamma^3 \doteq \{\gamma : \pi^*_{(P,U)} - \pi^*_{(P,\varnothing)} = 0 \quad | \quad \pi^*_{(U,U)} - \pi^*_{(U,\varnothing)} = 0\}$ and $c_f^1 \doteq \{c_f : \pi^*_{(P,U)} - \pi^*_{(U,U)} = 0 \quad | \quad \pi^*_{(P,\varnothing)} - \pi^*_{(U,\varnothing)} = 0\}$.

Because of the nice structure for the first four policies, we have already shown that if $\gamma \leq \gamma^3$, $(P,U) \succcurlyeq (P,\varnothing)$ and $(U,U) \succcurlyeq (U,\varnothing)$. Also, when $c_f \leq c_f^1$, we have $(P,U) \succcurlyeq (U,U)$ and $(P,\varnothing) \succcurlyeq (U,\varnothing)$. Given this, we need to find the optimal region for (P,P) policy by comparing it to all other four policies. We have shown that all four difference functions, represented in Equations (2.58), (2.59), (2.60), and (2.61), are upward sloping w.r.t. γ. Thus, we can conclude that (P,P) is always optimal when γ is less than any of γ^1, γ^2, γ^4, or γ^5. Which one is biding, however, depends on two parameters of c_m and c_f. Thus, we divide the problem to different cases to show where (P,P) is optimal.

Case 1: $c_m \leq c_m^1$ This case represents Figure 2.1a. Following cases characterizes optimal policies in different values of c_f and γ:

(i) In this case, when $c_f \leq c_f^1$, $(U,\varnothing)$ and (U,U) are dominated. So, we need to compare (P,P), (P,U), and $(p,\varnothing)$ in this area. Thus only, γ^1 and γ^3 plays a role here. Since, $c_m \leq c_m^1$, there is no collision between γ^1 and γ^3. Thus, it is straightforward to conclude that (P,P) is optimal when $\gamma \leq \gamma^1$, (P,U) is optimal when $\gamma^1 \leq \gamma \leq \gamma^3$ and $(P,\varnothing)$ is optimal when $\gamma \geq \gamma^3$.

(ii) When $c_f^1 \leq c_f \leq c_f^4$, then (P,U) and $(P,\varnothing)$ cannot be optimal, and we need to compare (P,P), (U,U), and $(U,\varnothing)$. Under this conditions, only γ^3 and γ^4 plays a role. Also because $c_m \leq c_m^1$, which means c_f^3 is not in the feasible range, γ^5 is redundant here. It is again straightforward to show (P,P) is optimal when $\gamma \leq \gamma^4$, (U,U) is optimal when $\gamma^4 \leq \gamma \leq \gamma^3$, and $(U,\varnothing)$ is optimal when $\gamma \geq \gamma^3$.

(iii) Finally when $c_f \geq c_f^4$, γ^4 will be negative and out of range. Thus, the only relevant boundary is γ^3, where (U,U) is optimal when $\gamma \leq \gamma^3$, and $(U,\varnothing)$ is optimal, otherwise.

Case 2: $c_m^1 \leq c_m \leq c_m^2$ This case has been depicted in Figure 2.1b. In this case, c_F^2 comes to play, which means (P,P) and $(P,\varnothing)$ has a boundary together in the feasible range. Thus, their boundary, γ^2 plays a role here as well. Following cases characterizes optimal policies in different values of c_f and γ:

(i) When $c_f \leq c_f^2$, $\gamma^2 \geq \gamma^1$, thus, in this range, (P,U) policy is not optimal anymore. We only have (P,P) and $(P,\varnothing)$. It is straightforward to show that for $\gamma \leq \gamma^2$, (P,P) is optimal and for $\gamma \geq \gamma^2$, $(P,\varnothing)$.

(ii) When $c_f^2 \leq c_f \leq c_f^1$, the situation is similar to the situation (i) in **Case 1**. We refer to that for details. Thus, (P,P) is optimal when $\gamma \leq \gamma^1$, (P,U) is optimal when $\gamma^1 \leq \gamma \leq \gamma^3$ and $(P,\varnothing)$ is optimal when $\gamma \geq \gamma^3$.

(iii) When $c_f^1 \leq c_f \leq c_f^4$, the situation exactly matches the situation (ii) of **Case 1**. We refer to that for details. Thus, (P,P) is optimal when $\gamma \leq \gamma^4$, (U,U) is optimal when $\gamma^4 \leq \gamma \leq \gamma^3$, and $(U,\varnothing)$ is optimal when $\gamma \geq \gamma^3$.

(iv) When $c_f \geq c_f^4$, the situation is similar to what we have in situation (iii) of **Case 1**. We refer to that for details. Thus, (U,U) is optimal when $\gamma \leq \gamma^3$, and $(U,\varnothing)$ is optimal, otherwise.

Case 3: $c_m \geq c_m^2$

Figure 2.1c represents this case. In this case, since γ^1 crosses γ^3 in a point bigger than c_f^1, the (P,U) policy is no longer optimal at any region. Other consequence of this is that cor

$c_f \leq c_f^1$, we only have (P,P) and $(P,\varnothing)$ as optimal policies. Following cases characterizes optimal policies in different values of c_f and γ:

(i) When $c_f \leq c_f^1$, we only have (P,P) and $(P,\varnothing)$ are feasible policies. Thus, there is only one boundary, which is γ^2. Similar to other cases, for all $\gamma \leq \gamma^2$, (P,P) is optimal and for all $\gamma \geq \gamma^2$, $(P,\varnothing)$ is optimal.

(ii) When $c_f^1 \leq c_d \leq c_d^3$, either (P,P), or $(U,\varnothing)$ is optimal. This shows that because $c_m \geq c_m^2$, we have a feasible c_f^3, thus there is an immediate boundary between (P,P) and $(U,\varnothing)$, which is γ^5. Thus, for $\gamma \leq \gamma^5$, (P,P) is optimal, and for all $\gamma \geq \gamma^5$, $(U,\varnothing)$ is optimal.

(iii) When $c_f^3 \leq c_f \leq c_f^4$, the situation is similar to situation (ii) in **case 1**. We refer to that for details. Thus, (P,P) is optimal when $\gamma \leq \gamma^4$, (U,U) is optimal when $\gamma^4 \leq \gamma \leq \gamma^3$, and $(U,\varnothing)$ is optimal when $\gamma \geq \gamma^3$.

(iv) Finally when $c_f \geq c_f^4$, the same situation as in situation (iii) of **Case 1** happens. We refer to that for details. Thus, (U,U) is optimal when $\gamma \leq \gamma^3$, and $(U,\varnothing)$ is optimal, otherwise.

□ □

Proof. **Proof of Proposition 6.** First we need to calculate optimal usage levels of each segment under each policy. Replacing optimal prices to the optimal usage formulas from Lemma 1 results in optimal usage levels. Under (U,U) policy, $\theta_H^{(U,U)^*} = \frac{\upsilon_H-\delta}{\alpha+c_f}$ and $\theta_L^{(U,U)^*} = \frac{\upsilon_L-\gamma\upsilon_H-\delta(1-\gamma)}{(1-\gamma)(\alpha+c_f)}$. Under (P,U) policy, $\theta_H^{(P,U)^*} = \frac{\upsilon_H}{\alpha}$ and $\theta_L^{(P,U)^*} = \frac{\upsilon_L-\gamma\upsilon_H-\delta(1-\gamma)}{(1-\gamma)(\alpha+c_f)}$. Under $(U,\varnothing)$ policy, $\theta_H^{(U,\varnothing)^*} = \frac{\upsilon_H-\delta}{\alpha+c_f}$ and under $(P,\varnothing)$, $\theta_H^{(P,\varnothing)^*} = \frac{\upsilon_H}{\alpha}$. Under (P,P), $\theta_H^{(P,P)^*} = \frac{\upsilon_H}{\alpha}$ and $\theta_L^{(P,P)^*} = \frac{\upsilon_L}{\alpha}$. Notice that $\theta_L^{(U,U)^*} = \theta_L^{(P,U)^*}$, $\theta_H^{(U,\varnothing)^*} = \theta_H^{(U,U)^*}$, and $\theta_H^{(P,\varnothing)^*} = \theta_H^{(P,U)^*} = \theta_H^{(P,P)^*}$.

Given the usage level under each policy, now, we an compare the total environmental impact of each policy using (2.3). Following functions show the total environmental impact of all the schemes:

$$EI_{(U,U)} = e_u\frac{\delta^2(1-\gamma)+\gamma\upsilon_H(\upsilon_H-2\upsilon_L)-2\delta\upsilon_L(1-\gamma)+\upsilon_L^2}{(1-\gamma)(\alpha+c_f)^2} + e_{pd} \tag{2.62}$$

$$EI_{(P,U)} = e_u\Big(\frac{\gamma\upsilon_H^2}{\alpha^2} + \frac{\alpha^2(\upsilon_L-\gamma\upsilon_H-(1-\gamma)\delta)^2}{\alpha^2(1-\gamma)(\alpha+c_f)^2}\Big) + e_{pd} \tag{2.63}$$

$$EI_{(U,\varnothing)} = e_u\frac{\gamma(\upsilon_H-\delta)^2}{(\alpha+c_f)^2} + \gamma e_{pd} \tag{2.64}$$

$$EI_{(P,\varnothing)} = e_u\frac{\gamma\upsilon_H^2}{\alpha^2} + \gamma e_{pd} \tag{2.65}$$

$$EI_{(P,P)} = \frac{e_u(\upsilon_L^2+\gamma(\upsilon_H^2-\upsilon_L^2))}{\alpha^2} + e_{pd} \tag{2.66}$$

Exactly like the profit functions that we have shown in Proposition 1, the same argument holds for environmental impacts. This means we can easily show that

$$EI_{(U,U)} - EI_{(P,U)} = EI_{(U,\varnothing)} - EI_{(P,\varnothing)} \tag{2.67}$$

Given (2.62) and (2.63), the difference between (U, U) and (P, U) policy can be calculated as $EI_{(U,U)} - EI_{(P,U)} = \frac{-e_u\gamma(\alpha^2\delta(2\upsilon_H-\delta)+2\alpha c_f \upsilon_H^2+c_f^2\upsilon_H^2)}{\alpha^2(\alpha+c_f)^2}$. It is obvious that this expression is negative. This not only implies that (U, U) policy outperforms (P, U), but also shows that $(U, \varnothing)$ outperforms $(P, \varnothing)$ given Eq. (2.67). Now, to find the best policy, we have to only compare (U, U) and $(U, \varnothing)$. From Equations (2.62) and (2.64), we have $EI_{(U,U)} - EI_{(U,\varnothing)} = \frac{e_u(\upsilon_L-\gamma\upsilon_H-(1-\gamma)\delta)^2}{(1-\gamma)(\alpha+c_f)^2}$, which is always positive. Also, the difference between the total impact of the (P, P) and $(P, \varnothing)$ policy is $EI_{(P,P)} - EI_{(P,\varnothing)} = \frac{\gamma(\upsilon_H^2-\upsilon_L^2)}{2\alpha}$, which is always positive. This shows that (P, P) is dominated by $(P, \varnothing)$, which we also shows is dominated by $(U, \varnothing)$. This means that $(U, \varnothing)$ policy has always the lowest environmental impact among all the policies.

□ □

Proof. **Proof of Proposition 7.** Using Equations (2.4), (2.5), (2.6) utility functions, we can rewrite the consumer surplus equation for all the four policies as follows:

$$CS_{(U,U)} = \gamma((\upsilon_H - p_H^* - \delta)\theta_H^* - F_H^* - \alpha\frac{\theta_H^{*2}}{2}) + (1-\gamma)((\upsilon_L - p_L^* - \delta)\theta_L^* - F_L^* - \alpha\frac{\theta_L^{*2}}{2}) \tag{2.68}$$

$$CS_{(P,U)} = \gamma(\upsilon_H\theta_H^* - S^* - \alpha\frac{\theta_H^{*2}}{2}) + (1-\gamma)((\upsilon_L - p^* - \delta)\theta_L^* - F^* - \alpha\frac{\theta_L^{*2}}{2}) \tag{2.69}$$

$$CS_{(U,\varnothing)} = \gamma((\upsilon_H - p_H^* - \delta)\theta_H^* - F_H^* - \alpha\frac{\theta_H^{*2}}{2}) \tag{2.70}$$

$$CS_{(P,\varnothing)} = \gamma(\upsilon_H\theta_H^* - S^* - \alpha\frac{\theta_H^{*2}}{2}) \tag{2.71}$$

$$CS_{(P,P)} = \gamma(\upsilon_H\theta_H^* - S_H^* - \alpha\frac{\theta_H^{*2}}{2}) + (1-\gamma)(\upsilon_L\theta_L^* - S_L^* - \alpha\frac{\theta_L^{*2}}{2}) \tag{2.72}$$

If we replace optimal usage levels from Lemma 1 and optimal price values from Proposition 1, we will get the following equations as consumer surplus:

$$CS_{(U,U)} = CS_{(P,U)} = \left[\frac{\big(\gamma(\upsilon_H - \upsilon_L)\big((1-\gamma)c_f(\upsilon_H - \upsilon_L) + \alpha(-2\delta(1-\gamma) + \upsilon_H(1-3\gamma) + \upsilon_L(1+\gamma))\big)}{2\alpha(1-\gamma)(\alpha + c_f)}\right] \tag{2.73}$$

It is also straightforward to show that $CS_{(U,\varnothing)} = CS_{(P,\varnothing)} = 0$ since the SP extract all the consumer surplus in these cases, which is because we only have one type of customers. To show where $CS_{(U,U)} > CS_{(U,\varnothing)}$, we have to show where the consumer surplus of (U,U) is positive. This condition boils down to $\gamma(\upsilon_H - \upsilon_L)\big((1-\gamma)c_f(\upsilon_H - \upsilon_L) + \alpha(-2\delta(1-\gamma) + \upsilon_H(1-3\gamma) + \upsilon_L(1+\gamma))\big) \geq 0$ since $0 < \gamma < 1$. This is a quadratic function with two roots, one of which is $\gamma = 0$, which is not so interesting for us since it is allowed boundary of γ. However. as an interior solution, the inequality can be further simplified to $\big((1-\gamma)c_f(\upsilon_H - \upsilon_L) + \alpha(-2\delta(1-\gamma) + \upsilon_H(1-3\gamma) + \upsilon_L(1+\gamma))\big) \geq 0$, which is linear in γ. linearity guarantees that the equation will change sign only once. Simple first-order condition, i.e., $\alpha(2\delta + \upsilon_L - 3\upsilon_H) - c_f(\upsilon_H - \upsilon_L)$, shows that this is a decreasing line since $\upsilon_H > \upsilon_L > \delta$. This line has one root of $\bar{\gamma}^{CS} = \frac{\alpha(\upsilon_H+\upsilon_L-2\delta)+(\upsilon_H-\upsilon_L)c_f}{\alpha(3\upsilon_H-\upsilon_L-2\delta)+(\upsilon_H-\upsilon_L)c_f}$ which is always less than 1. Finally because the line is decreasing, for $\gamma < \bar{\gamma}^{CS}$, $CS_{(U,U)} > CS_{(U,\varnothing)}$.

But, if we look at the difference between similar policies in terms of consumer surplus and (P,P) policy, we have $CS_{(P,P)} - CS_{(P,\varnothing)} = \frac{\gamma(\upsilon_H^2 - \upsilon_L^2)}{2\alpha}$ and $CS_{(P,P)} - CS_{(P,U)} = \frac{\gamma(\upsilon_H-\upsilon_L)(\alpha(\delta(1-\gamma)+\gamma(\upsilon_H-\upsilon_L))+(1-\gamma)c_f\upsilon_L)}{\alpha(1-\gamma)(\alpha+c_f)}$. Both this values are positive because $\upsilon_H \geq \upsilon_L$ and $\gamma \leq 1$. Thus, $CS_{(P,P)} \geq CS_{(P,U)}$ and $CS_{(P,P)} \geq CS_{(P,\varnothing)}$, which means (P,P) policy results in the highest consumer surplus among all the policies.

□ □

Proof. **Proof of Lemma 2.** In this case, we also have to first find the optimal solution of Problem **P.6**. To do so, we have to first present the model by replacing optimal usage levels. Usage levels are different from Lemma 1 in this case. An FOC will show that optimal usage levels in case of offering a green and a regular product are $\frac{\upsilon_i - p_i - \delta + g}{\alpha}$ and $\frac{\upsilon_i + g}{\alpha}$ in a pay-per-use and a pay-per-period scheme, respectively.

$((U,\varnothing),(U,\varnothing))$ **policy.** Using this values, we can reformulate **P.6** as follows:

$$\max_{p_i,F_i,g,i\in\{G,R\}} \pi^E_{((U,\varnothing),(U,\varnothing))} = \gamma\lambda[p_G\frac{\upsilon_H - p_G - \delta + g}{\alpha} + F_G - c_f\frac{(\upsilon_H - p_G - \delta + g)^2}{2\alpha^2} - c_m - c_p g^2] + \gamma(1-\lambda)[p_R\frac{\upsilon_H - p_R - \delta}{\alpha} + F_R - c_f\frac{(\upsilon_H - p_R - \delta)^2}{2\alpha^2} - c_m]$$

S.t.

$$\frac{(\upsilon_H - p_G - \delta + g)^2}{2\alpha} - F_G + \mu g \geq 0 \qquad (IR_G)$$

$$\frac{(\upsilon_H - p_R - \delta)^2}{2\alpha} - F_R \geq 0 \qquad (IR_R)$$

$$\frac{(\upsilon_H - p_G - \delta + g)^2}{2\alpha} - F_G + \mu g \geq \frac{(\upsilon_H - p_R - \delta)^2}{2\alpha} - F_R \qquad (IC_G)$$

$$\frac{(\upsilon_H - p_R - \delta)^2}{2\alpha} - F_R \geq \frac{(\upsilon_H - p_G - \delta + g)^2}{2\alpha} - F_G \qquad (IC_R)$$

The same logic as in Proposition 1 applies here, which implies IR_R and IC_G are binding. This gives $F_R^{((U,\varnothing),(U,\varnothing))*} = \frac{(\upsilon_H - p_R - \delta)^2}{2\alpha}$ and $F_G^{((U,\varnothing),(U,\varnothing))} = \frac{(\upsilon_H - p_G - \delta + g)^2}{2\alpha} + \mu g$. We ignore, IC_R and find the solution by replacing F_i into the objective. Following an FOC, we can derive $p_G^{((U,\varnothing),(U,\varnothing))*} = \frac{\alpha^2 c_f + c_p c_f (1-\delta)}{-\alpha^2 + 2c_p(\alpha + c_f)}$, $p_R^{((U,\varnothing),(U,\varnothing))*} = \frac{c_f(\upsilon_H - \delta)}{\alpha + c_f}$, and $g^{((U,\varnothing),(U,\varnothing))*} = \frac{\alpha^2(1-\delta) + \alpha^2(\alpha - c_f)}{-\alpha^2 + 2c_p(\alpha + c_f)}$.

To prove the optimality, we calculate the second-order derivative as $\frac{\partial^2 \pi^E_{((U,\varnothing),(U,\varnothing))}}{\partial {p_G}^2} = -\frac{g\lambda(\alpha + c_f)}{\alpha^2} < 0$, $\frac{\partial^2 \pi^E_{((U,\varnothing),(U,\varnothing))}}{\partial {p_R}^2} = -\frac{g(1-\lambda)(\alpha + c_f)}{\alpha^2} < 0$, and $\frac{\partial^2 \pi^E_{((U,\varnothing),(U,\varnothing))}}{\partial g^2} = -\frac{\mu\lambda(-\alpha + 2\alpha^2 c_p + c_f)}{\alpha^2} < 0$. As can be seen, the objective is concave in all the variables, which proves optimality of the presented values.

Finally, we have to show whether IC_R has been satisfied. we replace the optimal values which gives $0 > -\mu g^E$ which is always true. Therefore, the solution is optimal and satisfy all the constraints.

$((P,\varnothing),(P,\varnothing))$ **policy.** Since the proof is similar, we skip the details and we just present the model and optimal values as follows:

$$\max_{S_i, g, i \in \{G,R\}} \quad \pi^E_{((P,\varnothing),(P,\varnothing))} = \gamma\lambda[S_G - c_f \frac{(\upsilon_H + g)^2}{2\alpha^2} - c_p g^2] + \gamma(1-\lambda)[S_R - c_f \frac{\upsilon_H^2}{2\alpha^2}]$$

S.t.

$$\frac{(\upsilon_H + g)^2}{2\alpha} - S_G + \mu g \geq 0 \qquad (IR_G)$$

$$\frac{\upsilon_H^2}{2\alpha} - S_R \geq 0 \qquad (IR_R)$$

$$\frac{(\upsilon_H + g)^2}{2\alpha} - S_G + \mu g \geq \frac{\upsilon_H^2}{2\alpha} - S_R \qquad (IC_G)$$

$$\frac{\upsilon_H^2}{2\alpha} - S_R \geq \frac{(\upsilon_H + g)^2}{2\alpha} - S_G \qquad (IC_R)$$

Optimal flat fees are $S_G^{((P,\varnothing),(P,\varnothing))*} = \frac{(\upsilon_H + g)^2}{2\alpha} + \mu g^*$ and $S_R^{((P,\varnothing),(P,\varnothing))*} = \frac{\upsilon_H^2}{2\alpha}$ and optimal efficiency is $g^{((P,\varnothing),(P,\varnothing))*} = \frac{\upsilon_H(\alpha - c_f) + \alpha^2\mu}{2c_p\alpha^2 - (\alpha - c_f)}$.

Hybrid policy. Since the proof is similar, we skip the details and we just first present the model and optimal values for $((P,\varnothing),(U,\varnothing))$ as follows:

$$\max_{p,F,S,g} \quad \pi^E_{((P,\varnothing),(U,\varnothing))} = \gamma\lambda[S - c_f \frac{(\upsilon_H + g)^2}{2\alpha^2} - c_p g^2] + \gamma(1-\lambda)[p\frac{\upsilon_H - p - \delta}{\alpha} + F - c_f \frac{(\upsilon_H - p - \delta)^2}{2\alpha^2} - c_m]$$

S.t.

$$\frac{(\upsilon_H+g)^2}{2\alpha}-S+\mu g\geq 0 \tag{IR_G}$$

$$\frac{(\upsilon_H-p-\delta)^2}{2\alpha}-F\geq 0 \tag{IR_R}$$

$$\frac{(\upsilon_H+g)^2}{2\alpha}-S+\mu g\geq \frac{(\upsilon_H-p-\delta)^2}{2\alpha}-F \tag{IC_G}$$

$$\frac{(\upsilon_H-p-\delta)^2}{2\alpha}-F\geq \frac{(\upsilon_H+g)^2}{2\alpha}-S \tag{IC_R}$$

The optimal prices are $S^{((P,\varnothing),(U,\varnothing))*}=\frac{(\upsilon_H+g)^2}{2\alpha}+\mu g,\ F^{((P,\varnothing),(U,\varnothing))*}=\frac{(\upsilon_H-p-\delta)^2}{2\alpha}$, and $p^{((P,\varnothing),(U,\varnothing))*}=\frac{c_f(\upsilon_H-\delta)}{\alpha+c_f}$. Also, the optimal efficiency level is $g^{((P,\varnothing),(U,\varnothing))*}=\frac{\upsilon_H(\alpha-c_f)+\alpha^2\mu}{2c_p\alpha^2-(\alpha-c_f)}$. It is important to note that we assume that $0<g^{((P,\varnothing),(U,\varnothing))*}<1$. To satisfy this condition, we have to apply some conditions on the parameters. From $g^{((P,\varnothing),(U,\varnothing))*}>0$ we get $c_p>\frac{\alpha^2}{2(alpha+c_f)}$ $c_p>\frac{\alpha-c_f}{2\alpha^2}$. From, $g^{((P,\varnothing),(U,\varnothing))*}<1$, we get $c_p>\frac{\alpha-c_f}{\alpha^2}+\frac{\mu}{2}$ and $c_p>\frac{\alpha^2(2-\delta)}{2(\alpha+c_f)}+\frac{\alpha^2}{2}$. It is straightforward to show the last two inequalities are binding. Therefore, we will apply these two conditions upfront to avoid trivial solutions.

The inverse hybrid policy. i.e., $((U,\varnothing),(P,\varnothing))$ is also feasible here. Since the proof is the same as Proposition 4, and the policy is in the end dominated, we skip the proof.

Comparison. First, we compare the $((P,\varnothing),(P,\varnothing))$ policy with its exclusion counterpart $(P,\varnothing)$. We can easily replace optimal values from Proposition 4 and second part of this Lemma to compare the optimal objective value of these policies. Following formulation shows the difference:

$$\pi^{E*}_{((P,\varnothing),(P,\varnothing))}-\pi^*_{(P,\varnothing)}=\frac{\gamma\lambda(\alpha+\alpha^2\mu-c_f)^2}{2\alpha^2(-\alpha+2\alpha^2c_p+c_f)} \tag{2.74}$$

Given the conditions are given in last part, i.e., $c_p>\frac{\alpha-c_f}{\alpha^2}$, this value is always positive. Therefore, we can conclude the $((P,\varnothing),(P,\varnothing))$ policy always dominates $(P,\varnothing)$ policy in terms of profitability.

Optimal objective value of the hybrid policy, using last part of this proof, is as follows:

$$\begin{aligned}\pi^{E*}_{((P,\varnothing),(U,\varnothing))}=\gamma\big[\lambda&\frac{-c_p(\alpha+\alpha^2\mu-c_f)+\mu(\alpha+\alpha^2\mu-c_f)(-\alpha+2\alpha^2c_p+c_f)}{2(-\alpha+2\alpha^2c_p+c_f)}\\&+\frac{(\alpha-c_f)(\mu+2c_p)^2}{2(-\alpha+2\alpha^2c_p+c_f)}+(1-\lambda)\frac{(c_f+\alpha c_f^2)(1-\delta)^2}{2(\alpha+c_f)^2}\big]\\&=\lambda\pi^{E*}_{((P,\varnothing),(P,\varnothing))}+(1-\lambda)\pi^{E*}_{((U,\varnothing),(U,\varnothing))}\end{aligned} \tag{2.75}$$

where the last equality comes from first and second part of this lemma. We have shown $\pi^{E*}_{((P,\varnothing),(U,\varnothing))}$ is a linear combination of $\pi^{E*}_{((P,\varnothing),(P,\varnothing))}$ and $\pi^{E*}_{((U,\varnothing),(U,\varnothing))}$, and they are always positive. Therefore, one of the following situation can happens: $\pi^{E*}_{((P,\varnothing),(P,\varnothing))}\leq$

$\pi^{E^*}_{((P,\varnothing),(U,\varnothing))} \leq \pi^{E^*}_{((U,\varnothing),(U,\varnothing))}$ or $\pi^{E^*}_{((U,\varnothing),(U,\varnothing))} \leq \pi^{E^*}_{((P,\varnothing),(U,\varnothing))} \leq \pi^{E^*}_{((P,\varnothing),(P,\varnothing))}$. In either of these cases the $((P,\varnothing),(U,\varnothing))$ is dominated by one of the pure policies. Thus, we can say $((P,\varnothing),(U,\varnothing))$ is always dominated by either of the pure policies. This proves the hybrid policy is never optimal.

A similar argument can be used to show that $((U,\varnothing),(P,\varnothing))$ is also dominated. Just the linear combination would be inverse as follows: $\pi^{E^*}_{((U,\varnothing),(P,\varnothing))} = \lambda\pi^{E^*}_{((U,\varnothing),(U,\varnothing))} + (1-\lambda)\pi^{E^*}_{((P,\varnothing),(P,\varnothing))}$ □. But, following the same reasoning this policy is also always dominated by either of pure policies.

□ □

Proof. **Proof of Proposition 8.** Here, we prove the optimality conditions for different policies in terms of profitability and environmental impact.

Profitability. We have shown in Lemma 2 that $(P,\varnothing)$ is dominated by $((P,\varnothing),(P,\varnothing))$ and also the hybrid policy is dominated by either one of pure policies. Now, we have to compare $((U,\varnothing),(U,\varnothing))$, $((P,\varnothing),(U,\varnothing))$, and $(U,\varnothing)$ policies. We have $\frac{\partial \pi^{E^*}_{((U,\varnothing),(U,\varnothing))}}{\partial \delta} < 0$, $\frac{\partial \pi^{E^*}_{((P,\varnothing),(P,\varnothing))}}{\partial \delta} = 0$, and $\frac{\partial \pi^*_{(U,\varnothing)}}{\partial \delta} < 0$ for $\delta \leq 1$. Also, we have $\frac{\partial \pi^{E^*}_{((U,\varnothing),(U,\varnothing))}}{\partial \delta} \leq \frac{\partial \pi^*_{(U,\varnothing)}}{\partial \delta}$ (analytical expressions will be provided upon request). Now, if we define $\underline{\delta} \doteq \{\delta : \pi^{E^*}_{((U,\varnothing),(U,\varnothing))} - \pi^*_{(U,\varnothing)} = 0\}$, this means for $\delta \leq \underline{\delta}$, $((U,\varnothing),(U,\varnothing))$ outperforms $(U,\varnothing)$ and for $\delta \geq \underline{\delta}$, vice versa. Now, if we define $\hat{\delta} \doteq \{\delta : \pi^{E^*}_{((P,\varnothing),(P,\varnothing))} - \pi^*_{((U,\varnothing),(U,\varnothing))} = 0\}$, since $\frac{\partial \pi^{E^*}_{((P,\varnothing),(P,\varnothing))} - \pi^{E^*}_{((U,\varnothing),(U,\varnothing))}}{\partial \delta} \geq 0$, we could say for for $\delta \leq \hat{\delta}$, $((U,\varnothing),(U,\varnothing))$ outperforms $((P,\varnothing),(P,\varnothing))$, and for $\delta \geq \hat{\delta}$, vice versa. Finally, if we define $\bar{\delta} \doteq \{\delta : \pi^{E^*}_{((P,\varnothing),(P,\varnothing))} - \pi^*_{(U,\varnothing)} = 0\}$, since we have $\frac{\partial \pi^{E^*}_{((P,\varnothing),(P,\varnothing))} - \pi^*_{(U,\varnothing)}}{\partial \delta} \geq 0$, we can say for $\delta \leq \bar{\delta}$, $(U,\varnothing)$ outperforms $((P,\varnothing),(P,\varnothing))$ and for $\delta \geq \bar{\delta}$, vice versa.

Given this specifications, if $\underline{\delta} \leq \hat{\delta}$, which can be translated to $c_f \geq \bar{c}_f^E$, then we have all the policies in the map. This means that for $\delta \leq \underline{\delta}$, optimal policy is $((U,\varnothing),(U,\varnothing))$, for $\underline{\delta} \leq \delta \leq \bar{\delta}$, $(U,\varnothing)$ is optimal, and for $\delta \geq \bar{\delta}$, $((P,\varnothing),(P,\varnothing))$ is optimal. However, if $\underline{\delta} \geq \hat{\delta}$, or $c_f \leq \bar{c}_f^E$, this means $(U,\varnothing)$ is not optimal anymore. This way $\hat{\delta}$ plays a role and as we said before, for $\delta \leq \hat{\delta}$, $((U,\varnothing),(U,\varnothing))$ is optimal and for $\delta \geq \hat{\delta}$, $((P,\varnothing),(P,\varnothing))$ is optimal. Exact expressions for $\underline{\delta}$, $\hat{\delta}$, and $\bar{\delta}$ are available upon request

Environmental Impact. To compare environmental impact of three superior policies, first we present the final formulation of the environmental impact of each policy as follows:

$$EI^{E*}_{((U,\varnothing),(U,\varnothing))} = \gamma\lambda\big(e_{pd} + \frac{e_u(\alpha^2+2c_p(1-\delta))^2}{(\alpha^2-2c_p(\alpha+c_f))^2} + \frac{e_{pd}\alpha^2(1+\alpha-\delta+c_f)}{\alpha^2-2c_p(\alpha+c_f)}\big) + \gamma(1-\lambda)\big(e_{pd} + \frac{e_u(1-\delta)^2}{(\alpha+c_f)^2}\big) \tag{2.76}$$

$$EI^{E*}_{((P,\varnothing),(P,\varnothing))} = \gamma\lambda\big(e_{pd} + \frac{e_u\alpha^2(2c_p+\mu)^2}{(-\alpha+2\alpha^2c_p+c_f)^2} - \frac{e_{pd}(\alpha+\alpha^2\mu-c_f)}{-\alpha+2\alpha^2c_p+c_f}\big) + \gamma(1-\lambda)\big(e_{pd} + \frac{e_u}{\alpha^2}\big) \tag{2.77}$$

$$EI^*(U,\varnothing) = \frac{\gamma(e_{pd}(\alpha+c_f)^2) + e_u(1-\delta)^2}{(\alpha+c_f)^2} \tag{2.78}$$

From a first-order derivative we have: $\frac{\partial EI^E_{((U,\varnothing),(U,\varnothing))}}{\partial e_u} = \frac{\gamma(1-\lambda)(1-\delta)^2}{(\alpha+c_f)^2} + \frac{\gamma\lambda(\alpha^2+2c_p(1-\delta))^2}{(\alpha^2-2c_p(\alpha+c_f))^2} > 0$, $\frac{\partial EI^*_{((P,\varnothing),(P,\varnothing))}}{\partial e_u} = \gamma\frac{1-\lambda}{\alpha^2} + \frac{\alpha^2(2c_p+\mu)^2}{(-\alpha+2\alpha^2c_p+c_f)^2} > 0$, and $\frac{\partial EI_{(U,\varnothing)}}{\partial e_u} = \frac{\gamma(1-\delta)^2}{(\alpha+c_f)^2} > 0$. This shows all environmental impacts are linear and strictly increasing in e_u.

Now we focus on difference functions. We have $\frac{\partial EI^E_{((P,\varnothing),(P,\varnothing))} - EI_{((U,\varnothing),(U,\varnothing))}}{\partial e_u} = \gamma\big[\frac{1-\lambda}{\alpha^2} - \frac{(1-\lambda)(1-\delta)^2}{(\alpha+c_f)^2} + \frac{\lambda\alpha^2(2c_p+\mu)^2}{(-\alpha+2\alpha^2c_p+c_f)^2} - \frac{\lambda(\alpha^2+2c_p(1-\delta))^2}{(\alpha^2-2c_p(\alpha+c_f))^2}\big]$. Consider first two terms. With some algebra, we could simplify it to $(1-\lambda)\frac{c_f^2+2\alpha c_f+\alpha^2\delta(2-\delta)}{\alpha^2(\alpha+c_f)^2} > 0$ since $\delta \leq 1$ and based on conditions on c_p presented in Lemma 2. Now, consider second two terms. The denominator of the second term is bigger, $-\alpha + 2\alpha^2c_p + c_f < -\alpha^2 + 2c_p\alpha + 2c_pc_f$, because every single term is bigger in the second denominator. If we show the numerator of the first term is bigger, we are done. With some algebra, we would have condition $c_p > \frac{\alpha(\alpha-\mu)}{2(\alpha+\delta-1)}$. This is satisfied based on conditions presented in Lemma 2 for c_p.fun Therefore, we can say $\frac{\partial EI^E_{((P,\varnothing),(P,\varnothing))}}{\partial e_u} > \frac{\partial EI^E_{((U,\varnothing),(U,\varnothing))}}{\partial e_u}$.

Now consider, $\frac{\partial EI^E_{((U,\varnothing),(U,\varnothing))} - EI^E_{(U,\varnothing)}}{\partial e_u} = \gamma\big[\frac{\lambda(\alpha^2+2c_p(1-\delta))^2}{(-\alpha^2+2c_p(\alpha+c_f))^2} - \frac{\lambda(1-\delta)^2}{(\alpha+c_f)^2}\big]$. Now, consider $\frac{(2c_p(1-\delta))^2}{(2c_p(\alpha+c_f))^2} = \frac{(1-\delta)^2}{(\alpha+c_f)^2}$. If we add a positive amount to the numerator and subtract the denominator by a positive amount, the fraction will be smaller. Therefore, $\frac{(\alpha^2+2c_p(1-\delta))^2}{-\alpha^2+(2c_p(\alpha+c_f))^2} < \frac{(1-\delta)^2}{(\alpha+c_f)^2}$, which show finally that $\frac{\partial EI^E_{((U,\varnothing),(U,\varnothing))}}{\partial e_u} > \frac{\partial EI(U,\varnothing)}{\partial e_u}$. Overall, we could say:

$$\frac{\partial EI^E_{((P,\varnothing),(P,\varnothing))}}{\partial e_u} > \frac{\partial EI^E_{((U,\varnothing),(U,\varnothing))}}{\partial e_u} > \frac{\partial EI_{(U,\varnothing)}}{\partial e_u}$$

Now, if we define $\underline{e}_u = \{e_u : EI^E_{((P,\varnothing),(P,\varnothing))} - EI^E_{((U,\varnothing),(U,\varnothing))} = 0\}$, since we have proved $\frac{\partial EI^E_{((P,\varnothing),(P,\varnothing))} - EI^E_{((U,\varnothing),(U,\varnothing))}}{\partial e_u} > 0$, for $e_u \leq \underline{e}_u$, $((P,\varnothing),(P,\varnothing))$ has the lowest environmental impact. If we define, $\bar{e}_u = \{e_u : EI^E_{((U,\varnothing),(U,\varnothing))} - EI_{(U,\varnothing)} == 0\}$, since we have shown

$\frac{\partial EI^E_{((U,\varnothing),(U,\varnothing))} - EI_{(U,\varnothing)}}{\partial e_u} > 0$, for $\underline{e}_u \leq e_u \leq \bar{e}_u$, $((U,\varnothing),(U,\varnothing))$ has the lowest environmental impact and for $e_u \geq \bar{e}_u$, $(U,\varnothing)$ has the lowest environmental impact.

□ □

2.8.2 Appendix B

In this part, we provide the SP's decision making model when there are four segments in the market. The customers in the market have either high (denoted with H) or low (L) usage-valuation. Similar to the basic model, γ fraction of the customers are high usage-valuation and $1-\gamma$ are low usage-valuation. Also, they might be green (G) with environmental concerns or regular (R) customers. Simialr to the product-line mode, λ fraction of customers are green and $1-\lambda$ are regular. Thus, we high usage valuation green customers, denoted by HG, high usage-valuation regular customers, denoted by HR, low usage valuation green customers, denoted by LG, and low usage-valuation regular customers, denoted by LR. Please note that all the prices will be indicated with these double subscripts in these models while there was only one in the models before. For example, p_{HG} represents the per-use price for the high usage-valuation green customers.

Here, we only focus on two examples of possible pairs of product-schemes, namely $((U,U),(U,U))$ and $((P,P),(P,P))$.

Proof. **((U,U),(U,U)):** First, we need to model the problem the SP faces to decide the optimal prices. In principle, we need 4 individual rationality (IR) constraints and 12 incentive compatibility (IC) constraints. Thus, we have:

$$\begin{aligned}\max_{p,F,g} \quad \pi^E_{((U,U),(U,U))} = & \gamma\lambda[p_{HG}\theta_{HG} + F_{HG} - c_f\frac{\theta^2_{HG}}{2} - c_p g^2] + \\ & \gamma(1-\lambda)[p_{HR}\theta_{HR} + F_{HR} - c_f\frac{\theta^2_{HR}}{2}] + \\ & (1-\gamma)\lambda[p_{LG}\theta_{LG} + F_{LG} - c_f\frac{\theta^2_{LG}}{2} - c_p g^2] + \\ & (1-\gamma)(1-\lambda)[p_{LR}\theta_{LR} + F_{LR} - c_f\frac{\theta^2_{LR}}{2}] - c_m\end{aligned}$$

S.t.

$$\frac{(\upsilon_H - p_{HG} - \delta + g)^2}{2\alpha} - F_{HG} + \mu g \geq 0 \tag{IR_{HG}}$$

$$\frac{(\upsilon_H - p_{HR} - \delta)^2}{2\alpha} - F_{HR} \geq 0 \tag{IR_{HR}}$$

$$\frac{(\upsilon_L - p_{LG} - \delta + g)^2}{2\alpha} - f_{LG} + \mu g \geq 0 \tag{IR_{LG}}$$

$$\frac{(\upsilon_L - p_{LR} - \delta)^2}{2\alpha} - F_{LR} \geq 0 \tag{IR_{LR}}$$

$$\frac{(\upsilon_H - p_{HG} - \delta + g)^2}{2\alpha} - F_{HG} + \mu g \geq \frac{(\upsilon_L - p_{LG} - \delta + g)^2}{2\alpha} - F_{LG} + \mu g \tag{IC_{HG}}$$

$$\frac{(\upsilon_H - p_{HG} - \delta + g)^2}{2\alpha} - F_{HG} + \mu g \geq \frac{(\upsilon_H - p_{HR} - \delta)^2}{2\alpha} - F_{HR} \tag{$IC^{'}_{HG}$}$$

$$\frac{(\upsilon_H - p_{HG} - \delta + g)^2}{2\alpha} - F_{HG} + \mu g \geq \frac{(\upsilon_H - p_{LR} - \delta)^2}{2\alpha} - F_{LR} \tag{$IC^{''}_{HG}$}$$

$$\frac{(\upsilon_L - p_{LG} - \delta + g)^2}{2\alpha} - F_{LG} + \mu g \geq \frac{(\upsilon_H - p_{HR} - \delta)^2}{2\alpha} - F_{HR} \tag{IC_{LG}}$$

$$\frac{(\upsilon_L - p_{LG} - \delta + g)^2}{2\alpha} - F_{LG} + \mu g \geq \frac{(\upsilon_L - p_{HG} - \delta + g)^2}{2\alpha} - F_{HG} + \mu g \tag{$IC^{'}_{LG}$}$$

$$\frac{(\upsilon_L - p_{LG} - \delta + g)^2}{2\alpha} - F_{LG} + \mu g \geq \frac{(\upsilon_L - p_{LR} - \delta)^2}{2\alpha} - F_{LR} \tag{$IC^{''}_{LG}$}$$

$$\frac{(\upsilon_H - p_{HR} - \delta)^2}{2\alpha} - F_{HR} \geq \frac{(\upsilon_H - p_{LR} - \delta)^2}{2\alpha} - F_{LR} \tag{IC_{HR}}$$

$$\frac{(\upsilon_H - p_{HR} - \delta)^2}{2\alpha} - F_{HR} \geq \frac{(\upsilon_H - p_{HG} - \delta)^2}{2\alpha} - F_{HG} \tag{$IC^{'}_{HR}$}$$

$$\frac{(\upsilon_H - p_{HR} - \delta)^2}{2\alpha} - F_{HR} \geq \frac{(\upsilon_H - p_{LG} - \delta)^2}{2\alpha} - F_{LG} \tag{$IC^{''}_{HR}$}$$

$$\frac{(\upsilon_L - p_{LR} - \delta)^2}{2\alpha} - F_{LR} \geq \frac{(\upsilon_L - p_{HG} - \delta)^2}{2\alpha} - F_{HG} \tag{IC_{LR}}$$

$$\frac{(\upsilon_L - p_{LR} - \delta)^2}{2\alpha} - F_{LR} \geq \frac{(\upsilon_L - p_{LG} - \delta)^2}{2\alpha} - F_{LG} \tag{$IC^{'}_{LR}$}$$

$$\frac{(\upsilon_L - p_{LR} - \delta)^2}{2\alpha} - F_{LR} \geq \frac{(\upsilon_L - p_{HR} - \delta)^2}{2\alpha} - F_{HR} \tag{$IC^{''}_{LR}$}$$

According to Bolton et al. (2005), in such a model, only downward-comparison IC constraints are binding. Therefore, we only have three binding ICs left, i.e., IC_{HG}, IC_{LG} and IC_{HR}. Also, we can easily show that the only binding IR is the IR_{LR}. Thus, we would have $F^*_{LR} = \frac{(\upsilon_L - p_{LR} - \delta)^2}{2\alpha}$. Also, from IC constraints, we would have $F_{HR} = \frac{(\nu_H - p_{HR} - \delta)^2}{2\alpha} - \frac{(\nu_H - p_{LR} - \delta)^2}{2\alpha} + \frac{(\nu_L - p_{LR} - \delta)^2}{2\alpha}$, $F_{LG} = \frac{(\nu_L - p_{LG} - \delta + g)^2}{2\alpha} - \frac{(\nu_L - p_{HR} - \delta)^2}{2\alpha} + F_{HR} + \mu g$, and $F_{HG} = \frac{(\nu_H - p_{HG} - \delta + g)^2}{2\alpha} - \frac{(\nu_H - p_{LG} - \delta + g)^2}{2\alpha} + F_{LG} + \mu g$.

Now, assuming these values are optimal, we calculate the optimal ps and g in the objective function. Then, we will check whether the optimal solution meets the constraints. With an

FOC, we have the following optimal values for per-use prices and g:

$$p^*_{LR} = \frac{\alpha(\nu_H - \nu_L)}{(\alpha + c_f)(1-\gamma)(1-\lambda)} - \frac{c_f(\delta - \nu_H)}{\alpha + c_f} \tag{2.79}$$

$$p^*_{HR} = \frac{c_f\gamma(1-\lambda)(\nu_H - \delta) - \alpha\lambda(\nu_H - \nu_L)}{(\alpha + c_f)\gamma(1-\lambda)} \tag{2.80}$$

$$p^*_{LG} = \left[\frac{\begin{array}{r}\big((2\alpha^2 c_p\gamma - \alpha\gamma)(\nu_H - \nu_L) + c_f^2(1-\gamma)(-2c_p\delta + \mu + \gamma\mu + 2c_p\nu_L) + \\ \alpha c_f(\mu - \gamma^2\mu + 2c_p(\gamma\nu_H - \nu_L - 2\gamma\nu_L - \delta(1-\gamma)))\end{array}}{(1-\gamma)(\alpha + c_f)(-1 + 2\alpha c_p + 2c_f c_p)} \right] \tag{2.81}$$

$$p^*_{HG} = \frac{(\alpha c_f + c_f)(-2c_p\delta + \mu + \gamma\mu + 2c_p\nu_H) - c_f(\nu_H - \nu_L)}{(\alpha + c_f)(-1 + 2\alpha c_p + 2c_f c_p)} \tag{2.82}$$

$$g^* = \frac{-delta + (1+\gamma)c_f\mu + \alpha(1+\gamma)\mu + \nu_L}{-1 + 2\alpha c_p + 2c_f c_p} \tag{2.83}$$

To prove these are optimal values, we need to show that the profit function is concave in all of them. The second-order derivative of the profit function w.r.t. these variables are $\frac{\partial^2\pi}{\partial p^2_{LR}} = \frac{-(\alpha+c_f)(1-\gamma)(1-\lambda)}{\alpha^2}$, $\frac{\partial^2\pi}{\partial p^2_{LG}} = \frac{-(\alpha+c_f)(1-\gamma)\lambda}{\alpha^2}$, $\frac{\partial^2\pi}{\partial p^2_{HR}} = \frac{-(\alpha+c_f)\gamma(1-\lambda)}{\alpha^2}$, $\frac{\partial^2\pi}{\partial p^2_{HG}} = \frac{-(\alpha+c_f)\gamma\lambda}{\alpha^2}$, and finally $\frac{\partial^2\pi}{\partial g^2} = -\frac{(-\alpha+c_f+2\alpha^2 c_p)\lambda}{\alpha^2}$. The first four are obviously negative since $\gamma \leq 1$ and $\lambda \leq 1$. The last one needs the condition $c_p \geq \frac{\alpha - c_f}{2\alpha^2}$.

((U,U),(U,U)): Following the same procedure, we first present the SP's decision model as follows including only those ICs that are biding:

$$\begin{aligned}\max_{p,F,g} \quad \pi^E_{((P,P),(P,P))} =& \gamma\lambda[S_{HG} - c_f\frac{\theta^2_{HG}}{2} - c_p g^2] + \gamma(1-\lambda)[S_{HR} - c_f\frac{\theta^2_{HR}}{2}] + \\ & (1-\gamma)\lambda[S_{LG} - c_f\frac{\theta^2_{LG}}{2} - c_p g^2] + (1-\gamma)(1-\lambda)[S_{LR} - c_f\frac{\theta^2_{LR}}{2}]\end{aligned}$$

S.t.

$$\frac{(\upsilon_H+g)^2}{2\alpha}-S_{HG}+\mu g\geq 0 \qquad (IR_{HG})$$
$$\frac{(\upsilon)^2}{2\alpha}-S_{HR}\geq 0 \qquad (IR_{HR})$$
$$\frac{(\upsilon_L+g)^2}{2\alpha}-S_{LG}+\mu g\geq 0 \qquad (IR_{LG})$$
$$\frac{(\upsilon_L)^2}{2\alpha}-S_{LR}\geq 0 \qquad (IR_{LR})$$
$$\frac{(\upsilon_H+g)^2}{2\alpha}-S_{HG}+\mu g\geq \frac{(\upsilon_H)^2}{2\alpha}-S_{HR} \qquad (IC_{HG})$$
$$\frac{(\upsilon_H+g)^2}{2\alpha}-S_{HG}+\mu g\geq \frac{(\upsilon_H)^2}{2\alpha}-S_{LG}+\mu g \qquad (IC^{'}_{HG})$$
$$\frac{(\upsilon_H+g)^2}{2\alpha}-S_{HG}+\mu g\geq \frac{(\upsilon_H)^2}{2\alpha}-S_{LR} \qquad (IC^{''}_{HG})$$
$$\frac{(\upsilon_H)^2}{2\alpha}-S_{HR}\geq \frac{(\upsilon_H+g)^2}{2\alpha}-S_{LG} \qquad (IC_{HR})$$
$$\frac{(\upsilon_H)^2}{2\alpha}-S_{HR}\geq \frac{(\upsilon_H)^2}{2\alpha}-S_{HG} \qquad (IC^{'}_{HR})$$
$$\frac{(\upsilon_H)^2}{2\alpha}-S_{HR}\geq \frac{(\upsilon_H)^2}{2\alpha}-S_{LR} \qquad (IC^{''}_{HR})$$
$$\frac{(\upsilon_L+g)^2}{2\alpha}-S_{LG}+\mu g\geq \frac{(\upsilon_L)^2}{2\alpha}-S_{LR} \qquad (IC_{LG})$$
$$\frac{(\upsilon_L+g)^2}{2\alpha}-S_{LG}+\mu g\geq \frac{(\upsilon_L+g)^2+}{2\alpha}-S_{HG}+\mu g \qquad (IC^{'}_{LG})$$
$$\frac{(\upsilon_L+g)^2}{2\alpha}-S_{LG}+\mu g\geq \frac{(\upsilon_L)^2}{2\alpha}-S_{HR} \qquad (IC^{''}_{LG})$$
$$\frac{(\upsilon_L)^2}{2\alpha}-S_{LR}\geq \frac{(\upsilon_L)^2}{2\alpha}-S_{HG} \qquad (IC_{LR})$$
$$\frac{(\upsilon_L)^2}{2\alpha}-S_{LR}\geq \frac{(\upsilon_L)^2}{2\alpha}-S_{LG} \qquad (IC^{'}_{LR})$$
$$\frac{(\upsilon_L)^2}{2\alpha}-S_{LR}\geq \frac{(\upsilon_L)^2}{2\alpha}-S_{HR} \qquad (IC^{''}_{LR})$$

Again, IR_{LR} is binding, thus we have $F_{LR}=\frac{\upsilon_L^2}{2\alpha}$. Then assuming IC_{HG}, IC_{HR}, and IV_{LG} are binding, we have $S_{LG}=\frac{(\upsilon_L+g)^2}{2\alpha}+\mu g$, $S_{HR}=\frac{\upsilon_H^2}{2\alpha}-\frac{(\upsilon_H+g)^2}{2\alpha}+\frac{(\upsilon_L+g)^2}{2\alpha}+\mu g$, and $S_{HG}=\frac{(\upsilon_L+g)^2}{2\alpha}+2\mu g$. Here, we only need to calculate the optimal g from the objective function. Plugging the S values into the objective function, and taking an FOC from it, we have:

$$g^*=\frac{\alpha^2(\gamma+\lambda)\mu-c_f\lambda(\gamma(\upsilon_H-\upsilon_L)+\upsilon_L)+\alpha(-\gamma(1-\lambda)(\upsilon_H-\upsilon_L)+\lambda\upsilon_L)}{\lambda(-\alpha+c_f+2\alpha^2c_p)} \qquad (2.84)$$

For this value to be optimal, we need to show the profit function is concave. Thus, we take the second order derivative as $\frac{\partial^2 \pi}{\partial g^2} = -\frac{(-\alpha+c_f+2\alpha^2 c_p)\lambda}{\alpha^2}$, which is negative if we have $c_p \geq \frac{\alpha - c_f}{2\alpha^2}$. □

□

Proof. **Proof of Proposition 9:** To show these properties, we need to take the first-order derivative of the objective function with respect to each of the desired variables.
$((U,\varnothing),(U,\varnothing))$ **policy:** The objective function for the SP is as follows:

$$\max_{\lambda} \quad \pi^E_{((U,\varnothing),(U,\varnothing))} = \gamma\lambda[p^*_G\theta^*_G + F^*_G - c_f\frac{(\theta^*_G)^2}{2} - c_m - c_p {g^*}^2] + \gamma(1-\lambda)[p^*_R\theta^*_R + F^*_R - c_f\frac{(\theta^*_R)^2}{2} - c_m] - c_g\lambda^2 \tag{2.85}$$

To show the properties for this policy, we have the following first-order derivatives with respect to c_p and μ:

$$\frac{\partial\lambda^*}{\partial\mu} = \frac{-\alpha^2\gamma(1-\delta+\alpha+c_f)}{2c_g(\alpha^2 - 2c_p(\alpha+c_f))} \tag{2.86}$$

$$\frac{\partial\lambda^*}{\partial c_p} = -(\alpha^2\gamma(1-\delta+\alpha+c_f))$$

$$\left[\frac{\alpha^5 + \alpha^4(1+2c_p-\delta+c_f) + 2\alpha^3(-1+(1-\delta)c_p+\mu+2c_pc_f) + 4\alpha c_p(\delta - 2\mu c_f - \upsilon_H) - 2\alpha^2(1+2c_p\mu+(1-\mu)c_f + c_p(-1+\delta-c_f)c_f - \upsilon_H) - 4c_pc_f(-\delta+\mu c_f+\upsilon_H)}{2c_g(\alpha^2 - 2\alpha c_p - 2c_pc_f)^3}\right] \tag{2.87}$$

Consider the first equation here. The numerator is obviously negative since $\delta \leq 1$. Also the denominator is negative based on the condition on c_p, we mentioned in Lemma 2. Thus, the whole fraction is positive, which implies $\frac{\partial\lambda^*}{\partial\mu} \geq 0$ and λ^* is increasing in μ.

If we look at the second equation, the term $-(\alpha^2\gamma(1-\delta+\alpha+c_f))$ is always negative since $\delta \leq 1$ and all other parameters are non-negative. Also, as we have shown in Lemma 2, the denominator is also negative. Therefore, if we show that the numerator of the fraction is negative, we are done. Please note that the numerator is a fifth-degree polynomial in α. Since $0 \leq \alpha \leq 1$, $\alpha^5 \leq \alpha^4 \leq \alpha^3 \leq \alpha^2 \leq \alpha \leq 1$, the terms with a degree higher than 2 are negligible. So, we only consider the 4th, 5th and 6th terms in the numerator. The 4th term is $4\alpha c_p(\delta - 2\mu c_f - \upsilon_H)$, which is negative since we have $\upsilon_H \geq \delta$. The 6th term, $-4c_pc_f(-\delta+\mu c_f+\upsilon_H)$ is also negative with the same reason. In the 5th term, the terms which dominate others are $2c_p$ and $c_p(-1+\delta-c_f)c_f$ because they contain c_p. These two terms have opposite signs, but it is easy to show $2c_p \geq c_p(-1+\delta-c_f)c_f$, which implies the whole term is negative. The neglected terms, of the 5th, 4th, and 3rd-degree, are all positive. Therefore, it is safe to say the whole numerator is negative. Thus, the whole equation will be negative. □

$((P,\varnothing),(P,\varnothing))$ **policy:** First, we need to formulate the problem. The new objective function of the SP will be as follows:

$$\max_{\lambda} \pi^{E}_{((P,\varnothing),(P,\varnothing))} = \gamma\lambda[S^*_G - c_f\frac{(\upsilon_H + g^*)^2}{2\alpha^2} - c_p {g^*}^2] + \gamma(1-\lambda)[S^*_R - c_f\frac{\upsilon_H^2}{2\alpha^2}] - c_g\lambda^2$$

We have similar set of first-order derivatives with respect to μ and c_p as follows:

$$\frac{\partial\lambda^*}{\partial\mu} = \frac{\gamma(\alpha^2\mu + \alpha\upsilon_H - c_f\upsilon_H)}{2c_g(-\alpha + 2\alpha^2 c_p + c_f)} \tag{2.88}$$

$$\frac{\partial\lambda^*}{\partial c_p} = -\frac{\gamma(\alpha^2\mu + \alpha\upsilon_H - c_f\upsilon_H)^2}{2c_g(-\alpha + 2\alpha^2 c_p + c_f)^2} \tag{2.89}$$

$$\frac{\partial\lambda^*}{\partial c_f} = -\frac{\gamma(\alpha^2\mu + \alpha\upsilon_H + \alpha^2(\mu + 4c_p\upsilon_H))}{4\alpha^2 c_g(-\alpha + 2\alpha^2 c_p + c_f)^2} \tag{2.90}$$

If we consider the first equation, we see the numerator is positive since all the parameters and variables are non-negative. The denominator is also positive given the condition on c_p mentioned in the proof of Lemma 2. Thus, $\frac{\partial\lambda^*}{\partial\mu} \geq 0$, which means λ^* is increasing in μ. In the second equation, the numerator and denominator are always positive because they are both squared terms and $c_g \geq 0$. Thus, the negative sign shows that $\frac{\partial\lambda^*}{\partial c_p} \leq 0$, which implies λ^* is decreasing in c_p. Finally, the last equation is also similarly all the terms are positive since all the parameters and variables are non-negative. Thus, the negative sign in front makes the whole equation negative. Therefore, $\frac{\partial\lambda^*}{\partial c_f} \leq 0$, which means λ^* is decreasing in c_f. □ □

Proof. **Proof of Proposition 10:**
$((U,\varnothing),(U.\varnothing))$ **policy:** The new model can be formulated as follows:

$$\max_{p_i,F_i,g_1,g_2,i\in\{G,R\}} \pi^{E}_{((U,\varnothing),(U,\varnothing))} = \gamma\lambda[p_G\theta_G + F_G - (1-g_2)c_f\frac{\theta_G^2}{2} - c_m - c_p^u {g_1}^2 - c_p^p {g_2}^2] + \gamma(1-\lambda)[p_R\theta_R + F_R - c_f\frac{\theta_R^2}{2} - c_m] \tag{P.7}$$

s.t.

$$IR_G : (\upsilon_H - p_G - \delta + g_1)\theta_G - F_G - \alpha\frac{\theta_G^2}{2} + \mu(g_1 + g_2) \geq 0$$
$$IR_R : (\upsilon_H - p_R - \delta)\theta_R - F_R - \alpha\frac{\theta_R^2}{2} \geq 0$$
$$IC_G : (\upsilon_H - p_G - \delta + g_1)\theta_G - F_G - \alpha\frac{\theta_G^2}{2} + \mu(g_1 + g_2) \geq (\upsilon_H - p_R - \delta)\theta'_R - F_R - \alpha\frac{\theta'_R 2}{2}$$
$$IC_R : (\upsilon_H - p_R - \delta)\theta_R - F_R - \alpha\frac{\theta_R^2}{2} \geq (\upsilon_H - p_G - \delta + g_1)\theta'_G - F_G - \alpha\frac{\theta'^2_G}{2}$$

The optimal analytical expressions are very complicated and in some cases impossible to derive. Therefore, we compare the solution of the first-order conditions for p_G, p_R, and g_1 here. The variables related to the two-dimensional case have been indicated with a bar. The following equations are the first-order conditions for the case of two-dimensional greenness:

$$\bar{p}_G^* = \frac{(1 - \bar{g}_2^*)c_f(\upsilon_H - \delta + \bar{g}_1^*)}{\alpha + (1 - \bar{g}_2^*)c_f} \tag{2.91}$$
$$\bar{P}_R^* = \frac{c_f(\upsilon_H - \delta)}{\alpha + c_f} \tag{2.92}$$
$$\bar{g}_1^* = \frac{\alpha^2\mu - (1 - \bar{g}_2^*)c_f(\upsilon_H - \bar{p}_G^* - \delta) + \alpha(\upsilon_H - \delta)}{-\alpha + 2\alpha^2 c_p^u + (1 - \bar{g}_2^*)c_f} \tag{2.93}$$
$$\bar{F}_G^* = \frac{(\upsilon - \bar{p}_G^* - \delta + g_1^*)^2}{2\alpha} + \mu(\bar{g}_1^* + \bar{g}_2^*) \tag{2.94}$$
$$\bar{F}_R^* = \frac{\upsilon_H - \bar{p}_R^* - \delta}{2\alpha} \tag{2.95}$$

Now, if we do the same for the Problem **P.7**, we have:

$$p_G^* = \frac{c_f(\upsilon_H - \delta + g_1^*)}{\alpha + c_f} \tag{2.96}$$
$$P_R^* = \frac{c_f(\upsilon_H - \delta)}{\alpha + c_f} \tag{2.97}$$
$$g_1^* = \frac{\alpha^2\mu - c_f(\upsilon_H - p_G^* - \delta) + \alpha(\upsilon_H - \delta)}{-\alpha + 2\alpha^2 c_p^u + c_f} \tag{2.98}$$
$$F_G^* = \frac{(\upsilon_H - p_G^* - \delta + g_1^*)^2}{2\alpha} + \mu g_1^* \tag{2.99}$$
$$F_R^* = \frac{\upsilon_H - p_R^* - \delta}{2\alpha} \tag{2.100}$$

Now, if we take the difference between these variables, we find:

$$\bar{g}_1^* - g_1^* = \frac{\alpha^2\mu - (1-\bar{g}_2^*)c_f(\upsilon_H - \bar{p}_G^* - \delta) + \alpha(\upsilon_H - \delta)}{-\alpha + 2\alpha^2 c_p^u + (1-\bar{g}_2^*)c_f} - \frac{\alpha^2\mu - c_f(\upsilon_H - p_G^* - \delta) + \alpha(\upsilon_H - \delta)}{-\alpha + 2\alpha^2 c_p^u + c_f} \tag{2.101}$$

$$\bar{p}_G^* - p_G^* = \frac{(1-\bar{g}_2^*)c_f(\upsilon_H - \delta + \bar{g}_1^*)}{\alpha + (1-\bar{g}_2^*)c_f} - \frac{c_f(\upsilon_H - \delta + g_1^*)}{\alpha + c_f} \tag{2.102}$$

$$\bar{F}_G^* - F_G^* = \frac{(\upsilon_H - \bar{p}_G^* - \delta + \bar{g}_1^*)^2}{2\alpha} + \mu(\bar{g}_1^* + \bar{g}_2^*) - \frac{(\upsilon_H - p_G^* - \delta + g_1^*)^2}{2\alpha} + \mu g_1^* \tag{2.103}$$

$$\bar{P}_R^* - P_R^* = \frac{c_f(\upsilon_H - \delta)}{\alpha + c_f} - \frac{c_f(\upsilon_H - \delta)}{\alpha + c_f} = 0 \tag{2.104}$$

$$\bar{F}_R^* - F_R^* = \frac{\upsilon_H - \bar{p}_R^* - \delta}{2\alpha} - \frac{\upsilon_H - p_R^* - \delta}{2\alpha} = 0 \tag{2.105}$$

Let us consider the first equation to compare the g_1^* difference. The two fractions in these equation are very similar. The difference lies in the denominator and the middle term of the numerator. The denominator of the first fraction is smaller by an amount of $\bar{g}_2^*$ and the middle term of the numerator of the first fraction is multiplied by a factor of $0 \le (1-\bar{g}_2^*) \le 1$. If we compare the two fractions term by term we have the following: The first and the third terms together are $\frac{\alpha^2\mu+\alpha(\upsilon_H-\delta)}{-\alpha+2\alpha^2 c_p^u+(1-\bar{g}_2^*)c_f} - \frac{\alpha^2\mu+\alpha(\upsilon_H-\delta)}{-\alpha+2\alpha^2 c_p^u+c_f}$. Here the numerators are the same, but the denominators of the first fraction is smaller, so the first fraction is bigger, which implies: $\frac{\alpha^2\mu+\alpha(\upsilon_H-\delta)}{-\alpha+2\alpha^2 c_p^u+(1-\bar{g}_2^*)c_f} - \frac{\alpha^2\mu+\alpha(\upsilon_H-\delta)}{-\alpha+2\alpha^2 c_p^u+c_f} \ge 0$. Now, similarly with some additional algebra for the middle terms: $\frac{-(1-\bar{g}_2^*)c_f(\upsilon_H-\delta)+(1-\bar{g}_2^*)c_f\bar{p}_G^*}{-\alpha+2\alpha^2 c_p^u+(1-\bar{g}_2^*)c_f} - \frac{-c_f(\upsilon_H-\delta)+c_f p_G^*}{-\alpha+2\alpha^2 c_p^u+c_f}$. The first terms in two fractions are again similar. However, the numerator and a part of the denominator of the first fraction is multiplied by $0 \le (1-\bar{g}_2^*) \le 1$, which makes it smaller. Thus, we have $\frac{-(1-\bar{g}_2^*)c_f(\upsilon_H-\delta)}{-\alpha+2\alpha^2 c_p^u+(1-\bar{g}_2^*)c_f} + \frac{c_f(\upsilon_H-\delta)}{-\alpha+2\alpha^2 c_p^u+c_f} \ge 0$. All the terms are smaller in the first fraction this equation. What remains is $\frac{(1-\bar{g}_2^*)c_f\bar{p}_G^*}{-\alpha+2\alpha^2 c_p^u+(1-\bar{g}_2^*)c_f} - \frac{c_f p_G^*}{-\alpha+2\alpha^2 c_p^u+c_f}$. If we assume $\bar{p}_G^* \le p_G^*$ (we will show it is true in the next step), similar logic implies that this term is non-positive. Therefore, this last term is the only negative term in the whole equation. But, since $P_G \le \upsilon_H$, the whole equation would remains positive. Thus, the whole equation is positive, which means $\bar{g}_1^* - g_1^* \ge 0$ and usage-phase greenness level increases in case of two-dimensional greenness.

Now, consider the second equation, which compares p_G^*s. Again, the two fractions in this equation are very similar. The difference is the first fraction's numerator and a part of denominator are decreased by a factor of $(1-\bar{g}_2^*)$. Since $0 \le (1-\bar{g}_2^*) \le 1$ the first fraction is smaller, which implies $\frac{(1-\bar{g}_2^*)c_f(\upsilon_H-\delta+\bar{g}_1^*)}{\alpha+(1-\bar{g}_2^*)c_f} - \frac{c_f(\upsilon_H-\delta+g_1^*)}{\alpha+c_f} \le 0$. This means $\bar{p}_G^* \le p_G^*$ and the SP charges a lower per-use fee in case of two dimensional greenness. This also approves our assumption in the last paragraph.

In the third equation, we take the term by term comparison approach again. First, let's compare the two fractions, $\frac{(\upsilon_H-\bar{p}_G^*-\delta+\bar{g}_1^*)^2}{2\alpha} - \frac{(\upsilon_H-p_G^*-\delta+g_1^*)^2}{2\alpha}$. It is straightforward to show that the numerator of the first fraction is bigger since we have $\bar{g}_1^* \geq g_1^*$ and $\bar{p}_G^* \leq p_g^*$. Thus $\frac{(\upsilon_H - \bar{p}_G^* - \delta + \bar{g}_1^*)^2}{2\alpha} \geq \frac{(\upsilon_H - p_G^* - \delta + g_1^*)^2}{2\alpha}$. Now, the second terms are $\mu(\bar{g}_1^* + \bar{g}_2^*) - \mu g_1^*$. This can be rewritten as $\mu(\bar{g}_1^* - g_1^*) + \mu\bar{g}_2^*$. This term is positive as we have $\bar{g}_1^* \geq g_1^*$ and also $\bar{g}_2^* \geq 0$. Thus, we have $\frac{(\upsilon_H - \bar{p}_G^* - \delta + \bar{g}_1^*)^2}{2\alpha} + \mu(\bar{g}_1^* + \bar{g}_2^*) - \frac{(\upsilon_H - p_G^* - \delta + g_1^*)^2}{2\alpha} + \mu g_1^* \geq 0$, which means $\bar{F}_G^* \geq F_G^*$ and the flat rate is higher in case of a two-dimensional greenness. Also the last two equations easily show the SP does not change the prices for the lower segment in case of a two-dimensional greenness. □

$((P, \varnothing), (P, \varnothing))$ **policy:** The model for this policy can be formulated as follows:

$$\max_{S_i, g_1, g_2, i \in \{G,R\}} \quad \pi^E_{((P,\varnothing),(P,\varnothing))} = \gamma\lambda[S_G - (1-g_2)c_f\frac{\theta_G^2}{2} - c_p^u g_1^2 - c_p^p g_2^2] + \gamma(1-\lambda)[S_R - c_f\frac{\theta_R^2}{2}] \qquad \textbf{(P.8)}$$

s.t.

$$IR_G : (\upsilon_H + g_1)\theta_G - S_G + \mu(g_1 + g_2) \geq 0$$
$$IR_R : \upsilon_H\theta_R - S_R \geq 0$$
$$IC_G : (\upsilon_H + g_1)\theta_G - S_G + \mu(g_1 + g_2) \geq \upsilon_H\theta_R^{'} - S_R$$
$$IC_R : \upsilon_H\theta_R - S_R \geq (\upsilon_H + g_1)\theta_G^{'} - S_G$$

If we do the same procedure for the SP's problem in case of a pay-per-period policy, i.e., $((P, \varnothing), (P, \varnothing))$, we will have the following difference functions between different variables in case of two-dimensional greenness and one-dimensional greenness:

$$\bar{g}_1^* - g_1^* = \frac{\alpha^2\mu + \alpha\upsilon_H - (1-\bar{g}_2^*)c_f\upsilon_H}{-\alpha + 2\alpha^2 c_p^u + (1-\bar{g}_2^*)c_f} - \frac{\alpha^2\mu + \alpha\upsilon_H - c_f\upsilon_H}{-\alpha + 2\alpha^2 c_p^u + c_f} \qquad (2.106)$$

$$\bar{S}_G^* - S_G^* = \frac{(\upsilon_H + \bar{g}_1^*)^2}{2\alpha} + \mu(\bar{g}_1^* + \bar{g}_2^*) - \frac{(\upsilon_H + g_1^*)^2}{2\alpha} - \mu g_1^* \qquad (2.107)$$

$$\bar{S}_R^* - S_R^* = \frac{\upsilon_H^2}{2\alpha} - \frac{\upsilon_H^2}{2\alpha} = 0 \qquad (2.108)$$

In the first equation, the two terms are very similar. The only difference is that the numerator of the first fraction is bigger than the numerator of the second fraction by amount of $\bar{g}_2^* c_f \upsilon_H$. The denominator of the first fraction is smaller than the denominator of the second one by amount of $\bar{g}_2^* c_f$. Since $\bar{g}_2^*$ and the rest of parameters are all positive, we can conclude the first fraction is bigger than the second one since the numerator is bigger and the denominator is smaller in the first fraction. Thus, $\bar{g}_1^* \geq g_1^*$.

If we look at the second equation in this case, the first two terms and the second two terms are similar. The only difference is that instead of $\bar{g}_1^*$, we have g_1^* in second two terms. Also, the first two terms are bigger by amount of $\mu\bar{g}_2^*$. We just showed that $\bar{g}_1^* \geq g_1^*$, and considering g_1^*s only show up in the numerator with positive signs, and also considering

$\bar{g}_2^* \geq 0$, it is straightforward to show that $\bar{S}_G^* \geq S_G^*$. It is also obvious that $\bar{S}_R^* = S_R^*$. The proof of part c) follows immediately as the case with one dimension for greenness becomes a special case of two dimensional greenness with $g_2 = 0$. □ □

3 Design of a Servicizing Business Model

3.1 Introduction

Businesses are increasingly adding a service element to their products. This trend has given rise to a new category of business models called product-service systems (PSS). A PSS refers to a collection of products and services that can effectively meet consumers' needs in a cost-effective and environmentally sustainable way (Reim et al., 2015). PSS are categorized into product-, use-, and result-oriented (Tukker, 2004). In use-oriented PSS (PSS hereafter), the product ownership usually remains with the service provider (SP), and the consumers only pay contingent on their amount or time of usage. Companies deploying a usage-based payment system include Xerox, which charges per page printed (Xerox, 2020), Mobike, which sets a fee per minute (Mobike, 2020), and Bundles, which charges per wash cycle (Bundles, 2021). Some companies use a time-based payment system. For example, Ahrend offers furniture as a service (Ahrend, 2020), Gerrard Street supplies headphones for a fee per month (EMF, 2018d), and Philips provides light for a fixed fee per month (Phillips, 2020).

The increasing popularity of PSS is partly the result of advances in technology, e.g., Internet of Things applications, for measuring actual usage. A second driver is that PSS has significant potential environmental benefits (Tukker, 2004). First, they can reduce usage (Vafa Arani et al., 2023), which decreases the environmental impact in the usage phase. Second, PSS allow the SP to take the product back after use and remanufacture or recycle it. This reduces material use and the environmental impact in the disposal phase (Fu et al., 2022). Third, PSS incentivize SPs to design or choose durable products when they are responsible for maintenance. This can reduce the use of material. The Ellen MacArthur Foundation (EMF) estimates an annual material cost saving of up to €630 billion in Europe alone (EMF, 2013).

Businesses implementing PSS must make several big design choices. Examples include the payment scheme (pay-per-use vs. pay-per-period), price, and contract duration. Despite the popularity of PSS, many businesses have little experience and evidence on which they can base these choices (Vezzoli et al., 2015; Agrawal & Bellos, 2016). Research on PSS has extensively explored potential commercial and environmental benefits and organizational and operational changes required for successful implementation (see, e.g., Baines et al., 2017; Zhang & Banerji, 2017). However, while the success of PSS relies on adoption by consumers, their preferences are understudied. Correspondingly, OSCM models for PSS design typically disregard the demand side of PSS, and many businesses have a limited understanding of how the attributes of PSS affect consumer choices. Furthermore, it is unclear whether and how these PSS attributes affect the perception of product-related characteristics such as energy efficiency, selling price, and quality (Kreye & van Donk, 2021). For example, given that many PSS take responsibility for product maintenance, the utility customers derive from such a product's quality may differ from when they purchase the product.

The lack of understanding could lead to businesses launching a PSS that is weakly aligned with consumer preferences. Consumers may easily switch to convenient and easily accessible purchasing options. Therefore, businesses must understand which attributes strongly impact consumer choices, how changing the level of such attributes affects these choices, and how consumer characteristics drive those choices. This understanding helps businesses tailor their PSS to a market or focus on specific market segments. Our research aims to address this gap by answering the following research questions: 1) How do PSS attributes affect consumer choices? 2) How do consumers' characteristics affect their choices? 3) How should businesses set up a PSS to maximize their market share?

We study four attributes of PSS. The first is the *payment scheme*. Research shows that purchasing, pay-per-use, and pay-per-period trigger different psychological mechanisms and consumer traits. These include risk attitude (Winer, 2005; Lambrecht & Skiera, 2006), sensitivity to paying contingent on usage (Sundararajan, 2004; Cachon & Feldman, 2011), and willingness to own things (Edbring et al., 2016; Poppelaars et al., 2018). We hypothesize that such mechanisms also affect consumer preferences and their choices. The second PSS attribute is *price*. Although it is well-known that price is an important attribute in general, it can strongly affect consumer choices for PSS as consumers may lack the information, skills, or willingness to assess the financial appeal of a PSS objectively. The third includes the termination terms and conditions. Many PSS impose or financially incentivize a *minimum contract duration* (MCD). For example, Swapfiets does not charge a one-off fee if a consumer chooses a six-month MCD (Swapfiets, 2021). This helps to stabilize the SP's income stream. However, it may also discourage consumers who value flexibility (Becker et al., 2015; Rayburn et al., 2020) and those who prefer state-of-the-art technologies (Macdonald & Uncles, 2007; Cui et al., 2009). The fourth attribute is the environmental footprint of the PSS, which is represented by *energy efficiency*. We assume that green consumers prefer energy-efficient products. However, it is unclear whether the utility consumers derive from a product's greenness differs when they adopt a PSS compared to when they purchase the product. On the one hand, users might think that the PSS in itself is environmentally friendly and might thus not be interested in the energy efficiency as much as if they were to purchase it. For example, in line with climate compensation, users might feel that the PSS is environmentally friendly and would feel less compelled to opt for an environmentally friendly product (See e.g., Sörqvist & Langeborg (2019)). On the other hand, the greenness of a PSS might also encourage and remind them to use the more energy-efficient product to be even greener.

To answer our research questions, we conduct a choice experiment for washing machines among 298 Dutch adults. Several businesses have successfully launched a PSS for this product (Homie, 2020; Coolblue, 2020; Bundles, 2021), and the attributes discussed above apply to these PSS. We specifically use a choice-based conjoint analysis (CBCA) to calculate the relative importance of the payment scheme (purchase, pay-per-use, and pay-per-period), price (low, medium, and high), MCD (one year, three, and five years), and energy efficiency (labels A and C). We use the Hierarchical Bayes (HB) method to analyze the data. Our follow-up survey measures participants' characteristics. As we motivate in Section Section 3.2.3.2, we specifically consider the impact of the ticking meter effect, psychological ownership, need for flexibility, insurance effect, greenness, usage level, breakdown probability perception, and cost expectation on consumer choices. We also conduct a cluster analysis in which we find four segments with homogeneous choices in the market. The implications of our main findings are illustrated through simulation analysis. We specifically use the results of the conjoint choice experiment to predict consumers' choices and use these to simulate the impact of attribute-level choices on a company's market share.

Our key contributions to the literature are fourfold. We are the first to quantify and compare the relative importance of payment scheme, price, MCD, and energy efficiency in the choice of consumers between purchase and PSS. Our results show that the payment scheme is the strongest determinant of consumer preferences (32.2%), followed by price (22.9%), MCD (22.8%), and energy efficiency (22%). Second, we shed light on the mechanisms explaining consumer choices. While these mechanisms are well established in the consumer behavior literature, we specifically show how they explain the choice among various payment schemes. For example, we show that the ticking-meter effect strongly impacts the relative importance of price for consumers. We also show that consumers' psychological ownership strongly affects the relative importance of energy efficiency while their greenness does not play a major role in their choice. Third, our cluster analysis helps SPs better understand the market and choices on attributes based on the existing clusters in the market. Last, by quantifying how PSS design choices and consumer characteristics affect PSS consumption choices, we inform future OSCM modelling studies on PSS design. Our findings can especially guide the development of comprehensive objective functions that capture how PSS design choices affect both the supply and demand sides of PSS.

The paper is organized as follows. Section 2 reviews the literature on PSS and section 3 discusses our experimental design and the data collection process. Section 4 provides the results, and the final section discusses the results and provides some concluding remarks.

3.2 Literature review

The increase in the number of businesses moving towards PSS business models has increased research on PSS.

3.2.1 General studies on PSS adoption by businesses

One literature stream explores how PSS affects businesses and their supply chains. These studies typically refer to offering PSS as *servitization* and use qualitative research methodologies. For example, they examine implications for the organizational structure (e.g., Bigdeli et al. (2021)), supply chain management (e.g., Gölgeci et al., 2021; Kreye & van Donk, 2021), risk management (e.g., Benedettini et al. (2017)), and customer management (e.g., Tukker (2015)). We refer to Baines et al. (2017), and Zhang & Banerji (2017) for an extensive review of this stream of literature. Papers in this category primarily focus on the upstream supply chain. We contribute to this stream of literature by providing insight in final consumer's preferences and adoption.

3.2.2 Analytical OSCM studies on PSS adoption by businesses

A second stream of literature addresses the economic and environmental consequences of PSS adoption by SPs (Avci et al., 2014; Agrawal & Bellos, 2016; Örsdemir et al., 2019; Yu et al., 2018; Ladas et al., 2022; Kanatlı & Karaer, 2022; Vafa Arani et al., 2023). Papers in this category mainly use mathematical modeling approaches and game theory. Most use a simple utility function that solely depends on price (Agrawal & Bellos, 2016; Örsdemir et al., 2019; Yu et al., 2018; Ladas et al., 2022; Kanatlı & Karaer, 2022). Some also incorporate energy efficiency (Vafa Arani et al., 2023). Many other determinants of utility (e.g., MCD and payment scheme) are not considered.

3.2.3 Empirical studies on PSS adoption by consumers

A third stream of literature examines what drives PSS adoption choices. Vezzoli et al. (2015) review the literature on sustainable PSS and explore barriers for adoption. They identify a lack of empirical studies quantifying the impact of such barriers on PSS acceptance/adoption. Our study aims to address this gap and builds upon two streams of empirical research.

3.2.3.1 Impact of design choices (attributes)

First, we build upon literature examining the impact of design choices or attributes of PSS. Tunn et al. (2021) conduct a conjoint analysis to identify the barriers to the acceptance of access-based PSS. They randomly assign respondents to two product types (bicycle vs. clothing) and two durations of access (short-term vs. long-term) and study the impact of five attributes: effort of access, contamination, trust, product quality, and product characteristics. In contrast with their study, we also allow the consumer to choose a purchasing option as this is what happens in reality. We also consider various payment schemes.

The study of Lieder et al. (2018) is the closest to ours. They conduct a CBCA by varying the payment scheme (purchase, pay-per-use, and pay-per-period), service level (level of maintenance support), and environmental friendliness (CO2 reduction compared to purchasing a new washing machine). They identify the service level as the main determinant of consumer choices. In contrast to their study, we study price and contract duration as attributes and the mechanisms behind consumer choices. Furthermore, their study implicitly assumes that consumers can calculate the per-use fee for the purchase option and the pay-per-period scheme. We consider the more realistic setting where consumers have difficulties comparing the schemes financially.

Gülserliler et al. (2022) study the adoption of PSS for washing machines and its implications for providers' profits. They use several discrete choice experiments to compare PSS with purchasing new or remanufactured products. Their results show that many respondents always choose purchase over a PSS regardless of the price. They only consider price and whether a product is new or remanufactured as attributes, whereas we also study the pricing scheme and the MCD. Akbar & Hoffmann (2018) use an online survey to explore the drivers of PSS adoption and measure tangible reasons, such as sustainability and intangible reasons, such as the need for socializing. Their study uses a direct inquiry instead of an experiment to measure PSS adoption, which is generally perceived as a weaker evidence form (Nagle & Müller, 2017; Schmidt & Bijmolt, 2020). They do not study how PSS attributes affect adoption.

3.2.3.2 Impact of consumer characteristics

Our paper is also related to studies examining the characteristics and psychological effects which potentially impact consumer preferences and adoption choices. We briefly discuss some consumer characteristics and psychological effects, and the corresponding literature. The *ticking meter effect* describes people experiencing disutility when paying for a service each time they use it (Sundararajan, 2004; Cachon & Feldman, 2011). It associates the disutility of paying for a service directly with the utility derived from its consumption (Prelec & Loewenstein, 1998). Since the ticking meter effect could affect utility associated with different payment schemes in different directions, it potentially impacts adoption choices. Second, *psychological ownership* refers to seeing non-ownership models as an indication of insufficient means to own (Edbring et al., 2016; Poppelaars et al., 2018). Some people avoid non-ownership because of social stigma (Beggan, 1992). This suggests that psychological ownership could be an important driver of consumers' choices between purchasing and adopting a PSS, as also emphasized in prior literature (Moeller & Wittkowski, 2010; Bardhi & Eckhardt, 2012; Edbring et al., 2016; Lawson et al., 2016; Poppelaars et al., 2018). Third, the *need for flexibility* refers to people's need to be able to switch between providers/products and avoid captivity by providers. This characteristic is especially relevant when PSS have different termination conditions, such as different MCDs (Becker et al., 2015; Rayburn et al., 2020). It could also drive the choice between purchasing and adopting a PSS, due to the relative flexibility of the latter. The *insurance effect* implies risk aversion. People with this characteristic associate higher utility to insuring their costs in case of more-than-average usage (Winer, 2005; Lambrecht & Skiera, 2006). Hence this effect has the potential affect the relative utility associated with the pay-per-period scheme and the pay-per-use payment scheme, and subsequently their adoption. Fifth, *greenness* captures the importance of climate change and reducing emissions and waste to consumers. As PSS can reduce a product's environmental footprint, greenness may affect a consumer's choice (Ferguson & Toktay, 2006; Atasu et al., 2008; Örsdemir et al., 2019).

As the sixth variable, we measure *usage* of co0consumers , which can impact consumer choices. Specifically, higher usage tends to make a pay-per-use payment scheme relatively expensive (cf. Akbar & Hoffmann, 2018). Seventh and eighth variables are *break-down probability perception* and *cost expectation*, which capture the risks of maintenance costs for the consumers. Since those costs will be paid by the service provider in PSS, we expect that a higher value of these two variables make PSS relatively more attractive than purchasing (See also Catulli, 2012; Cusumano et al., 2015).

The impact of some of these consumer characteristics and psychological effects has been studied empirically and analytically in some previous studies on PSS. For example, Paundra et al. (2017) and Gülserliler et al. (2022) have researched psychological ownership, and Vafa Arani et al. (2023) have written an analytical paper on the ticking meter effect in the context of PSS. To the best of our knowledge, other characteristics, such as the insurance effect, need for flexibility, and greenness have not been considered in previous studies in the PSS literature. Table Table 3.1 summarizes how our work relates to and differs from closely related papers.

3.3 Data and methodology

This section describes the design of the experiment and the technical details of the conjoint analysis.

Table 3.1: A summary of the closest stream of literature

Study	Attribute: Payment scheme	Price	MCD	Energy efficiency	Ease of access	Product features	Purchase option	Drivers	Cluster or simulation analysis	Methodology
Tunn et al. (2021)	-	-	-	-	✓	✓	-	PT, U	-	CBCA
Lieder et al. (2018)	✓	✓	-	✓	-	-	✓	-	-	CBCA
Gülserliler et al. (2022)	-	✓	-	-	-	-	✓	PO, CV	-	DCE
Akbar & Hoffmann (2018)	-	-	-	-	-	-	-	PO, U, GR	-	Survey
Our Study	✓	✓	✓	✓	-	-	✓	TM, PO, IE, GR, U, CE, BP	✓	CBCA

PT: Product type, U: Usage, PO: Psychological ownership
CV: Convenience, GR: Greenness, TM: Ticking meter
IE: Insurance effect, CE: Cost Expectations
BP: Break-down Probability
CBCA: Choice-based conjoint analysis
DCE: Discrete-choice experiment

3.3.1 Experiment design and procedures

To measure the relative importance of different attributes, we use a CBCA, in which the participants choose among fictitious options. Other versions of the conjoint analysis ask participants to rate or rank all possible options, but these are cognitively more involved than a CBCA (Orme, 2009). CBCA has been argued to mirror a real choice experience better (Huber, 1997). After the choice task, participants completed a survey to obtain personal characteristics and demographic information.

3.3.2 Choice task

Our CBCA includes 15 choice sets. Three of these are fixed and are used as a holdout sample to assess the quality of our results. In each choice set, participants first choose among three possible options. Each option is a washing machine with specified levels for the four attributes. In the second stage, participants indicate whether they would really choose the selected option, given the market information and their experience with washing machines. This represents the "none" or outside option. This *dual-response* approach increases the propensity of choosing the none option and decreases the risk of unrealistic choices from the first-stage choice set (Brazell et al., 2006).

3.3.2.1 Participants

We used the Prolific platform to hire participants. Several studies show that the quality of data collected through this platform is comparatively high (Peer et al., 2017, 2021). The sample consists of 298 people living in the Netherlands who are familiar with washing machines. Each respondent received €3.50. Among the respondents, 58% were female. We excluded those whose response time was too short or too long. We confirmed the data quality by comparing our model's prediction for the three holdout tasks with the actual choice of participants. The results show a hit rate of 72.3%, which is relatively high compared to other studies (Moore, 2004; Chrzan, 2015).

3.3.2.2 Attributes and levels

The options offered to the participants vary over the four attributes (i.e., payment scheme, price, MCD, and energy efficiency). We based these attributes on real offerings by, for example, Homie (2020) and Bundles (2021). The payment scheme has three levels: purchase, pay-per-use, and pay-per-period. In a purchase scheme, the consumer pays the total price of a washing machine upfront. In a pay-per-use scheme, the consumer pays a flat fee per month and a small fee per cycle. In a pay-per-period scheme, consumers only pay a flat fee per month. We specify low, medium, and high prices per payment scheme (see Table 3.2 for a summary). We based the medium purchase price on a Miele washing machine sold by Coolblue (Coolblue, 2022), one of the biggest online retailers in the Netherlands. The low and high prices are 15% lower and higher than the medium price. The rates for PSS resemble the prices offered by Dutch SPs. The break-even point between a pay-per-use and a pay-per-period scheme is 15 wash cycles per month in the medium price level. We also use three levels for the MCD (i.e., one, three, and five years) based on commonly used durations in the Netherlands. (see e.g., Homie (2020), Splash (2021), and Bundles (2021)). We specify two energy labels: *A* and *C*.

Table 3.2: Price levels per payment scheme

Payment scheme	Low	Medium	High
Purchase	€765	€900	€1035
Pay-per-use	€11.9t+€0.5x	€14t+€0.5x	€16.1t+€0.5x
Pay-per-period	€18.25t	€21.5t	€24.75t

t: Contract duration in month. x: Number of cycles.

We created the choice sets based on a randomized design generated by Sawtooth Lighthouse Studio Version 9.14.0[1] and randomized the order of the choice sets and the attributes in each option. A sample choice set is presented in Figure 3.1.

[1] https://sawtoothsoftware.com/lighthouse-studio

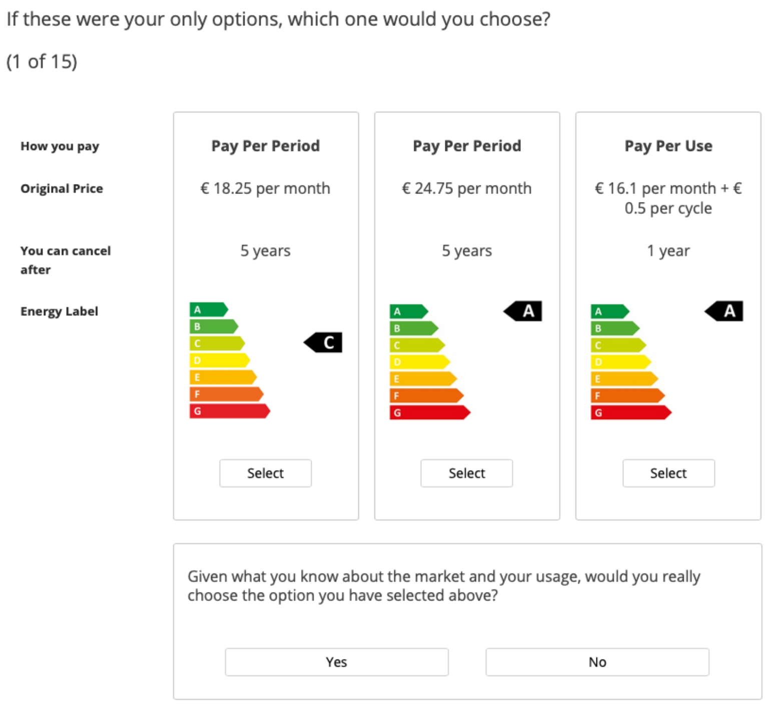


Figure 3.1: A sample choice set

We used the following incentive-aligned mechanism to stimulate the participants to perform the choice task truthfully. At the beginning of the experiment, we informed participants that they could win a prize of up to €300, which would be determined as follows. A random choice set judged by a random participant would be selected. Then, a panel of experts would rank the options in that specific choice set for that specific participant based on his/her characteristics measured in the second part of the experiment. If the participant's choice matched the panel's first choice, the participant would receive €300. If it matched the panel's second choice, the participant would receive half the amount. Otherwise, the process would be repeated for another randomly chosen participant until the prize was awarded. There was intentional vagueness in this procedure to ensure the participants would reveal their true characteristics and choose truthfully. Appendix A includes the exact information provided to the participants. Similar mechanisms are used in conjoint experiments (Dong et al., 2010) and have proven to improve the responses compared to traditional Becker-DeGroot-Marschak (BDM) mechanisms introduced by Ding et al. (2005).

3.3.3 Participants' characteristics

After finishing the choice task, the participants answered some follow-up questions to measure their characteristics including gender, income, household size, and age. The survey also measured the ticking meter effect, psychological ownership, the need for flexibility, the insurance effect, and greenness on a 1 to 5 Likert scale using standard constructs/ questions from the literature. The constructs to measure ticking meter effect, psychological ownership, insurance effect, need for flexibility, and greenness are all modified versions used in Lambrecht & Skiera (2006), Bardhi & Eckhardt (2012), Lambrecht & Skiera (2006), Becker et al. (2015), and Dunlap et al. (2000). Finally the survey included several questions about the participant's use and perception of washing machines. Specifically, questions focused on 1) *cost expectation*, which is the participant's estimate of the maintenance cost of a washing machine in the first five years, 2) *breakdown probability perception*, which is the participant's estimate of the probability of the washing machine breaking down in five years, and 3) *usage*, which refers to the participant's current weekly number of washing cycles. Appendix A includes details of these constructs. We present a summary of descriptive statistics on the main characteristics in Table 3.3.

Table 3.3: Descriptive statistics

Variable	Age	Ticking meter effect	Psychological ownership	Need for flexibility	Insurance effect	Greenness	Usage
Mean	30.00	3.59	3.49	3.04	3.30	3.74	3.90
St. Dev.	9.31	0.73	0.95	0.60	0.86	0.50	3.00

3.3.4 The model

Following Allenby et al. (1998) and Ding (2007), we estimate the utility for each attribute level for the participants using a random-effects hierarchical Bayesian multinomial logit model. According to this model, the probability that the i^{th} participant chooses the j^{th} option (there are m options per choice set) from the c^{th} choice set is given by:

$$Pr\{z_{ic} = j\} = \frac{e^{\alpha_i + \beta_i^T x_{icj}}}{\sum_{l=1}^{m} e^{\alpha_i + \beta_i^T x_{icl}}} \tag{3.1}$$

where z_{ic} represents the choice of participant i in choice set c. x_{icl} describes the l^{th} option in the c^{th} choice set evaluated by the i^{th} participant. Specifically, x_{icl} is a vector of binary components indicating whether each attribute-level combination applies to the option. α_i is the constant term for participant i. β_i is a vector of so-called *partworths* for the i^{th} participant. A participant's partworth for a given attribute-level captures the relative utility a participant derives from including this attribute level in the option he/she chooses. We select $\beta_i \sim Normal(\bar{\beta}, D)$ as the prior distribution, where $\bar{\beta}$ represents the vector of means of the distribution of individuals' partworths and D the corresponding covariance matrix. Next to individual partworths, we also report average partworths across all individuals.

We use an iterative procedure to calculate the individual-level partworths based on the described Hierarchical Bayes model. In every iteration, the model updates the prior distribution of β_i to improve the fit between the model and observed choices. We did not see any trends after 10,000 iterations and thus used the final estimates after another 10,000 iterations.

In line with Ding (2007), we subsequently quantify the *importance* individual i attaches to attribute k as I_k:

$$I_{ik} = |\beta_{ik}^{high} - \beta_{ik}^{low}| \tag{3.2}$$

where β_{ik}^{high} represents the highest partworth individual i attaches to a level of attribute k and β_{ik}^{low} is the lowest. The individual's *relative importance* is then calculated as:

$$R_{ik} = \frac{I_{ik}}{\sum_k I_{ik}} \tag{3.3}$$

We also report on the *average relative importance* of an attribute across all individuals. We use the 2 log likelihood (2LL) test to find potential interactions between different attributes by comparing the log likelihood fit between the model with and without the interaction terms. Finally, we use multiple linear regression to find possible associations between the partworth utilities or the relative importance of attributes with participants' characteristics.

3.4 Results

This section presents our results. We address research question 1 in Section Section 3.4.1 by presenting partworth utilities and the relative importance of the PSS attributes. Section Section 3.4.3 describes how partworth utilities and the relative importance of PSS attributes relate to consumer characteristics, addressing research question 2. Finally, to answer research question 3, we present the results of our cluster and simulation analyses in Section Section 3.4.4.

3.4.1 The impact of PSS attributes

3.4.1.1 Partworths and relative importance of attributes

Figure 3.2 depicts the estimated individual-level partworths and the sample mean (bold line). Table 3.4 summarizes the partworth utilities for each attribute level and the none option. The table and figure reveal some interesting insights. First, most participants derived a higher utility from the purchase option. Furthermore, the average utility of the pay-per-use scheme was higher than that of the pay-per-period scheme. It is important to note the substantial heterogeneity in preferences (i.e., individual partworth utilities): 32% of the participants derived most utility from the pay-per-use scheme, whereas 6% did so from the pay-per-period scheme. This suggests that multiple business models are viable in the washing machine market. Figure 3.3 shows the distribution of individual-level relative importance, the 95% highest density interval, and the average relative importance levels.

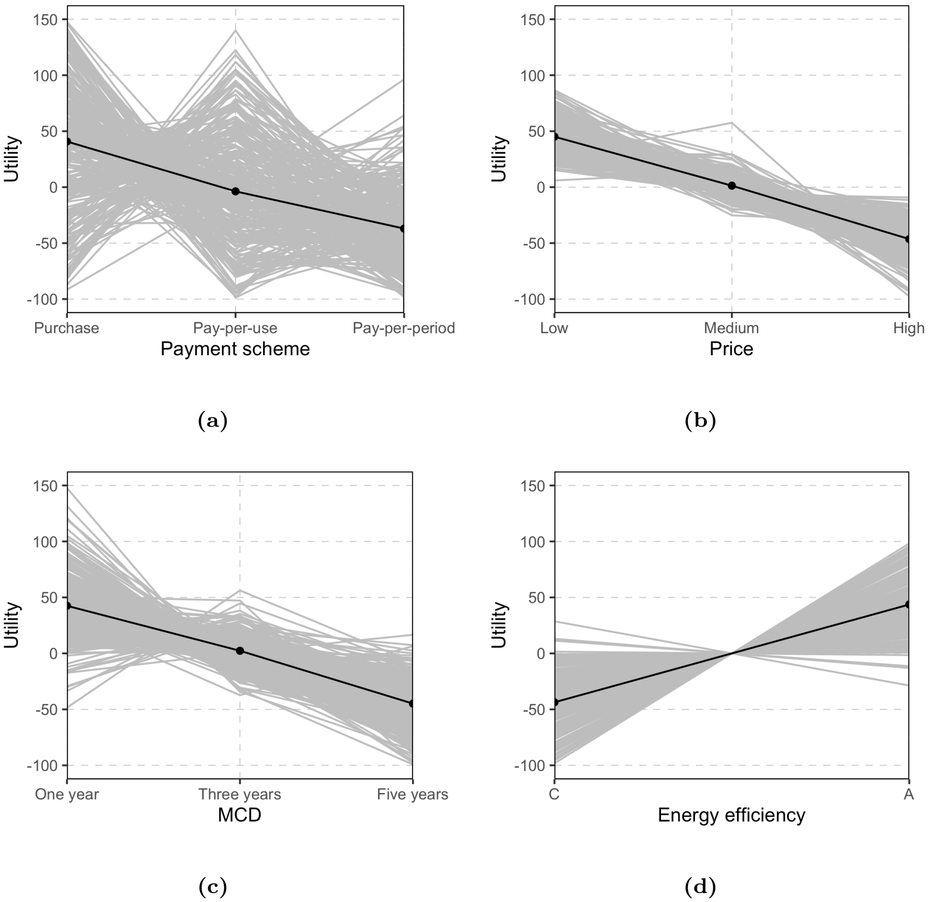


Figure 3.2: Individual-level partworths for a: Payment scheme, b: price, c: MCD, and d: Energy efficiency. The black line shows the sample mean of the partworths

Second, the payment scheme is the most important attribute among the ones considered, having an average relative importance of 32.23%. This suggests that many consumers have

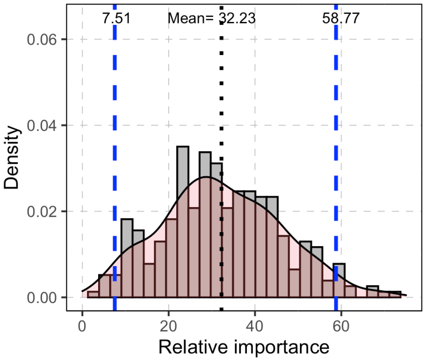
Table 3.4: Partworth utilities, the relative importance of attributes, and their standard deviations

Attribute	Average relative importance	Attribute levels	Average utilities	Standard deviation
Payment scheme	32.23	Purchase	40.77	57.48
		Pay-per-use	-3.75	56.05
		Pay-per-period	-37.02	36.04
Price	22.91	Low	45.07	14.74
		Medium	1.31	9.25
		High	-46.39	14.95
MCD	22.83	1 year	42.53	29.75
		3 years	2.33	14.62
		5 years	-44.87	23.22
Energy efficiency	22.03	C	-43.69	23.22
		A	43.69	23.22
None			-39.48	125.55

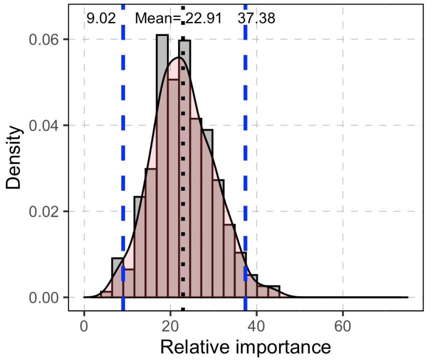
a *relatively strong* preference for one of the three schemes. A comparison of partworth utilities for different payment schemes confirms this. Consumers who prefer purchasing on average derive 144% and 156% less utility from pay-per-use and pay-per-period schemes, respectively. Those who prefer pay-per-use derive 134% and 166% less utility from purchase and pay-per-period, and those who prefer pay-per-period derive 142% and 158% less utility from purchase and pay-per-use schemes, respectively.

Third, as expected, people derive higher utility from lower prices, shorter MCDs, and more energy-efficient washing machines. Surprisingly, the order of magnitude of the utility gain is similar across the three attributes. The average relative importance of price, MCD, and energy efficiency are 22.91, 22.83, and 22.03, respectively. This suggests that consumers seriously weigh each of these attributes when making a decision, and that companies have multiple tools to enhance their market share.

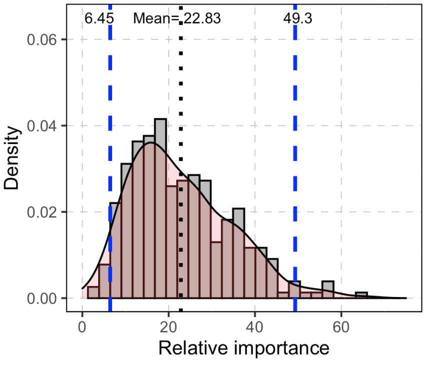
We now illustrate the implications of these results. Figure 3.4 depicts the average utility for a range of options (recall: an option is a washing machine with specified levels for the four attributes). Adjacent options are the same, except for one attribute, which shows the impact of changing it. Comparing these options, one can observe that moving from a pay-per-use to a pay-per-period scheme keeping everything the same, causes a considerable drop in average utility. The same happens when we offer a longer MCD. However, a pay-per-use scheme with a short MCD is almost as desirable as a purchase option.



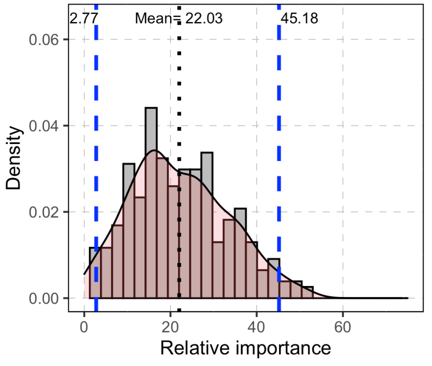
(a) Payment scheme



(b) Price



(c) MCD



(d) Energy efficiency

Figure 3.3: Individual-level relative importance of a: Payment scheme, b: Price, c: MCD, and d: Energy efficiency

3.4.2 Interaction effects

Understanding the interaction between the attributes helps the SP find the best possible combination of attribute levels. Table 3.5 describes the impact of adding each two-way interaction effect to the main model (i.e., the one described in Section 3.4) to examine whether adding such a term leads to a significant change in the log-likelihood based on a 95% confidence interval.

The table shows that the only statistically significant interaction effect is between payment scheme and price. Table 3.6 shows the partworth utilities and relative importance of attributes for the corresponding model. Comparing these two models in the table in terms of the total partworth utility of price for different payment schemes (e.g., original utility of

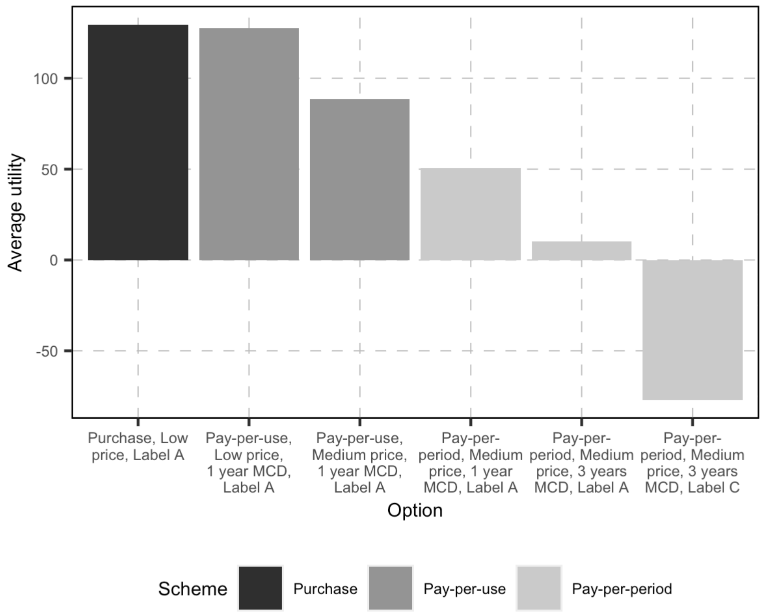


Figure 3.4: Average utility of some possible options

45.07 versus 35.88 (46.24-10.36) when accounting for the interaction for the low price and pay-per-use), we see a big difference between the price sensitivity for the payment schemes. This shows us that people are less sensitive to the PSS price than to the purchase price. This could be explained by the difference between price scales of purchasing and PSS. For example, purchasing costs €900,00, whereas the pay-per-period scheme costs €21.50 per month. A 15% price change thus represents €135 for the former and €3.23 for the latter. The *present bias* could explain why the former affects utility more strongly. This bias stems from the phenomenon of hyperbolic discounting and is defined as the tendency to prefer a smaller present reward to a larger future reward (O'Donoghue & Rabin, 1999; Frederick et al., 2002). In our case, this captures that consumers might discount the future costs from the PSS and thus become less sensitive to price. Another explanation is that people who prefer PSS may be strongly driven by sustainability concerns or by practical matters (e.g., low usage, high need for flexibility), which could decrease the relative importance of price. We examine this in the next section.

3.4.3 The impact of consumer characteristics

If SPs know which consumer segments are likely to choose a PSS instead of purchasing a product, they can target these segments to enter the PSS market. In this section, we explore

Table 3.5: Contribution of each interaction term in the final results

Interaction term added	Log-likelihood fit	Chi square value	2LL p-value
+ Payment scheme × Price	-4,733.23	12.43	**0.01**
+ Payment scheme × MCD	-4,738.25	2.39	0.66
+ Payment scheme × Energy efficiency	-4,739.23	0.43	0.81
+ Price × MCD	-4,738.08	2.73	0.60
+ Price × Energy efficiency	-4,738.99	0.91	0.63
+ MCD × Energy efficiency	-4,737.28	4.33	0.11

how consumer characteristics affect the relative importance of the attributes in general (Table 3.7) and the utility derived from various payment schemes specifically (Table 3.8). Here we focus on those with strong implications for SPs.

The results in Table 3.8 show that the partworth utility of the pay-per-period scheme increases with the strength of the ticking meter effect ($p < 0.01$) and the insurance effect ($p < 0.05$). This could be because the costs in the pay-per-period scheme are fixed and independent of usage. As expected, the psychological ownership level decreases the utility derived from the pay-per-period ($p < 0.05$) and the pay-per-use schemes ($p < 0.1$). The same holds for the results that a higher usage significantly decreases the utility of the pay-per-use scheme ($p < 0.01$) and increases the utility for the other two schemes ($p < 0.01$). The only variable that increases the partworth utility of a pay-per-use scheme is cost expectations ($p < 0.05$). In contrast, it decreases the partworth utility of the purchase ($p < 0.01$), which is expected since the maintenance costs are the SP's responsibility in PSS.

Hence, when target consumers score higher on the ticking meter and the insurance effect, adding a pay-per-period scheme to the offering becomes relatively more attractive. This also holds for high-use consumers and consumers with low psychological ownership levels. The pay-per-use payment scheme is relatively attractive to consumers with low levels of psychological ownership, relatively low usage, and/or high expected maintenance costs. It is relatively attractive for the SP to offer a purchase option if the psychological ownership is high, usage is high, and/or the cost expectation is low.

Unlike the payment scheme, the relative importance of price increases with the strength of the ticking meter effect ($p < 0.1$) (see Table 3.8). This suggests that people with a high pain of paying are generally more price sensitive. A lower usage ($p < 0.05$) and a higher breakdown probability perception ($p < 0.1$) are associated with a higher relative importance of price. Surprisingly, cost expectation does not affect the relative importance of price. This could be partly explained by the concept of mental accounting (see Thaler, 1985; Prelec & Loewenstein, 1998), which argues that consumers have different 'mental accounts' for the fees they pay to use or purchase a machine and the maintenance costs, especially if they do not incur them at the same time.

Table 3.6: Partworth utilities, and relative importances with the interaction of payment scheme and price

Attribute	Average relative importance	Levels	Average utilities	Standard deviation
Payment scheme	32.32	Purchase	39.21	59.39
		Pay per use	-2.34	56.30
		Pay per period	-36.87	36.07
Price	23.30	Low	46.24	16.05
		Medium	0.60	9.36
		High	-46.85	16.05
MCD	22.30	1 year	41.88	28.69
		3 years	1.63	14.08
		5 years	-43.51	22.64
Energy efficiency	22.08	C	-43.72	23.76
		A	43.72	23.76
Payment scheme×Price		Purchase×Low	10.75	19.54
		Purchase×Medium	0.60	11.97
		Purchase×High	-11.35	15.79
		Pay per use×Low	-10.36	18.63
		Pay per use×Medium	-0.53	14.60
		Pay per use×High	10.89	14.28
		Pay per period×Low	-0.39	9.47
		Pay per period×Medium	-0.07	9.04
		Pay per period×High	0.46	9.44
None			-35.02	124.01

Our results also reveal that the relative importance of energy efficiency is negatively associated with the level of psychological ownership ($p < 0.01$) and the need for flexibility ($p < 0.01$). Thus, if these scores are high, offering products with a higher energy efficiency is relatively attractive. On the other hand, cost expectation positively impacts the relative importance of energy efficiency ($p < 0.01$) because cost-sensitive consumers also account for energy costs in their calculations. Hence, the energy efficiency of the washing machine is relatively important to them.

The relative importance of the MCD is positively affected by the need for flexibility ($p < 0.01$), which is to be expected. Usage decreases the relative importance of the MCD ($p < 0.05$). Thus, we can conclude that the MCD is less important for high-use consumers. This is because most high-use consumers opt for the purchase option, which has an infinite MCD (see Figure 3.5c).

As argued, we expect consumers with a higher greenness to assign a higher utility to PSS. The regression coefficients are consistent with this hypothesis. Likewise, if we call participants with higher-than-average greenness score ‘green’ and the others ‘non-green’, 45% of

Table 3.7: The relationship between the relative importance of attributes and consumer characteristics

	Dependent variable: relative importance of			
	Payment scheme	Price	MCD	Energy efficiency
Ticking meter effect	−2.71**	1.15*	0.16	1.39
	(1.11)	(0.61)	(0.98)	(0.94)
Psychological ownership	1.65**	0.19	−0.03	−1.81***
	(0.81)	(0.45)	(0.71)	(0.68)
Need for fexibility	−2.06	0.41	4.79***	−3.14***
	(1.25)	(0.69)	(1.10)	(1.06)
Insurance effect	−2.09**	−0.28	1.16	1.20
	(0.96)	(0.53)	(0.84)	(0.81)
Greenness	−1.17	0.51	−0.16	0.82
	(1.50)	(0.82)	(1.32)	(1.27)
Usage	1.12***	−0.35**	−0.54**	−0.23
	(0.26)	(0.14)	(0.23)	(0.22)
Breakdown probability perception	−2.54**	1.13*	1.62*	−0.21
	(1.07)	(0.59)	(0.94)	(0.90)
Cost expectation	−1.70**	−0.28	0.19	1.79***
	(0.76)	(0.42)	(0.67)	(0.64)
Constant	−145.93	−49.25	27.30	267.89*
	(172.88)	(95.00)	(152.00)	(145.89)
Control variables (See Appendix C)				
Observations	298	298	298	298
R^2	0.19	0.05	0.10	0.12
Adjusted R^2	0.15	0.02	0.07	0.09
Residual Std. Error (df = 286)	12.74	7.00	11.20	10.75
F Statistic (df = 11; 286)	5.90***	1.45	2.98***	3.60***

Note: *p<0.1; **p<0.05; ***p<0.01

Table 3.8: The relationship between the partworth utilities of payment schemes and consumer characteristics

	Dependent variable		
	Purchase	Pay-per-use	Pay-per-period
Ticking meter effect	−4.42	−3.89	8.31***
	(4.65)	(4.44)	(3.01)
Psychological ownership	10.19***	−5.61*	−4.58**
	(3.39)	(3.23)	(2.19)
Need for flexibility	1.32	−2.96	1.64
	(5.23)	(4.99)	(3.38)
Insurance effect	−2.04	−3.72	5.75**
	(3.99)	(3.81)	(2.58)
Greenness	−6.82	8.32	−1.51
	(6.27)	(5.98)	(4.05)
Usage	5.05***	−6.57***	1.52**
	(1.07)	(1.02)	(0.69)
Breakdown probability perception	−5.91	4.11	1.80
	(4.47)	(4.26)	(2.89)
Cost expectation	−8.25***	6.76**	1.50
	(3.17)	(3.02)	(2.05)
Constant	256.00	−325.01	69.01
	(722.04)	(689.14)	(467.20)
Control variables (See Appendix C)			
Observations	298	298	298
R^2	0.18	0.21	0.12
Adjusted R^2	0.14	0.18	0.09
Residual Std. Error (df = 286)	53.20	50.78	34.43
F Statistic (df = 11; 286)	5.52***	6.90***	3.59***
Note:			*p<0.1; **p<0.05; ***p<0.01

participants who prefer the purchase scheme are green, compared to those who prefer pay-per-use (52%) and pay-per-period (53%). Nevertheless, the relationship is not statistically significant. This may be due to the so-called *attitude-behavior* or *values-action gap*, which refers to the challenge people face when they try to translate their attitudes into action (see Hughner et al., 2007; Young et al., 2010, and references therein).

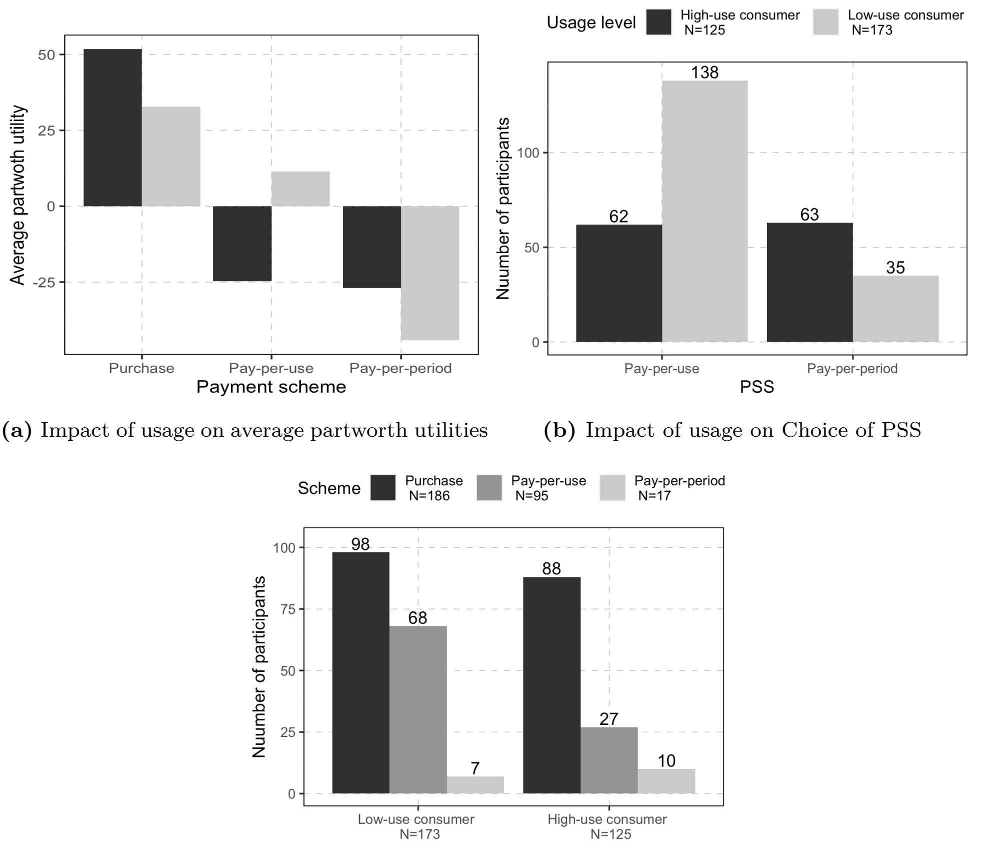
Usage appears to play a pivotal role in the choice of pricing schemes. If consumers only care about the operating costs of a washing machine, it is more reasonable to purchase or opt for a pay-per-period than a pay-per-use scheme simply because they are cheaper. As mentioned, 15 washing cycles per month is the break-even point between a pay-per-use and a pay-per-period scheme. We use this number to label consumers as high-use or low-use. Figure 3.5 shows the average partworth utilities for both groups. The left panel shows that high-use consumers derive a higher utility from the purchase and pay-per-period schemes, whereas low-use consumers derive a higher utility from the pay-per-use scheme. The right panel only compares the choice of PSS among low- and high-use consumers based on their partworth utilities. This figure shows that 80% of low-use consumers choose a pay-per-use scheme, compared to only 50% of high-use consumers. This means that many consumers (i.e., 20% of low-users and 50% of high-users) do not choose the cheapest scheme. This can be partly explained by the ticking meter and the insurance effect, which impact the utility of these two schemes in opposite directions. The average ticking meter and insurance effect scores for low-use consumers who choose the pay-per-period scheme are 3.61 and 3.36, respectively, compared to 3.49 and 3.15 for those who select the pay-per-use option. Similarly, for high-use consumers, these scores are 3.78 and 3.51 for the pay-per-period scheme and 3.63 and 3.40 for the pay-per-use scheme. High-use consumers are more likely to choose the purchase and pay-per-period schemes. Figure 3.5c zooms in on which of the two schemes they prefer. It shows that 70% are most likely to purchase compared to 8% who prefer the pay-per-period. These numbers are 57% and 4% for low-use consumers. Thus, low-use consumers are 19% less likely to purchase, and 50% are less likely to choose a pay-per-period.

3.4.4 Market analysis

3.4.4.1 Cluster analysis

Section 3.4.1.1 shows that significant heterogeneity exists in terms of consumer preferences. This section explores how the consumer base can be divided into groups of individuals with similar preferences. Specifically, we use the K-means method to cluster participants based on the relative importance they assign to each attribute and the elbow method to choose the number of clusters. We identified four clusters each representing between 64 and 84 respondents (see Table 3.9).

Each cluster is characterized by high relative importance for one of the attributes (compared to the complete sample; see Table 3.4). Consumers in the first cluster assign a higher relative importance to the payment scheme (47.93 vs. 32.23). The other three attributes are relatively unimportant. People in the second cluster are price sensitive (35.28 vs. 32.91). Due to the interaction between the payment scheme and price (Table 3.5), consumers in this cluster also assign a higher relative importance to the payment scheme (35.28 vs. 32.23). The MCD and the energy efficiency are relatively unimportant for this cluster. Cluster 3 includes people who are relatively sensitive to the energy efficiency (35.84 vs. 22.03). Compared to the complete sample, consumers in Cluster 3 value price and the MCD as equally important and the payment scheme of much less importance. Finally, consumers in cluster 4 are highly sensitive to the MCD (39.49 vs. 22.83). Like the complete sample, they perceive price to be important, but assign a lower relative importance to the payment scheme and the energy efficiency.



(a) Impact of usage on average partworth utilities

(b) Impact of usage on Choice of PSS

(c) Scheme choice among low- and high-use consumers

Figure 3.5: Impact of usage

3.4.4.2 Simulation analysis

Our simulation analysis calculates the market share for a baseline scenario in which a company offers three options. These are based on real PSS (e.g., Homie (2020); Bundles (2021); Coolblue (2022)). We estimate the market share by calculating the fraction of respondents choosing each option. We then change the level of one attribute at a time and reestimate the market shares. The first part of Table 3.10 shows the baseline scenario and the corresponding market shares. The majority (60%) would opt to purchase the washing machine, 17% for the pay-per-use scheme, 4% for the pay-per-use scheme, and 19% for none of the options.

Table 3.9: Average partworth utilities per cluster

Cluster	Cluster 1	Cluster 2	Cluster 3	Cluster 4
	N=84	**N=64**	**N=84**	**N=66**
Payment scheme	47.93	35.28	21.96	22.37
Purchase	91.1	25.22	18.91	19.60
Pay-per-use	-47.30	33.50	2.03	8.20
Pay-per-period	-43.80	-58.72	-20.94	-27.80
Price	17.20	30.94	22.27	23.21
Low	34.07	61.18	43.29	45.74
Medium	0.65	0.91	2.23	1.37
High	-34.72	-62.09	-45.52	-47.11
MCD	18.54	15.07	19.92	39.49
1 year	33.75	23.80	34.27	82.39
3 years	3.99	5.19	5.68	-6.80
5 years	-37.74	-28.98	-39.95	-75.59
Energy efficiency	16.33	18.71	35.84	14.91
A	32.66	36.07	71.68	29.49
C	-32.66	-36.07	-71.68	-29.49
None	-17.34	-69.68	-55.42	-18.07

Now, if we change the MCD from five years to three years, the PSS becomes more attractive to participants: 9% more would opt for the pay-per-use scheme, and 4% more would opt for the pay-per-period scheme.

If we change the energy label from A to C, more consumers will choose the none option (35% instead of 19%). Consumers who initially preferred a PSS are relatively more sensitive to this change. The PSS market share decreased from 21% to 16%, corresponding to a 25% decrease, and the purchase market share fell by 18% (from 60% to 49%).

We now examine how the *combination of* payment schemes offered affects market shares (see parts 4-6 of Table 3.10). Understanding this matter is highly important for SPs. Companies typically offer only one or two schemes and would like to know to what extent adding a new payment scheme cannibalizes other schemes' market shares and possibly expands the overall market share (i.e., reducing the share of people choosing the none option). Our results show that adding a pay-per-period scheme to the other two schemes leads to a negligible increase in overall market share. However, adding a purchase scheme to the other two induces a 16% increase in total market share. In contrast, adding a pay-per-use scheme to the other two only leads to a 3% increase. Interestingly, more than a third of the consumers (35%) prefer the none option when we only offer PSS.

Finally, if we increase the price of all the schemes ceteris paribus, the market share of the pay-per-use option decreases more strongly than that of the purchase and pay-per-period schemes (18% vs. 8% and 9%, respectively, when increasing the prices from medium to high). The discussion in Section 3.4.2 showed that participants are more sensitive to price when choosing a purchase option, which is in contrast with what we see here. The reason behind this is partly because we use a specific level of other attributes here (i.e., energy label *A* and a five-year MCD) whereas in Table 3.4, we control for other attributes. The other reason is that participants derive a much lower utility from PSS than the purchase option (See Table 3.4), making them more likely to choose the none option when a high price instead of the medium price is offered. Hence, people appear to incur a higher disutility from a price increase for the purchase option, but it prompts relatively few people to switch to the none option. The reverse appears to hold for PSS.

Table 3.10: Summary of the simulation analysis

Label	Payment scheme	Price	MCD	Energy efficiency	Market share
BS1	Purchase	Medium	N/A	A	60%
BS2	Pay-per-use	Medium	5 years	A	17%
BS3	Pay-per-period	Medium	5 years	A	4%
None					19%
BS1	Purchase	Medium	N/A	A	51%
BS2MCD	Pay-per-use	Medium	3 years	A	26%
BS3MCD	Pay-per-period	Medium	3 years	A	8%
None					15%
BS1EL	Purchase	Medium	N/A	C	49%
BS2EL	Pay-per-use	Medium	5 years	C	13%
BS3EL	Pay-per-period	Medium	5 years	C	3%
None					35%
BS1Scheme1	Purchase	Medium	N/A	A	62%
BS2Scheme2	Pay-per-use	Medium	5 years	A	19%
None					19%
BS1Scheme3	Purchase	Medium	N/A	A	69%
BS2Scheme4	Pay-per-period	Medium	5 years	A	9%
None					22%
BS1Scheme5	Pay-per-period	Medium	5 years	A	25%
BS2Scheme6	Pay-per-use	Medium	5 years	A	40%
None					35%
BS1PriceH	Purchase	High	N/A	A	55%
BS2PriceH	Pay-per-use	High	5 years	A	14%
BS3PriceH	Pay-per-period	High	5 years	A	4%
None					27%
BS1PriceL	Purchase	Low	N/A	A	63%
BS2PriceL	Pay-per-use	Low	5 years	A	19%
BS3EPriceL	Pay-per-period	Low	5 years	A	5%
None					13%

3.5 Discussion and conclusion

Product-service systems (PSS) are new business models that add a service element to a product while the ownership of the product remains with the company. This paper examined how PSS attributes and consumers' characteristics drive their choice to adopt a PSS or purchase a product. To understand this, we designed a conjoint experiment and gave participants some fictitious PSS and purchasing options. We specifically examined four attributes: payment scheme, price, MCD, and energy efficiency.

The results show that consumers considered the payment scheme to be the most important attribute. The other three attributes were considered almost equally important. This suggests that many people strongly prefer one of the payment schemes and that it differs significantly across consumers. An important implication is that there appears to be space for multiple business models in the market. The equal relative importance of the other attributes suggests that companies have multiple strong levers for gaining market share. Among the three payment schemes, purchase is the most preferred option, followed by pay-per-use and pay-per-period. Thus, businesses that would like to invest in a PSS should be aware that consumers are still more likely to purchase a washing machine than to adopt a PSS. On average, people also strongly prefer pay-per-use to pay-per-period. This is probably because the pay-per-use option has a lower fixed monthly payment and is cheaper for low-usage consumers. In any case, this suggests that pay-per-use dominates pay-per-period for washing machines from an SP's perspective. This could also be why Bundles, one of the pioneers in PSS in the Netherlands, removed the pay-per-period option from their offering (Bundles, 2021).

Further analysis of the attributes' interaction shows that consumers' price sensitivity depends on the payment scheme. Specifically, consumers are less sensitive to the price of PSS. One explanation could be the difference in the price scales of the PSS and the purchase option. The so-called present bias could also partly explain this since consumers may discount the future costs from the PSS. This suggests that SPs have more flexibility in their pricing, which is an important finding.

Our results also show that consumers' choices are strongly determined by their characteristics. First, consumers with a high ticking meter effect are more likely to choose the pay-per-period option than the pay-per-use option. The ticking meter effect also increases the relative importance of price. Thus, in markets where consumers have a high ticking meter effect, it is relatively attractive to offer the pay-per-period scheme and cheaper products. Second, our analysis shows that people with a lower psychological ownership level are more likely to adopt a PSS. This metric can be an important indicator of the market potential for PSS.

Third, a high insurance effect makes the pay-per-period relatively more attractive than a pay-per-use option. Thus, if people are relatively risk-/loss-averse in a market, offering a pay-per-period option is relatively attractive. Fourth, people with a higher need for flexibility derive a higher utility from shorter MCDs. The same applies to more ”tech-savvy” people who like to use state-of-the-art technology. Offering shorter MCDs is relatively attractive in market segments where tech-savviness is high and people have a relatively high need for flexibility.

Finally, although greener consumers are more likely to choose a PSS (i.e., a greener option) than purchasing (Tukker, 2004; EMF, 2013, 2019)), this relationship and the evidence behind it is weak. One potential explanation is that consumers struggle to translate their attitudes into actual behaviour. This attitude-behaviour gap has been found in several studies.

Businesses who seek an efficient combination of payment schemes to offer based on the consumer characteristics can incorporate the following findings. Consumers with a high level of psychological ownership, usage level, and/ or expect low maintenance costs are most likely to adopt purchasing a product. If the ticking meter effect is high, the level of psychological ownership low, the insurance effect strong, and/or usage high, consumers will most likely adopt a pay-per-period payment scheme. A segment with low psychological ownership, low usage, and/ or high expected maintenance costs will most likely adopt a pay-per-use scheme. The latter aligns with the finding that PSS are relatively attractive at the start and end of the product life cycle because of the costs (maintenance and capital) and risks associated with the product at those stages (Cusumano et al., 2015).

Our cluster analysis reveals that consumer preferences are strongly heterogeneous but can be divided into four clusters of relatively similar consumers. The first assigns high relative importance to the payment scheme. The second assigns a higher relative importance to both the payment scheme and price. For the third and the fourth, MCD and energy efficiency are more important than other attributes. Each cluster represents a considerable segment of the market. Given that there are tradeoffs between attributes (e.g., price vs. MCD, energy efficiency, and payment scheme), this suggests that there is space for multiple payment schemes and product offerings in the market.

Our simulation analysis illustrates how the results from the conjoint analysis can be used to support business model choices and highlights the potential of doing so. For example, simulating the market with and without a specific payment scheme shows that adding a purchase option significantly increases the overall market share. This increase is much lower for PSS, especially for the pay-per-period scheme. Their addition induces significant cannibalization. This shows that there is a sizeable segment in the market that does not prefer PSS in the setting of our experiment. This is in line with the findings of Gülserliler et al. (2022). SPs could account for this when they enter a market by offering a purchase option along with the PSS.

Our study contributes to the OSCM literature on PSS in the following ways. First, we shed light on consumer acceptance of PSS, which is so far underexplored in the servitization literature (see, e.g., Baines et al., 2017; Zhang & Banerji, 2017), as it focuses mainly on the operational and organizational challenges associated with servitization. Future OSCM studies on this topic can use our findings to develop more holistic objective functions that capture how design choices affect operations/ supply *and* demand. Second, while we confirm the dominant preference for purchasing revealed in prior OSCM studies (Gülserliler et al., 2022; Lieder et al., 2018), our study also contributes novel insights on the importance of PSS attributes. In particular, we show that MCD, energy efficiency, and price are about equally important, which has important implications. Similarly, we confirm findings on the impact of various psychological mechanisms and consumer characteristics, such as usage (Akbar & Hoffmann, 2018; Tunn et al., 2021) and psychological ownership (Akbar & Hoffmann, 2018; Gülserliler et al., 2022). We also add new variables to the OSCM literature on PSS, such as the ticking meter effect, the insurance effect, the need for flexibility, and cost expectation. Finally, we confirm the prior finding that consumer preferences are strongly heterogeneous (See e.g., Vafa Arani et al., 2023; Örsdemir et al., 2019, and referencses therein), and additionally characterize heterogeneity through our regression models and by revealing four clusters of relatively similar consumers. These results can help parametrize future OSCM models considering heterogeneous consumers.

This study can be extended in several ways. First, our insights cannot be trivially generalized to other products. First, our insights cannot be trivially generalized to other products. We chose washing machines because both PSS and purchase options exist for this product. Future studies could repeat our analyses for, e.g., bikes, cell phones, or other products that might be shared by consumers, and compare the results to distill the impact of product type. Second, our work can be extended by examining other commonly used payment schemes. Examples include three-part tariff schemes and quantity-dependent types of schemes, which could trigger different consumer behaviors and interact with consumer characteristics differently. Third, future studies could consider remanufactured and new products or include competing SPs offering PSS and purchasing. Finally, our study considers how certain attributes affect consumer preferences and market shares. Future research could integrate costs and environmental impacts.

The need to innovate more circular business models is becoming increasingly clear among consumers and businesses. A first step in this journey is understanding how consumers respond to such innovation. Our study contributes to this step by offering practical insights on how PSS business model design choices affect consumer preferences and market shares.

3.6 Appendix

3.6.1 Appndix A: The experiment details and constructs

Table 3.11: Psychological Ownership (Cronbach's α of 91%)

Think about the experiences and feelings associated with the statement 'THIS IS MY Washing Machine!' The following questions deal with the sense of ownership that you feel for the washing machine that you (may) own.					
Indicate the degree to which you personally agree or disagree with the following statements.					
	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly disagree
This is MY Washing Machine	○	○	○	○	○
I feel a very high degree of personal ownership for this washing machine	○	○	○	○	○
I sense that this is MY Washing Machine	○	○	○	○	○
It is hard for me to think about this washing machine as MINE	○	○	○	○	○

Table 3.12: Ticking Meter Effect (Cronbach's α of 63%)

Please indicate the extent to which you agree/disagree with the following statements.					
	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly disagree
The flat rate (pay-per-period) is great because I don't have to worry about the costs.	○	○	○	○	○
It isn't as desirable to wash my clothes when I have to think about the costs increasing every cycle.	○	○	○	○	○
It's only when I have a flat rate (pay-per-period) that I can really use the washing machine as much as I want.	○	○	○	○	○
When I'm paying a flat rate (pay-per-period), I feel much freer and more relaxed about using the washing machine than with a variable rate (pay-per-use).	○	○	○	○	○

Table 3.13: Insurance Effect (Cronbach's α of 66%)

Please indicate the extent to which you agree/disagree with the following statements.					
	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly disagree
For the security of knowing that my washing costs will never go above a certain value, I'm willing to pay a little more.	○	○	○	○	○
Even if a fixed fee (pay-per-period) is somewhat more expensive for me than a usage-driven rate (pay-per-use), I'm happy because my costs won't exceed the fixed amount.	○	○	○	○	○

Table 3.14: Flexibility (Cronbach's α of 55%)

Imagine you are already subscribed for either of pay-per-use or pay-per-period schemes. Please indicate the extent to which you agree/disagree with the following statements.					
	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly disagree
I don't like the idea of committing myself to a provider for a long time.	○	○	○	○	○
I like to try different providers and products.	○	○	○	○	○
When I have the choice, I would prefer a new product over a product I already know.	○	○	○	○	○
I DO NOT like switching between different providers because I do not like the hassles of finding a new provider and replacing the device.	○	○	○	○	○
I wouldn't switch as long as the machine is working well even though there are better alternatives.	○	○	○	○	○

Table 3.15: NEP scale for (Cronbach's α of 83%)

Please indicate the extent to which you agree/disagree with the following statements.					
	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly disagree
We are approaching the limit of the number of people the earth can support.	◯	◯	◯	◯	◯
Humans have the right to modify the natural environment to suit their needs.	◯	◯	◯	◯	◯
When humans interfere with nature it often produces disastrous consequences.	◯	◯	◯	◯	◯
Human ingenuity will insure that we do NOT make the earth unliveable.	◯	◯	◯	◯	◯
Humans are severely abusing the environment.	◯	◯	◯	◯	◯
The earth has plenty of natural resources if we just learn how to develop them.	◯	◯	◯	◯	◯
Plants and animals have as much right as humans to exist.	◯	◯	◯	◯	◯
The balance of nature is strong enough to cope with the impacts of modern industrial nations.	◯	◯	◯	◯	◯
Despite our special abilities humans are still subject to the laws of nature.	◯	◯	◯	◯	◯
The so-called "ecological crisis" facing humankind has been greatly exaggerated.	◯	◯	◯	◯	◯
The earth is like a spaceship with very limited room and resources.	◯	◯	◯	◯	◯
Humans were meant to rule over the rest of nature.	◯	◯	◯	◯	◯
The balance of nature is very delicate and easily upset.	◯	◯	◯	◯	◯
Humans will eventually learn enough about how nature works to be able to control it.	◯	◯	◯	◯	◯
If things continue on their present course, we will soon experience a major ecological catastrophe.	◯	◯	◯	◯	◯

Reward:

You have the chance to win a **bonus of 300 Euros**. The following steps will be taken to determine the winner:

1. We will first randomly choose a participant as a potential winner.

2. If that is you, we will randomly choose one of the 15 choice sets you have observed.

3. Then, a panel of experts will rank the best choices for you in that specific choice set based on your characteristics, extracted from your answers to the questions in the second part of the survey.

a. If your actual choice in the chosen choice set matches the expert's best choice, you will get the **full reward**.

b. If your actual choice matches the expert's second best choice, you will get **half of the full reward**.

c. Otherwise we will do the whole process again for another participant.

Figure 3.6: The reward scheme announcement in the survey

3.6.2 Appendix B: Pilot results

Table 3.16: Relative importance of attributes and partworth utilities for the pilot experiment

Attribute	Average Importance	levels	Average utilities	Standard deviation
Payment scheme	43.24344	Purchase	40.75763	88.10122
		Pay-per-use	8.81840	66.92246
		Pay-per-period	-49.57603	45.51913
Price	23.36969	Low	43.85761	15.22914
		Medium	5.45036	11.61942
		High	-49.30797	18.45243
MCD	13.46373	6 Months	-21.33861	20.53363
		1 year	4.97222	16.84586
		2 years	16.36639	26.62463
Energy efficiency	19.92313	C	-30.00051	39.01218
		A	30.00051	39.01218

Table 3.17: The relationship between the importance of attributes and consumer characteristics for the pilot experiment

	Dependent variable:			
	Payment scheme	Price	MCD	Energy efficiency
	(1)	(2)	(3)	(4)
Ticking meter effect	−6.835*	4.691**	−1.375	3.519
	(3.409)	(1.802)	(1.919)	(3.519)
Psychological Ownership	1.001	1.279	−0.998	−1.282
	(2.575)	(1.361)	(1.449)	(2.658)
Flexibility	1.384	2.675	−3.563	−0.496
	(3.793)	(2.005)	(2.135)	(3.916)
Insurance	1.969	−2.633*	0.577	0.087
	(2.536)	(1.340)	(1.427)	(2.618)
Greenness	4.043	−1.351	−1.780	−0.913
	(4.371)	(2.310)	(2.461)	(4.512)
Usage	0.749	0.406	0.620	−1.775
	(1.137)	(0.601)	(0.640)	(1.174)
Cost Expectation	−1.164	1.162	0.712	−0.709
	(2.287)	(1.209)	(1.287)	(2.361)
Breakdown probability perception	1.272	2.141	1.400	−4.813
	(3.826)	(2.022)	(2.154)	(3.950)
Household size	−0.693	−0.301	0.373	0.622
	(0.899)	(0.475)	(0.506)	(0.928)
Age	−0.079	0.027	−0.065	0.117
	(0.238)	(0.126)	(0.134)	(0.246)
Task complexity	−1.726	−0.047	0.578	1.195
	(1.865)	(0.985)	(1.050)	(1.925)
Constant	201.239	−51.865	157.043	−206.417
	(477.045)	(252.128)	(268.552)	(492.457)
Observations	50	50	50	50
R^2	0.208	0.251	0.188	0.150
Adjusted R^2	−0.021	0.034	−0.048	−0.096
Residual Std. Error (df = 38)	14.522	7.675	8.175	14.991
F Statistic (df = 11; 38)	0.909	1.155	0.797	0.610
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 3.18: The relationship between the partworth utilities of the payment schemes and consumer characteristics in the pilot experiment

	Dependent variable:		
	Purchase	Pay-per-use	Pay-per-period
	(1)	(2)	(3)
Ticking meter effect	−0.105	1.843	−1.738
	(18.617)	(11.439)	(10.655)
Psychological ownership	29.143**	−12.972	−16.172*
	(14.061)	(8.640)	(8.047)
Need for flexibility	−2.340	2.931	−0.591
	(20.715)	(12.728)	(11.856)
Insurance effect	5.376	−19.701**	14.325*
	(13.848)	(8.508)	(7.925)
Greenness	−7.954	10.885	−2.931
	(23.871)	(14.667)	(13.662)
Usage	13.896**	−14.993***	1.096
	(6.210)	(3.815)	(3.554)
Cost expectation	−7.065	9.237	−2.172
	(12.487)	(7.673)	(7.147)
Breakdown probability perception	−13.648	22.490*	−8.843
	(20.895)	(12.838)	(11.958)
Household size	3.282	−3.856	0.573
	(4.909)	(3.016)	(2.810)
Age	−2.390*	2.021**	0.369
	(1.301)	(0.799)	(0.744)
Task complexity	−8.851	3.022	5.830
	(10.183)	(6.257)	(5.828)
Constant	4,728.149*	−3,969.494**	−758.656
	(2,605.157)	(1,600.698)	(1,490.979)
Observations	50	50	50
R^2	0.372	0.589	0.229
Adjusted R^2	0.190	0.470	0.006
Residual Std. Error (df = 38)	79.306	48.729	45.388
F Statistic (df = 11; 38)	2.043*	4.947***	1.026
Note:			*p<0.1; **p<0.05; ***p<0.01

3.6.3 Appendix C: Extensive results of the analysis

Table 3.19: The relationship between the importance of attributes and consumer characteristics

	Dependent variable: Importance of			
	Payment scheme	Price	MCD	Energy efficiency
	(1)	(2)	(3)	(4)
Ticking meter effect	-2.71^{**}	1.15^{*}	0.16	1.39
	(1.11)	(0.61)	(0.98)	(0.94)
Psychological Ownership	1.65^{**}	0.19	-0.03	-1.81^{***}
	(0.81)	(0.45)	(0.71)	(0.68)
Flexibility	-2.06	0.41	4.79^{***}	-3.14^{***}
	(1.25)	(0.69)	(1.10)	(1.06)
Insurance effect	-2.09^{**}	-0.28	1.16	1.20
	(0.96)	(0.53)	(0.84)	(0.81)
Greenness	-1.17	0.51	-0.16	0.82
	(1.50)	(0.82)	(1.32)	(1.27)
Usage	1.12^{***}	-0.35^{**}	-0.54^{**}	-0.23
	(0.26)	(0.14)	(0.23)	(0.22)
Cost expectation	-1.70^{**}	-0.28	0.19	1.79^{***}
	(0.76)	(0.42)	(0.67)	(0.64)
Breakdown probability perception	-2.54^{**}	1.13^{*}	1.62^{*}	-0.21
	(1.07)	(0.59)	(0.94)	(0.90)
Household size	0.19^{*}	0.001	-0.06	-0.13
	(0.11)	(0.06)	(0.09)	(0.09)
Age	0.10	0.03	-0.01	-0.12^{*}
	(0.09)	(0.05)	(0.08)	(0.07)
Task complexity	-0.95	0.39	-0.31	0.86
	(0.65)	(0.36)	(0.57)	(0.55)
Constant	-145.93	-49.25	27.30	267.89^{*}
	(172.88)	(95.00)	(152.00)	(145.89)
Observations	298	298	298	298
R^2	0.19	0.05	0.10	0.12
Adjusted R^2	0.15	0.02	0.07	0.09
Residual Std. Error (df = 286)	12.74	7.00	11.20	10.75
F Statistic (df = 11; 286)	5.90^{***}	1.45	2.98^{***}	3.60^{***}

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Table 3.20: The relationship between the partworth utilities of the payment schemes and consumer characteristics

	Dependent variable:		
	Purchase	Pay-per-use	Pay-per-period
	(1)	(2)	(3)
Ticking meter effect	−4.42	−3.89	8.31***
	(4.65)	(4.44)	(3.01)
Psychological Ownership	10.19***	−5.61*	−4.58**
	(3.39)	(3.23)	(2.19)
Flexibility	1.32	−2.96	1.64
	(5.23)	(4.99)	(3.38)
Insurance effect	−2.04	−3.72	5.75**
	(3.99)	(3.81)	(2.58)
Greenness	−6.82	8.32	−1.51
	(6.27)	(5.98)	(4.05)
Usage	5.05***	−6.57***	1.52**
	(1.07)	(1.02)	(0.69)
Cost expectation	−8.25***	6.76**	1.50
	(3.17)	(3.02)	(2.05)
Breakdown probability perception	−5.91	4.11	1.80
	(4.47)	(4.26)	(2.89)
Household size	−0.71	0.89**	−0.17
	(0.44)	(0.42)	(0.28)
Age	−0.09	0.17	−0.08
	(0.36)	(0.35)	(0.24)
Task complexity	−4.52*	2.10	2.42
	(2.71)	(2.58)	(1.75)
Constant	256.00	−325.01	69.01
	(722.04)	(689.14)	(467.20)
Observations	298	298	298
R^2	0.18	0.21	0.12
Adjusted R^2	0.14	0.18	0.09
Residual Std. Error (df = 286)	53.20	50.78	34.43
F Statistic (df = 11; 286)	5.52***	6.90***	3.59***
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 3.21: Interaction effects table: extensive version

Interaction term added	Parameters in model	Log-likelihood fit	chi square value	2LL p-value for interaction effect	Gain in pct. cert. over main effects
+ Payment scheme x Price	12	-4733.23	12.42515	**0.01445**	10.79 %
+ Payment scheme x MCD	12	-4738.25	2.39311	0.66387	2.08%
+ Payment scheme x Energy efficiency	10	-4739.23	0.43053	0.80633	0.37%
+ Price x MCD	12	-4738.08	2.73227	0.60358	2.37%
+ Price x Energy efficiency	10	-4738.99	0.91252	0.63365	0.79%
+ MCD x Energy efficiency	10	-4737.28	4.33100	0.11469	3.76%

4 The Bitter Pill: The Impact of Tendering on Nationwide Drug Shortages

4.1 Introduction

Countries across the globe are experiencing increasing numbers of drug shortages. In the US, drug shortages are labeled a “national security issue” (Acosta et al., 2019) and a “persistent problem” (FDA, 2019). The European Commission similarly portrays it as a “growing problem for many EU/EEA countries” and “a major problem for the quality and continuity of patient care” (EC, 2021). The consequences of drug shortages can be severe, including increased mortality rates (Vail et al., 2017; Yurukoglu et al., 2017), medication errors (Fox & Tyler, 2003), and less effective treatment. In the US, over half of the hospitals reported using alternative or delayed care due to drug shortages, and nearly 40% rescheduled or canceled procedures (Phuong et al., 2019). Shortages also have significant economic consequences. Pharmacies or wholesalers may have to source from expensive small-scale local producers (EAHP, 2019) or provide different, more costly alternatives (Caulder et al., 2015). Handling shortages also places a considerable burden on pharmacies. For example, Dutch pharmacies spend 17.5 person-hours per week to handle shortages, estimated to cost between €45 and €105 million per year (Ministerie van VWS, 2019a).

The causes of drug shortages can be categorized into two groups: manufacturing/ supply causes and economic causes (Economist, 2017). The former include quality issues (which can lead to recalls), disrupted supply of active pharmaceutical ingredients (APIs), disrupted transportation, or poor inventory management. Economic causes encompass regulations, policies, and practices making markets less attractive and/or affecting incentives to invest in supply resilience (Economist, 2017; Kanavos et al., 2009). The most heavily debated economic cause is the use of tendering. Tendering is a formal procedure to procure goods, work, or services – drugs in our case – using competitive bidding for a particular contract (Dranitsaris et al., 2017). In Europe, tenders are commonly used to procure drugs, with hospital pharmacies procuring 80-100% of drugs through tenders in almost all EU member states. Several countries, including Germany, Belgium, the Netherlands, Spain, Slovakia, and Denmark, use tendering to procure drugs for outpatient care (Medicines for Europe, 2022; Gawronski et al., 2022). Tenders can consider various criteria for awarding to authorized suppliers, and tendering can lead to multiple winners. Price is often the only factor, and winner-takes-all tenders dominate (EC, 2021).

Tendering can significantly reduce prices and enhance affordability. For example, the Netherlands observed a price reduction of up to 95% after implementing tendering in 2008 (Kanavos et al., 2011). Despite this benefit, price-based, winner-takes-all tendering is increasingly criticized for causing drug shortages through four mechanisms (Biedermann, 2022; de Vries et al., 2021):

- First, it *puts suppliers' margin under pressure*, incentivizing them to decrease inventories and offshore production and reduce slack production capacity, thereby increasing the risk of shortages (Besancon & Chaar, 2013; Jagtenberg et al., 2021). Low margins also cause suppliers to put a country at the back of the line when there is a shortage (KNMP, 2020; VIG, 2023).
- Second, it creates uncertainty for suppliers, as they may gain or lose a significant market share from one month to the next. Losing a tender, with uncertainty and pressure on margins, can *prompts suppliers to exit the market* (EC, 2021), resulting in fewer suppliers who can quickly "jump in" to fill shortages caused by other suppliers (Pauwels et al., 2014).
- Third, it *can lead to more concentrated markets*, with one or a few suppliers serving most patients. This leaves few suppliers with enough capacity to fill the shortages caused by a major supplier (EC, 2021).
- Last, it *induces switches in suppliers*, which can lead to additional risk of shortages. The former supplier might ramp down the supply chain too quickly, while the new supplier can face difficulties ramping up (Kanavos et al., 2009; EFPIA, 2022; Biedermann, 2022; Jagtenberg et al., 2021).

Despite these plausible mechanisms, no strong empirical evidence exists that tendering increases shortages (see Section 4.2). In fact, many doubt whether this effect exists or is substantial for several reasons. First, winning a tender leads to a relatively stable and predictable demand during the contract period, offering the tender winner the financial security needed to justify investments in production capacity and inventory (EC, 2021). Second, the prospect of serving a major share of the market also attracts *new suppliers*, often those who participate in tenders across multiple countries (Bruijnooge, 2021; Hordijk, 2019). To participate in tenders, they must obtain market authorization for their drugs. They thereby expand the set of alternative suppliers available to jump in when a disruption occurs. Third, in markets that have become more concentrated (due to tendering), suppliers are believed to feel a stronger sense of responsibility to prevent shortages (See Francas et al., 2023). Last, many suppliers have a diverse portfolio of drugs, allowing them to hedge against uncertainty induced by tendering. This may limit the effect of tendering on market exit decisions (Bruijnooge, 2021).

In short, practitioners and academic literature suggest that tendering induces mechanisms that can *trigger* shortages and *reduce* them. Scientific literature quantifying the *net impact* of tendering on shortages is lacking. This leads to an ongoing debate in which stakeholders emphasize different mechanisms and question the validity of others. For example, while several studies (see, e.g., Economist, 2017; Jagtenberg et al., 2021) argue that tendering makes the market less attractive for suppliers, a recent Lancet article shows that practitioners question this, arguing that the number of suppliers *increased* over the period in which tendering was implemented (Biedermann, 2022). Therefore, this study examines the following empirical research question: *What is the impact of tendering on drug shortages?*

Most studies on drug shortages use cross-sectional data to study causes. Reverse causality and many third causes make inferring causality from such analyses difficult. We bought and combined large *longitudinal* datasets on tenders and sales volumes, shortages, and features of outpatient drugs in the Netherlands. Insurance companies in the Netherlands use tendering to procure a share of generic drugs [1] under the so-called preference policy. Our data allows us to leverage a set of natural experiments wherein plausibly exogenous variation through (new) tenders presents an opportunity to identify the effect of tendering on shortages. This enables us to conduct analyses beyond what was achievable in prior studies, which mainly rely on public data.

We answer our research question using a panel data staggered difference-in-difference (DiD) framework, a state-of-the-art method in policy evaluation (Roth et al., 2023). This setup enables us to compare drugs affected by initiating a tendered contract (treatment group) to unaffected drugs (control group). Our data enables us to study shortages on the prescription cluster level – a cluster of identical articles except for the pack size and/or the supplier or manufacturer. From the patient's perspective, this is more meaningful than analyzing shortages on the *article level*, as done in almost all prior studies. It also allows for a holistic analysis of the impact of tendering – how it affects the capability of *the entire market* to ensure the availability of articles in a given prescription cluster. Our analyses cover both short-term and long-term impacts. Since it is key for policymakers to understand *under what conditions* tendering enhances shortages, we also investigate three potential *moderators*: 1) the number of alternative suppliers in the prescription cluster, 2) the magnitude of change in the tendered market share, and 3) the market concentration within the prescription cluster. We explain the mechanisms through which these variables can moderate the impact of tendering on shortages in Section 4.4.3.

Our empirical analyses yield the following primary findings. First, tendering decreases prices and makes the market more concentrated. Second, there is a strong relationship between tendering and the market share in shortage. Shortages increase right after an insurance company initiates a tendered contract and peak three months after the tender to an 8.1 percentage point increase relative to one month before the initiation. This supports

[1] A generic drug is a medication created to be the same as an already marketed brand-name drug in dosage form, safety, strength, route of administration, quality, performance characteristics, and intended use (FDA, 2022).

the hypothesized mechanism that supplier switches cause shortages. We observe the same results if we only consider extreme shortages, e.g., cases when more than 80% of the market for a given prescription cluster is affected by shortages. Third, the impact of tendering sustains. Over a 48-month period, the market share in shortage increases by 11.5 percentage points on average after an insurance company initiates a tendered contract. We find no evidence that this is due to an increase in market exits. Though shortages caused by market exits do slightly increase two years past the initiation of tendered contracts, this increase is not statistically significant. Fourth, we find that the effect on shortages is strong when (1) a large market share is allocated through tender, (2) there are few alternative suppliers, and (3) the market is fairly concentrated. Conversely, tendering appears to have little to no impact when the market is fragmented and less than 20% of the market is granted through the tender. Our results prove consistent and reliable through several robustness checks.

Our key contributions to the drug shortages literature are fourfold. First, we are the first to quantitatively evaluate the short- and long-term effects of tendering on drug shortages. We are also the first study combining (proprietary) longitudinal datasets on tenders, drug characteristics, market shares, and shortages. Second, we quantitatively evaluate the *mechanisms* that explain the link between tendering and shortages. Prior academic and grey literature solely *hypothesized* those mechanisms. Third, we contribute to the scarce but growing literature on (1) public policy and operations management (Helper et al., 2021) and (2) the impact of procurement on supply security or resilience. While prior literature has mainly explored this at the firm level, we investigate this at the market level. Last, we derive conditions in which tendering has a relatively strong vs. weak impact on shortages. Our work yields and discusses actionable insights for policymakers and organizations running tenders on how to modify tendering or selectively apply it to improve the balance between affordability and availability. Our paper serves the United Nations Sustainable Development Goal 3[2] in general and Target 3.8 specifically: to achieve *"(...) access to safe, effective, quality and affordable essential medicines and vaccines for all"*.

The rest of the paper is organized as follows. In Section 2, we briefly review the most relevant streams of literature. Section 3 provides background information on the Dutch tendering system and describes our data and econometric models. We present our empirical findings in Section 4 and extensively discuss them in Section 5.

4.2 Literature Review

Drug shortages are a growing and multi-faceted global problem. It is therefore receiving increasing attention from academics from various disciplines in the form of studies on causes, effects, shortage management, and shortage mitigation. Tucker et al. (2020a) review academic literature from 2002 to 2019. de Vries et al. (2021) examine open questions

[2] UN SDG3 is to ensure healthy lives and promote well-being for all at all ages (United Nations, 2023)

practitioners face and overlap those with questions addressed in academic literature. They emphasize the need for more Operations Management (OM) research on this topic and advocate “further research that can establish sound evidence on understudied cause and effect relationships.” They especially highlight the lack of evidence of the relationship between tendering and shortages. Next, we summarize three streams of studies that are most closely related to our work.

Empirical studies on the causes of drug shortages. The first stream of literature *explores* the multitude of causes underneath the problem. Examples include the study by Heiskanen et al. (2015) on Finland, Ventola (2011) on the United States, Poulsen et al. (2022) on Denmark, and Jagtenberg et al. (2021) on the Netherlands. van Oorschot et al. (2022) explore how causes interrelate, using practitioners’ sources from six European countries. Some studies specifically examine the economic and regulatory causes of drug shortages and corresponding solutions. Economic causes studied include pricing policies (e.g., Yang (2020)), reimbursement policies (e.g., Yurukoglu et al., 2017; De Weerdt et al., 2015), competition (e.g., Ball et al., 2018), and tendering (e.g., De Weerdt et al., 2015). Regulatory causes studies include drug quality requirements (e.g., Gray et al., 2011; Marucheck et al., 2011; Schweitzer, 2013; Dabestani et al., 2023), operational transparency regulations (e.g., Lee et al., 2021), and inspection regulations (e.g., Anand et al., 2012; Stomberg, 2016).

While some of the exploratory studies mention tendering as a potential cause (see e.g., De Weerdt et al. (2015)), they do not quantify this impact. Furthermore, they typically rely on expert opinion, surveys, or data from shortage reporting platforms. These have been argued to produce relatively weak evidence (de Vries et al., 2021). We contribute to the literature by using a panel data DiD model to derive strong quantitative evidence on the impact of tendering on shortages.

Operations and Supply Chain Management (OSCM) studies on drug shortages. Our work is also related to OSCM studies[3] on drug shortages. Most studies investigate inventory management practices or policies (e.g., Saedi et al., 2016; Azghandi et al., 2018; Jia & Zhao, 2017; Lücker & Seifert, 2017; Tucker et al., 2020b), and API supplier policies and problems (e.g., Steven & Britto, 2016; Parsons et al., 2016; Lücker & Seifert, 2017; Tucker & Daskin, 2022). Some studies analytically examine the economic causes of shortages and/or corresponding interventions. For example, Iravani et al. (2020) evaluate the impact of reference pricing and parallel import on drug shortages. Jia & Zhao (2017) derive pareto-improving contracts that can reduce shortages, increase suppliers’ profit, and cut government spending. We refer to de Vries et al. (2021) and Tucker et al. (2020a) for extensive reviews of these papers. We could find no study in this category that focuses on tendering as a cause and/or the design of a tendering system as a measure to mitigate drug shortages.

[3] We define a study as an OSCM study if it is published in an OSCM journal.

Literature on tendering and resilience. This stream of literature examines the impact of contractual agreements, specifically tendering on supply chain risk management or resilience. Selviaridis et al. (2022) provide a comprehensive literature review on the role of three contracting stages – pre-contract, contract design, and contract management – in managing risks and resilience. They show that the literature on this topic 1) is scant in general, 2) focuses on the contract design and management phase, and 3) mainly focuses on single buyer-supplier relationships for a focal firm. Some papers specifically study tendering for public contracts (e.g., Domberger & Rimmer, 1994; Faunce et al., 2006). However, they do not study how this can contribute to shortages and focus on the price-reducing impact of tenders. Studies examining the effects of tendering on the supply security for a whole market are lacking. We address this gap.

4.3 Data and Methods

We address our research question using a unique proprietary dataset on drug shortages and tenders in the Netherlands. This section provides background information on the Dutch tendering system, motivates why the Dutch case provides a unique opportunity to study the effect of tendering on shortages, describes the dataset, and specifies the model we use to analyze the data.

4.3.1 Tendering System in The Netherlands

We first introduce some terminology. We define the term "article" as a unique combination of active substance(s), dosage, quantity (e.g., in grams or milliliters), dosage form, route of administration, excipients/ auxiliary materials, the manufacturer, the pack size/ volume, and the market authorization holder. In the Netherlands, such articles receive a unique code called the *Z-index number*. For example, Z-index number 15822761 refers to a package of 100 oral tablets of Paracetamol with a dosage 1000 mg manufactured by and authorized for SANDOZ BV in the Netherlands with Paracetamol as its active ingredient and four excipients. Articles can be clustered in various ways, four of which will play an important role in our analysis. First, when two articles are identical except for the pack size, manufacturer, and/or market authorization holder, they are in the same *prescription cluster* and receive the same PRK code (SFK, 2022). Healthcare providers in the Netherlands typically prescribe drugs using a PRK code and a quantity. Second, the Dutch government additionally clusters articles with the same active substance(s) and route of administration. Drugs in such a *reimbursement cluster* (a *GVS cluster*) are labeled as therapeutically interchangeable. Third, as we detail below, insurance companies can create *preference clusters* and label a subset of articles from the same cluster as "preferred" (Berenschot, 2018). Fourth, the *Anatomical Therapeutic Chemical* (ATC) classification system clusters articles based on the active substance(s).

Dutch citizens are legally obliged to take out basic health insurance. The government decides what health services and drugs this insurance must cover. To contain the costs of this insurance package, insurance companies have some freedom in deciding which specific articles to cover. Specifically, they must cover at least one article from each GVS cluster. They can label a subset of articles from such a cluster as "preferred", and only reimburse the costs of those drugs. Pharmacies should always provide patients insured by a given company with the article labeled preferred by that company. Otherwise, the patient is not reimbursed[4] (Jagtenberg et al., 2021). Insurance companies hold tenders to select preferred articles, which grants the winner the right to provide that article to all patients from that insurance company. The contract period is usually between six months and two years. Insurance companies apply tendering to a sizeable share of all generic drugs. For others, pharmacists are free to select the specific article for an agreed maximum price.

In the Netherlands, four insurance companies possess almost 90% of the market share (KPMG, 2020): Zilveren Kruis, CZ, VGZ, and Menzis. These companies started tendering in 2005 (for three prescription clusters) and have gradually expanded the use of tendering (Berenschot, 2018). In our study, we define the *tendered market share* for a prescription cluster as the fraction of the total market sales volume of that prescription cluster that is being supplied through a tendered contract in a certain month. This equals the sum of market shares of insurance companies with a tendered contract for that prescription cluster. Figure 4.1 shows the evolution of the tendered market share for prescription cluster 117633. Before 2017, no insurance company had a tendered contract. VGZ initiated a tendered contract at the start of 2017, which increased the tendered market share to 38%. VGZ had no tendered contracts at the end of 2017, causing the drop to 0%. In January 2018, CZ, ZK, and VGZ initiated tendered contracts for this cluster, which increased the tendered market share to 65%. CZ and VGZ stopped using tendered contracts at the start of 2019, causing another drop.

4.3.2 Research scope

We focus on shortages of generic outpatient drugs in the Netherlands. We focus on *generics* because tendering is common for these drugs (since multiple suppliers are commonly present). In 2021, 78% of all drugs dispensed in the Netherlands were generics (SFK, 2021). We exclude hospital pharmacies and focus on *outpatient* care for two reasons. First, hospital care is a minor part of the Dutch market[5], so the strength of the mechanisms outlined in

[4]Reimbursement for non-preferred drugs only happens in case of emergency medical need.

[5]In 2019, hospitals dispensed drugs to 300,981 patients while outpatient pharmacies dispensed to 11.5 million patients (Ministerie van VWS, 2021)

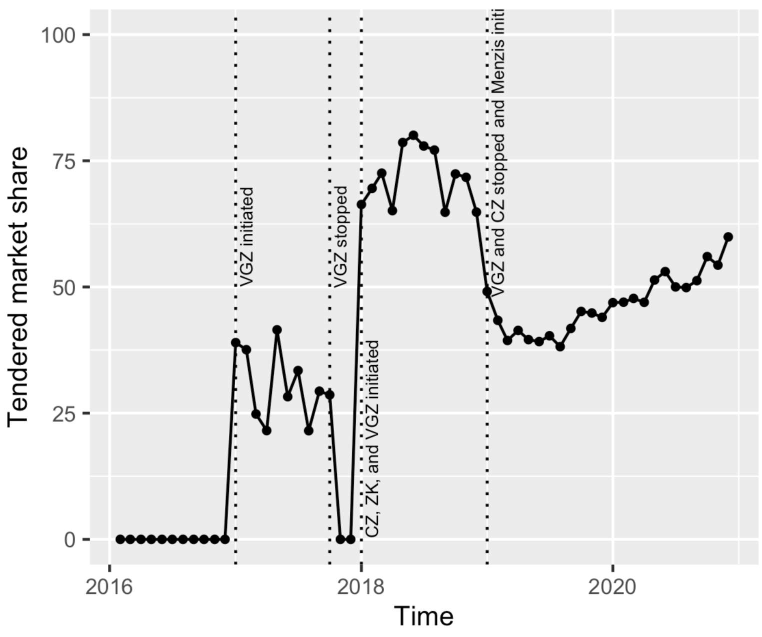


Figure 4.1: Average tendered market share for prescription cluster 117633

Section 4.1 would likely be limited, making it less interesting to study. Second, our data solely covers tendered contracts for outpatient drugs.

A key reason to focus on *the Netherlands* is that it has a tendering system that, by design, induces many variations in the tendered market share for a given prescription cluster (see Section 4.3.1). This allows for a DiD analysis, which yields strong evidence (most prior studies on drug shortages analyze cross-sectional data). The country also suffers from one of Europe's highest shortage rates (OECD & European Union, 2022). At the time of this study, about 15% of all insured articles, or 0.25 million order lines per week, were unavailable (Hollak, 2023; Tinke, 2023). Finally, we obtained a unique dataset that allowed us to quantify shortages on the prescription cluster level. As argued, analyzing cases when none of the articles in a prescription cluster is available is more meaningful than analyzing shortages on the article level, as done in most prior studies. Accordingly, we use the market share of a given prescription cluster "in shortage" as our dependent variable. We formally define this variable and our independent variables in Section 4.3.4.

4.3.3 Data Description

To answer our research question, we constructed a master dataset that combines three proprietary data sets we bought from various Dutch health agencies:

- The first contains historical shortage data from January 2016 to December 2020, collected by *Farmanco*, an organization that collects and publishes information about shortages and suggests solutions (Farmanco, 2022). Farmanco defines a shortage as when an article is unavailable nationwide and which is likely to last longer than 14 days. Shortages in this dataset are reported by pharmacies and confirmed by suppliers. In our baseline analyses, we only consider resolved shortages, i.e., temporary ones, to avoid censoring issues in the data.
- The second dataset, obtained from *Z-index*, encompasses a diverse array of medical, technical, and market characteristics of all drugs registered in the Dutch market (Z-index, 2022). It also describes for each month (2011-2020), each prescription cluster, and each of the four insurance companies, whether there is currently a tendered contract with a specific supplier and, if so, which article(s) are labeled "preferred" vs. "non-preferred" by that specific insurance company. This reveals the months in which an insurance company initiates a tendered contract for a given prescription cluster and how the tendered market share for a given prescription cluster evolves over time.
- The third dataset contains sales data per insurer from 2011 to 2020. It describes for each article, insurer, and month how many defined daily doses (DDDs) were dispensed to patients insured by that insurer. We obtained these data from the *Foundation for Pharmaceutical Statistics* (SFK) (SFK, 2017).

We merged the three datasets at the article level. The aggregated dataset contains 4646 articles, which belong to 1744 prescription clusters. We removed 844 prescription clusters of on-patent drugs (as we focus on generics) and 32 clusters with more than five tenders[6]. The resulting dataset comprises monthly data of 3109 articles from 868 prescription clusters from January 2016 to December 2020.

The treatment moment in our study is a month in which an insurer initiates a tendered contract. That is, the insurer had a tendered contract in that month and none in the month before. Prescription clusters can get treated by multiple insurers, and an insurer can treat a cluster at multiple moments over time. DiD methods, however, allow for one treatment per unit. We therefore include each insurance company-tender-cluster triple separately in our model, increasing the number of units in our analysis to 4595. We use robust standard errors clustered on the prescription cluster to accommodate for this sampling strategy (Abadie et al., 2023).

[6] In the data, there are prescription clusters up for 13 tenders by a single insurance company over the course of our data. To avoid overlap of the effect of different tenders, we limit our study to those clusters with up to five tenders in the time horizon of our study.

4.3.4 Variables

Before we describe our model, we introduce central notations and define our dependent and independent variables. C represents the set of insurance companies, I the set of prescription clusters, H the set of suppliers, and J the set of articles. Subset J_i represents the articles $j \in J$ that belong to prescription cluster i, and element i_j represents the prescription cluster that article j belongs to. Parameter d_{cjt} denotes the total number of DDDs of article j dispensed in period t to patients insured by company c. We define the market share of article j at time t as the number of DDDs dispensed for article j divided by the total number of DDDs dispensed in the article's prescription cluster: $MS_{jt} = \sum_{c \in C} d_{cjt} / \sum_{c \in C, k \in J_{i_j}} d_{ckt}$.

4.3.4.1 Dependent variables.

Our main dependent variable is the market share in shortage at time t for prescription cluster i: S_{it}. Let J^S_{it} denote the set of articles in prescription cluster i that are in shortage at time t. Then S_{it} is calculated as $\sum_{j \in J^S_{it}} MS_{jt}$.

We also consider the market share of cluster i at time t that is lost due to market exits – ML_{it}. This represents the joint market share of articles from this cluster that are in shortage because they permanently left the market at or prior to time t. Section 4.6.1 includes a precise definition of this variable.

We introduce two additional dependent variables to examine how tendering affects prices and market concentration. We measure the first using the (log-transformed) average price of a DDD from prescription cluster i dispensed at time t: $P_{it} = \sum_{j \in J_i} Price_{jt} MS_{jt}$. Here, $Price_{jt}$ denotes the list price of article j at time t. Although the list price is not always the same as the actual price, they are strongly correlated (SFK, personal communication, March 21, 2023). We use the normalized Herfindahl-Hirschman index (HHI) to measure market concentration for prescription cluster i at time t – $NHHI_{it}$. A higher value of $NHHI_{it}$ indicates a higher market concentration and less competition. Section 4.6.1 provides a precise definition.

4.3.4.2 Independent variables.

Our key independent variable is the treatment variable. A treatment for cluster i happens in a given period t if an insurance company c initiates a tendered contract for some article $j \in J_i$ (i.e., it had no tendered contract at time $t-1$). Binary variable $Treat_{ic}$ captures whether cluster i was treated by insurance company c over the timespan of our data.

As we use a staggered DiD model, we also introduce relative time dummy variables for the period starting at K periods before the treatment and ending at L periods after the treatment. Specifically, we use a binary variable D^l_{ict} to indicate whether cluster i was treated by insurer c at time $t-l$, for $l \in \{-K, -K+1, ...L\}$.

4.3.4.3 Control variables.

Prescription clusters have different features that can explain part of the shortage variation. In our model, we control the sales volume (in DDDs), pharmaceutical form, ATC code, the number of APIs, and the excipients of articles in cluster i. We also control for the market share for prescription cluster i at time t that is supplied through tendered contracts, i.e., the tendered market share or M_{it}. Section 4.6.1 provides detailed definitions of all control variables.

4.3.5 Staggered DiD Model

The traditional DiD model assumes one fixed treatment moment for all the cross-sectional units. In our case, units (prescription clusters) can undergo multiple treatments, and treatment periods differ across prescription clusters. We, therefore, use a staggered DiD model (also called an event study). This method has been widely used in the literature (see Borusyak & Jaravel, 2017; Baker et al., 2022)). Equation 4.1 specifies our model:

$$S_{it} = \alpha_i + \sum_{l=-K}^{L} \mu_l (Treat_{ic} \times D^l_{ict}) + \sum_{l=-K}^{L} \zeta_l (Treat_{ic} \times D^l_{ict} \times M_{it}) + \gamma_i X_i + PRK_i + \lambda_t + IC_c + \epsilon_{it} \tag{4.1}$$

Here, the first interaction term shows the main DiD effect – our coefficient of main interest – which is an interaction of the treatment and relative time dummy variables. The third term in the equation is an interaction of tendered market share, treatment, and relative time dummies. This term is added to control for the market share subject to tendering. By including this term, we obtain the general effect of introducing a tender, irrespective of the tendered market share. X_i represents the control variables we use in our analysis. We also include the following fixed effect terms: λ_t for the calendar month to capture seasonal demand variations, PRK_i to capture inherent variations among prescription clusters not already captured by our control variables, and IC_c for insurance company c to capture the possible variations among insurance companies.

4.4 Empirical Findings

In this section, we first evaluate the effect of tendering on price and market concentration. We then present our findings on the effects of tendering on drug shortages and what drives this effect (i.e., the moderators). We conclude with a series of robustness checks.

4.4.1 Impact on price and market concentration

As explained in Section 4.1, tendering is claimed to enhance shortages by decreasing prices and increasing market concentration. Low prices can disincentivize suppliers to invest in supply security, cause them to exit the market, and push a country to the back of the line when there is a shortage. A higher market concentration is argued to make it less likely that an alternative supplier can jump in when one of the main suppliers causes a shortage. Before examining the direct relationship between tendering and shortages, we explore its impact on prices and market concentration. For this, we use a slightly adjusted version of Model 4.1 where we only replace the left-hand side with price and normalized HHI.

Figure 4.2a shows the effect of tendering on the average price of a DDD dispensed. It reveals a clear drop in prices immediately after initiating a tendered contract. The pre-treatment coefficients are not significant, which supports the parallel trend assumption. The post-treatment coefficients show a clear drop. The aggregate post-treatment effect is 0.031 and significant ($p < 0.01$). The price per DDD dispensed drops by 3.1% on average after an insurer initiates a tendered contract. Given that margins are razor-thin already[7], such a decrease is substantial. Prices stay low in the 12 months after: up to 4% below their initial levels. This supports the claim that tendering leads to a price decrease.

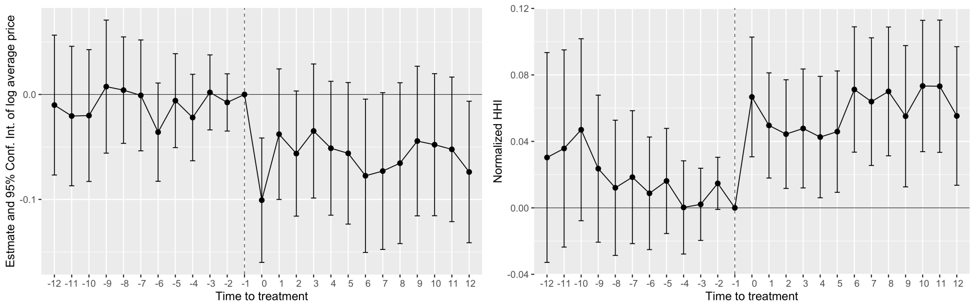
Figure 4.2b shows the effect of tendering on the normalized HHI. The parallel trend assumption is supported by the insignificant pre-treatment effect sizes. The figure also reveals a clear jump of 6.6 percentage points ($p < 0.001$) in the normalized HHI after initiating the tendered contract. To illustrate, if two suppliers had equal market shares before the treatment, the 6.6% rise would lead to their market shares becoming 63% and 37%, respectively, after the treatment. This lends support to the claim that tendering leads to greater market concentration. Online Appendix B provides more detailed results.

4.4.2 Impact on shortages

4.4.2.1 Short-term impact.

We now explore whether and how the initiation of a tendered contract affects drug shortages over a 12-month timespan. Figure 4.3a depicts our main coefficients of interest from

[7] The average price of a generic DDD dispensed in the Netherlands is 10 cents (Boogaard, 2023)



(a) Impact of tendering on log weighted price **(b)** Impact of tendering on normalized HHI

Figure 4.2: Impact of tendering on price and Normalized HHI

Model 4.1 alongside 95% confidence intervals. We observe that almost all the pre-treatment effect sizes are insignificant, supporting the parallel trend assumption. The key insight is that tendering significantly increases shortages. Specifically, the expected market share in shortage increases by 4.1 percentage points in the first month after the initiation of the tendered contract. The aggregate effect[8] over the 12-month period equals 7.0 percentage points ($p < 0.001$). This increase is rather substantial. It translates to an expected additional 26 days of market-wide shortage per year.

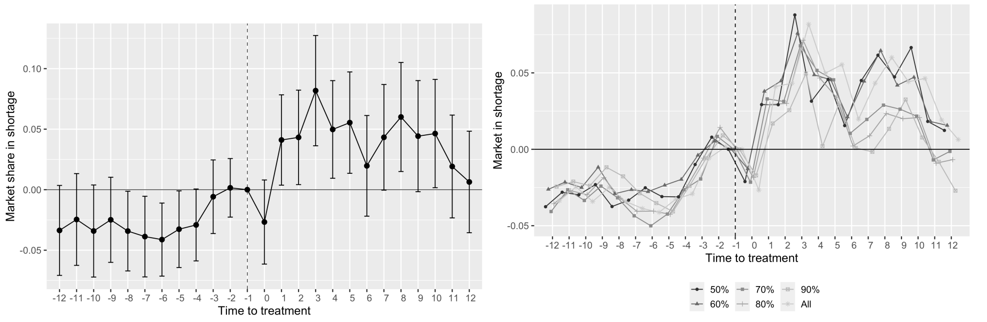
The increase peaks at 8.1 percentage points three months past the initiation of the tendered contract ($p < 0.01$). We also observe a strong upward trend in shortages starting four months before the initiation. These findings support the claim that the difficulties faced by the incumbent supplier ramping down its supply line and the new supplier ramping up cause shortages.

4.4.2.2 Impact on extreme shortages.

In our base model, we consider the market share in shortage as our outcome variable. However, one could argue shortages become particularly problematic when a sizeable market share is in shortage. This increases the time and effort needed to find alternative suppliers (e.g., through parallel import) and the chance that none can be found at all (i.e., that patients are forced to stop the course of medication or switch to a non-preferred alternative). This leads to the question whether tendering also enhances the likelihood of *extreme* shortages. In this section, we replace the market share in shortage by a binary variable that indicates whether the market share in shortage exceeds a critical threshold. Figure 4.3b[9]

[8] I.e., if we treat all the pre-treatment periods the same, as the pre-treatment, and all the post-treatment periods the same and run the DiD model

[9] In this figure and figures including more than two plots, we omit the confidence intervals for better readability and ease of comparison.



(a) Impact of tendering on drug shortages

(b) Impact of tendering on extreme shortages, with different thresholds defining what constitutes an extreme shortage.

Figure 4.3: Short-term effect

presents the results for various threshold values: 50, 60, 70, 80, and 90%. The findings are consistent with our main results in Figure 4.3a. Although the magnitude of the effect decreases slightly when the threshold increases, the likelihood of extreme shortages increases significantly after the initiation of a tendered contract.

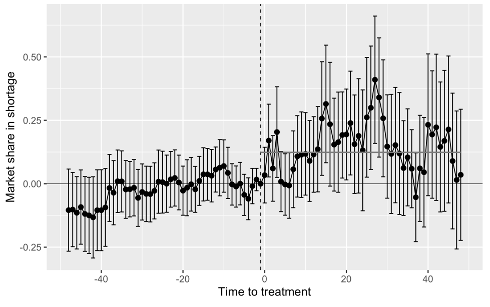
4.4.2.3 Long-term impact.

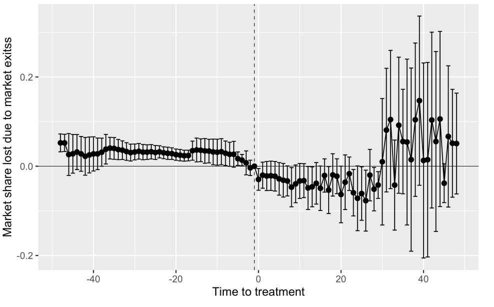
Part of the effect of tendering on shortages may only be visible in the longer term. Suppliers may not immediately reduce inventories or other forms of slack when prices decrease due to tendering. Similarly, if it prompts a supplier to leave the market, it may only do so after a periodic market prospect analysis rather than after the outcome of a single tender is announced (as also argued by Bruijnooge, 2021).

To examine this, we expand the time window before and after the introduction of tendering in our model to 48 months each. This creates one issue: some prescription clusters undergo multiple treatments over time, which induces overlap in their pre- and/or post-treatment periods. Therefore, we conduct a separate analysis on prescription clusters for which an insurance company initiated a tendered contract and has not stopped having one since then. This subsample includes 790 of the 868 initial prescription clusters (91%).

Figure 4.4a shows the effect sizes[10]. The horizontal line depicts the aggregate effect of tendering. The figure shows a persistent increase in the market share in shortage after initiating a tendered contract. The aggregate increase is 11.97 percentage points ($p < 0.01$) and peaks at 40 percentage points 27 months after initiating a tendered contract. This confirms that tendering strongly affects the collective capacity of suppliers that continue to operate in the market to guarantee availability. Furthermore, the observation that the

[10]The detailed results are available upon request.





(a) Impact of tendering on market share in shortage in the long term

(b) Impact of tendering on the market share lost due to market exits in the long term

Figure 4.4: Long-term effect

aggregate effect is much larger in the long term (compared to the short term) supports that a considerable share of the effect occurs with a delay.

Next, we examine how tendering affects shortages through *market exits*. Specifically, we analyze how tendered contract initiation affects the market share lost due to market exits (see Section 4.3.4) by using variable ML_{it} as the dependent variable in Model 4.1. Figure 4.4b depicts the results, which add nuance to the market exit mechanism discussed in Section 4.1. Specifically, they suggest that shortages caused by market exits slightly *decrease* in the first 2.5 years after tendered contract initiation, and slightly increase afterwards. However, this increase is not statistically significant and is relatively minor compared to the impact of tenders on suppliers that remain active. Hence, we find little support for the "market exit mechanism", which aligns with recent doubts about its validity (Biedermann, 2022).

4.4.3 Moderation effects

Stakeholders need to understand if the impact of tendering on shortages is universal or if it only materializes under specific conditions. This knowledge can guide adjustments to the tendering process or enable more targeted implementation. In this section, we investigate three potential moderators.

4.4.3.1 Number of alternative suppliers and market concentration.

As explained, tendering can contribute to shortages by impacting the ability of alternative suppliers to intervene during a disruption. For instance, if tendering results in one or two suppliers dominating the market for a specific prescription cluster, other suppliers may not invest heavily in inventories or prioritize serving that market during a disruption. The strength of this mechanism may depend on the number of alternative suppliers and the market concentration at the treatment moment. We expect that the effect of a tendered contract initiation is relatively minor if there are *numerous alternative suppliers* or the market is highly fragmented. The impact may also be minor if *very few alternative suppliers* are present or the market is highly concentrated: the main suppliers may feel a strong sense of responsibility to ensure availability, as argued by Francas et al. (2023). As such, one would expect that the impact of tendering is non-linearly affected by the number of alternative suppliers and market concentration.

To examine this, we split the sample based on the average number of suppliers in each cluster over time: 1, 1-2, 2-3, 3-4, and >4 . We also split the sample into five parts based on the value of the normalized HHI right before the treatment moment: 0-0.2, 0.2-0.4, 0.4-0.6, 0.6-0.8, and 0.8-1, respectively. Next, we fit our model for each split sample.

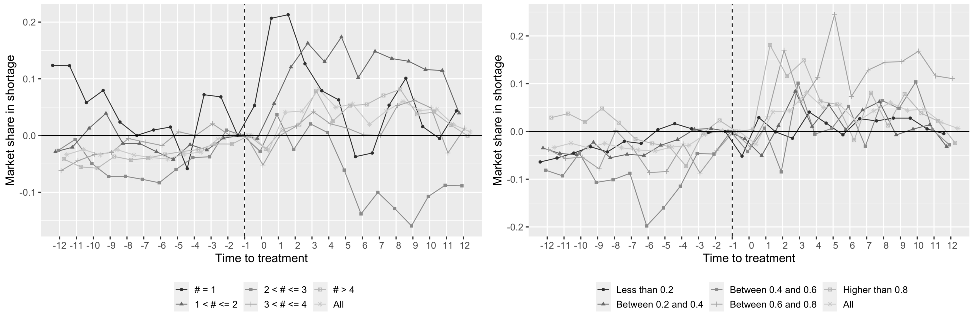
Figure 4.5a depicts the results for the number of alternative suppliers. It confirms that initiating a tendered contract has relatively little impact when there are many alternative suppliers (i.e., more than two on average). The strongest effect occurs when there are *multiple but few* suppliers. For clusters with one[11] to two suppliers on average, the aggregate effect size is 12.36 percentage points ($p < 0.001$). For clusters with one supplier, the expected market share in shortage also increases strongly. However, this increase seems smaller than clusters with one or two suppliers. This provides some evidence for the moderating mechanism that suppliers feel a stronger sense of responsibility in such markets.

Figure 4.5b shows the results for market concentration, which align with the hypothesized nonlinear effect. When the market is highly fragmented (normalized HHI < 0.4), the impact of tendering on shortages is marginal. The strongest effect occurs when the market is fairly concentrated ($0.6 \leq$ normalized HHI < 0.8). It is still strong but a bit lower when the market is a near-monopoly (normalized HHI ≥ 0.8). Online Appendix B provides more detailed results. These findings have strong policy implications, which we discuss in Section 4.5.

4.4.3.2 Jump in the tendered market share.

Section 4.4.2 shows that shortages increase after initiating a tendered contract. Part of the mechanisms outlined in Section 4.1 suggest that this effect increases when a larger market share is granted through the tender: it can lead to more complexities due to the ramp-up and ramp-down of supply chains and a larger change in market concentration. That is, the market share granted through the tender may moderate the impact of the corresponding contract initiation on shortages. To examine this, we split the sample into four parts: prescription cluster treatments that led to a 0-10%, 10-20%, 20-30%, and 30-100% increase in the tendered market share. Figure 4.6 shows the results when fitting the base model using a given subsample and the base results. We observe that our main result holds for

[11] Note that tenders can be run to select a preferred article from *a set of* prescription clusters.



(a) The sample split based on the average number of alternative suppliers per cluster

(b) The sample split based on the normalized HHI

Figure 4.5: Time window robustness check

each subsample: the expected market share in shortage increases after the tender. The main observation is that the effect on shortages is more significant if the tendered contract causes a bigger jump in the tendered market share. This effect becomes marginal when less than 20% of the market is granted through the tender. This finding also has important implications for practitioners, which we discuss in Section 4.5.

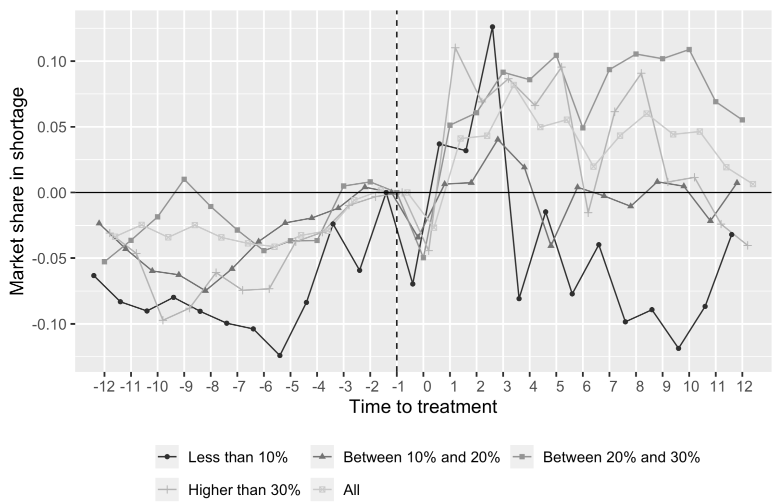


Figure 4.6: Impact of tendering on drug shortages when splitting the sample based on the jump in the tendered market share

4.4.4 Robustness Checks

In this section, we challenge several modeling assumptions to evaluate the robustness of our results. Specifically, we examine how our data and results satisfy the assumptions of our DiD model and check for possible biases that might influence the reliability of our results.

4.4.4.1 Limiting the number of treatment moments.

Multiple insurance companies can launch tenders for a given prescription cluster, and each can have done so numerous times over the timespan of our data. There are prescription clusters in our data with up to 13 tendered contract initiations. The overlap between the post-treatment periods of one treatment and the pre-treatment of the next one might distort our findings. We therefore limited our main analyses to prescription clusters with at most five tenders over the timespan. To examine how this may have affected our results, we test whether further restricting the number of tenders per cluster changes our insights[12]. Our results show that the estimated impact of tendering is hardly affected by the choice of the maximum number of tenders per prescription cluster per insurance company (Online Appendix C provides details). This supports the robustness of our findings.

4.4.4.2 Two-period aggregation.

A key asset of our study is longitudinal data. While this provides a solid basis to accurately capture temporal dynamics in shortages over time and prescription cluster-level idiosyncrasies using fixed effects, panel data can be prone to serial correlation. This could lead to underestimating standard errors and artificially increasing the probability of finding statistically significant effects. We implement the two-period test recommended by Bertrand et al. (2004) to examine whether this is the case. This test addresses serial correlation by ignoring longitudinal information when computing standard errors by collapsing the treated panels into two periods, such that each insurance-prescription cluster pair is observed once before a tender and once after it. We then replicate our estimation of Equation 4.1 using this technique. Online Appendix C provides detailed results of this test. This analysis confirms the positive impact of tendering on the market share in shortage and assuages concerns that our results are biased by serial correlation.

4.4.4.3 Relative time windows.

Our base model includes relative time dummies for $l \in \{-12, -11, ...11, 12\}$, i.e., a 24-month time window. Although we limited our sample to prescription clusters with at most five

[12] Examining how our results are affected when including prescription clusters with *more than five* tenders would induce the technical issues we strove to address

tenders, pre-treatment and post-treatment periods of different tenders can still overlap. To examine whether this impacts our results, we repeat our analyses using $l \in \{-6, -5, ..., 5, 6\}$, which is even more conservative in ruling out overlap in tenders. The result confirms that our findings are robust to the duration of the time window.

Another potential concern is that some of the time windows are partially out of the timespan of our data. We therefore have relatively few observations long before and after the treatment, which might bias the findings, especially if we have a relatively large number of treatment moments starting very early or very late in the timespan of our data. To test if this affects our results, we fit the model to prescription clusters for which the full time window is within the timespan of our data. Online Appendix C provides detailed results. The results are very similar to the base model, which supports the robustness of our findings.

4.4.4.4 Using never-treated clusters as the control group.

A staggered DiD model does not make a difference between prescription clusters that never experienced a tendered contract and those that are not currently subject to a tendered contract (i.e., those outside the -12 to 12 months time window). Recently emerging literature has documented that this can bias the results (see Sun & Abraham, 2021; Baker et al., 2022), especially if the treatment effects are dynamic. This literature (Baker et al., 2022) recommends using only never-treated units as the control group to remedy potential biases. Online Appendix C provides detailed results. Our results remain qualitatively unchanged when we implement this strategy, which supports the robustness of our findings.

4.4.4.5 Placebo tests.

Even though our pre-treatment coefficients indicate no violation of the parallel trends assumption and our results have proven robust, it is reasonable to test if our observed effects materialize purely by chance. According to Bertrand et al. (2004), DiD estimation can be prone to false positives in deflated standard errors. Consequently, it is imperative to test whether our DiD estimator merely captures a spurious effect rather than a real treatment effect. We follow Kogan et al. (2017) and conduct a *treatment placebo test* to do so. We exclude the treatment clusters from the sample, randomly select placebo treatment clusters and treatment moments, and re-estimate the base model. If our previous results are simply due to spurious effects, we would expect significant coefficients after the treatment. Yet, as depicted in online Appendix C, we observe no significant effect sizes after the treatment, which supports that the initiation of a tendered contract causes the jump in shortages, and it is not a false positive.

We also investigate the possibility of false positives regarding the treatment time. To this end, we pursue a similar strategy, but instead of randomizing the treatment group, we randomize the treatment moment in a *time placebo test*. In this test, we exclude the post-treatment periods from the sample, designate the middle period of the pre-treatment periods as the treatment period, and re-estimate the model. online Appendix C provides the results. We do not observe any significant effect except towards the end of the time window. This is to be expected because we approach the actual treatment moment. This test, therefore, also proves that our main results happen after the real treatment period. Our results are thus robust to both treatment and time placebo tests.

4.5 Conclusions and Discussion

Tendering is one of the most debated practices in drug procurement, especially in Europe. Although it has been effective in substantially reducing drug prices and improving *affordability*, tendering also faces significant criticism for its potential to negatively impact *availability* – i.e., to cause drug shortages. Shortages have been on the rise in Europe and the US and have significant health consequences for patients (Vail et al., 2017; Yurukoglu et al., 2017) and financial consequences for pharmacies and society (EAHP, 2019; Caulder et al., 2015; Ministerie van VWS, 2019a). Tendering is argued to increase shortages through four mechanisms: 1) by putting suppliers' margins under pressure, 2) by prompting suppliers to exit the market, 3) by causing more concentrated markets, and 4) by inducing switches in suppliers. Although the role of tendering is much-debated by government and industry stakeholders, there is currently a lack of evidence to show the full extent of its impact on availability. In fact, many doubt whether this impact exists or is substantial.

This paper uses three unique proprietary datasets from the Netherlands to examine the impact of tendering on the availability of drugs. The Netherlands applies tendering in a way that resembles a natural experiment and also suffers from one of the highest rates of drug shortages in Europe. We used a staggered DiD model to evaluate the impact of tendering on various market indicators and the market share in shortage for drug prescription clusters.

Our empirical findings support the claim that holding tenders for a prescription cluster causes a drop in the average price for articles from that cluster after the tender. This observation confirms that tendering is successful at improving the affordability of drugs (Kanavos et al., 2011; de Vries et al., 2021). We also support the claim that tendering increases market concentration, as we see an upward jump in the normalized Herfindahl-Hirschman Index after the initiation of tendered contracts.

Most importantly, our results indicate that tendering leads to a significant increase in drug shortages. We observe a sizeable jump of 7.0 percentage points in the expected market share in shortage in the twelve months after an insurance company initiates a tendered contract for a given prescription cluster. It translates to an expected additional 26 days of market-wide shortage for a cluster per year. To put the corresponding costs in perspective, the estimated annual costs associated with drug shortages in the Netherlands range from €60 to €135 million (Ministerie van VWS, 2019b). If a 7% rise in shortages leads to a corresponding cost increase, the additional expenses are €4.2 to €9.45 million. We also find that tendering leads to more *extreme* shortages, i.e., when the market share in shortage exceeds a given critical threshold. This is an important finding, as the financial and patient impact is expected to grow convexly in the market share in shortage.

Our results support the hypothesis that shortages are caused by the incumbent and the new supplier facing difficulties ramping down and ramping up their supply line (Jagtenberg et al., 2021; EFPIA, 2022; Biedermann, 2022). The market share in shortage steadily increases in the months before contract initiation and is particularly high in the months after. Three months after initiation, the expected market share in shortage is 8.1% higher compared to the month before.

Some of the other hypothesized mechanisms can come with a delay. Examples include the mechanism prompting suppliers to leave the market and the one causing suppliers to decrease slack in their supply chains. The effect of other mechanisms, such as the one related to difficulties ramping up and down, may disappear over time. We conducted separate analyses to examine the long-term impact of tendering. Our results confirm that tendering increases the expected market share in shortage in the long term. We also observe that the market share lost due to market exits slightly decreases in the 2.5 years after a tendered contract is initiated. Though it slightly increases afterwards, this increase is not statistically significant and is relatively minor compared to the impact of tenders on suppliers that remain active. Hence, we find little support for the "market exit mechanism". This aligns with recent doubts about its validity Biedermann (2022), and with the arguments that the prospect of serving a major share of the market also *attracts* suppliers and keeps them in the market, and that many can hedge the uncertainty coming with tenders involved. These are important findings, as they suggest that increasing the tendered market share predominantly affects the capability and motivation to avoid shortages among suppliers *who remain active*, and that this impact is *permanent*. The impact cannot be mitigated by solely incentivizing suppliers to keep their articles on the market (i.e., maintain their market authorization) and addressing the short-term consequences.

To examine whether the impact of tendering on shortages is universal vs. if it only materializes under specific conditions, we also investigate several key moderators. First, we show that tendering has a relatively minor impact when there are many suppliers or when the market is highly fragmented. Initiating a tendered contract then likely leaves enough suppliers who can fill supply gaps caused by a main supplier facing a disruption. The impact increases when the market becomes more concentrated or when fewer suppliers are present. Interestingly, this trend seems to reverse at some point. The impact decreases again when the market is highly concentrated or when very few suppliers are present. The latter is in line with the observation that suppliers feel a strong sense of responsibility in such circumstances (Francas et al., 2023). Second, we show that the impact of tendering on shortages increases when a larger market share is granted through the tender. Granting a larger market share can induce more complexities due to the ramp-up and ramp-down of supply chains and a larger change in market concentration. Importantly, tendering appears to have a negligible impact on shortages when less than 20% of the market is granted.

Our results have important implications for policymakers aiming to improve supply security and organizations procuring medicines. First, they confirm the significant potential of tendering to improve affordability. Given concerns regarding the future financial sustainability of health systems, this should not be dismissed or under-emphasized in ongoing debates. However, we also present strong evidence that, in its present form, tendering can increase shortages. Using price as the sole or dominant criterion triggers disruptions when initiating a tendered contract and permanently enhances the risk of shortages. While this does not mean that tendering should be abandoned altogether, it does call upon policymakers and practitioners to redesign the tendering system to mitigate these risks. The mechanisms we study offer three directions. The first involves redesigning the tendering system to provide stronger incentivizes for ensuring supply chain reliability. Policymakers could encourage or require using reliability as a criterion in tenders. The UK is already exploring this approach by incorporating diverse API sources, suppliers' business continuity plans, supplier past performance, and buffer stock as additional criteria for selecting a tender winner (Selviaridis et al., 2022). Incentives can also be strengthened *within the contract*. For example, one Dutch insurance company has extended contracts with suppliers by two years, conditional on supply reliability.

Second, policymakers could implement solutions that mitigate the market concentration mechanism. Examples include appointing multiple tender winners, only allowing suppliers with a relatively small market share to participate in tenders, and running separate tenders per region (Medicine for Europe, 2018; EC, 2021). Several countries and insurance companies are experimenting with these solutions (e.g., see Boogaard, 2023). Third, the apparent increase in shortages *around* the start of the contract term emphasizes the need to reserve enough time between the tendering period and the beginning of the contract term (Medicine for Europe, 2018). This reduces uncertainty and allows for careful planning of the supply chain ramp-up. Our findings also point to the need to find ways to avoid the outgoing incumbent from ramping down the supply chain too quickly. This could be disincentivized by assigning a weight to past shortages in future tenders, penalizing failures to supply (Jia & Zhao, 2017), or increasing future stock obligations after a shortage, as happens in France (GD Advocats, 2022).

Our moderator analysis provides insight into the *circumstances* in which tendering poses a significant threat to availability: when the market for a prescription cluster is fairly concentrated (normalized HHI > 0.6) and when more than 20% of that market is granted through the tender. Conversely, tendering appears to have little to no impact when the market is fragmented (i.e., normalized HHI < 0.4) and when less than 20% of the market is granted through the tender. These findings are important for policymakers and organizations running tenders and have three important implications. First, they stress the importance of selectively applying tendering based on sound analysis and understanding of the market. Second, they indicate that tendering can be employed safely in various settings, including hospital procurement. For many drugs, hospital care represents only a minor market share, and tendering for hospital care often occurs through procurement groups, each representing only a minor market share (Jagtenberg et al., 2021). Third, they emphasize the need for insurers to coordinate the timing of their tenders. Insurers presently initiate many tendered contracts in January (see e.g., Figure 4.1)), causing significant jumps in the tendered market share. Spacing out tendering activities throughout the year can reduce such jumps, and measures can be implemented to avoid highly concentrated markets.

While our insights are based on Dutch data, we deem it plausible that they generalize to countries with similar tendering systems, such as Germany, Belgium, Spain, Slovakia, and Denmark. More specifically, we contend that the mechanisms linking tendering to shortages broadly apply. The potential of tendering to push down prices and narrow margins is not restricted to the Netherlands; difficulties in ramping up and down the supply chain can be expected in any country. The same goes for the effect of tendering on uncertainty, market concentration, and market attractiveness (cf. Dranitsaris et al., 2017). However, the strength of the mechanisms – i.e., the extent to which they enhance shortages – will vary across countries. For example, the decision of suppliers to leave the market due to narrow margins and uncertainty will strongly depend on market size. Future research examining the strength of the mechanisms in other countries is highly needed.

Like all empirical studies, our study has its limitations. First, the impact of tendering is likely affected by many moderating factors. We only consider the number of suppliers, market concentration, and the jump size. Other potential moderators include the total annual revenue corresponding to a prescription cluster, how distinct the supply chains of suppliers are, the extent to which suppliers can hedge risks, and the inventory policy of the suppliers. Future research examining these moderators would help identify KPIs indicating how a tender for a prescription cluster would affect availability, informing whether or not to subject it to tendering. Second, we lack detailed data on drug suppliers' supply chains, including inventories, production, sourcing, and transportation information. As such, we lack a detailed understanding of how a firm's supply chain reacts to winning or losing a tender. Future research could analyze the impact of tenders on granular supply chain data and study how policymakers can mitigate the adverse effects of tendering on supply chains.

This paper is the first attempt to empirically estimate the impact of tendering on drug shortages. We clarify the adverse consequences of this practice, show that tendering leads to more shortages in the short and long term, and shed light on the underlying mechanisms.

This provides a strong appeal for policymakers worldwide to modify tendering systems or tailor their use to find a better balance between affordability and availability.

4.6 Appendix

4.6.1 Appendix A: Variables

Here we give a detailed definition of non-primary variables.

4.6.1.1 Detailed variables definitions

Normalized HHI. To precisely define this, let J_{h_i} represents a subset of articles in cluster i supplied by supplier h. Also, let MSH_{iht} represent the market share of supplier h in prescription cluster i at time t as $MSH_{iht} = \sum_{c \in C, j \in J_{h_{i_j}}} d_{cjt} / \sum_{c \in C, k \in J_{h_{i_j}}} d_{ckt}$. The value of the HHI for prescription cluster i at time t is then calculated as: $HHI_{it} = \sum_{h \in H_i} (MSH_{iht})^2$. We normalize the HHI to correct for the number of suppliers in the market for cluster i at time t, represented by N_{it}. The normalized HHI is calculated as $NHHI_{it} = (HHI_{it} - (1/N_{it}))/(1 - (1/N_{it}))$ for $N > 1$ and equals 1 for $N = 1$

Market share lost due to market exits Let $\bar{J}_{it}$ denote the set of articles from cluster i for which this is the case at time t and let $\bar{d}_j$ represent the average total number of DDDs dispensed for such article j in the 12 months prior to market exit. Then $ML_{it} = \sum_{j \in \bar{J}_{it}} \bar{d}_j / \sum_{c \in C, k \in J_{i_j}} d_{ckt}$.

Tendered market share.To specify this variable more precisely, we introduce parameter T_{cjt}, which is 1 if article j is supplied through a tendered contract by insurance company c at time t, and 0, otherwise. That is, at time t, an insurance company c has a contract with a single supplier granting it the right to provide a specific article $j \in J_i$ to all patients from that insurance company who need an article from prescription cluster i. Using these notations, we can specify variable M_{it} as: $\sum_{j \in J_{i_j}, h \in H_i} T_{cjt} d_{cjht} / \sum_{c \in C, k \in J_{i_j}, h \in H_i} d_{ckht}$.

Control variables. Sales volume denotes the total number of DDDs of prescription cluster i dispensed to patients in period t. .This variable is calculated as $TS_{it} = \sum_{j \in J_{i_j}, c \in C, h \in H_i} d_{cjht}$ for cluster i, API_i, the number of excipients for cluster i, EX_i, the of articles in cluster i, $Form_i$, and ATC category of the drug, represented by ATC_i. ATC code is the highest level of indexing drugs. Each ATC code consists of five levels. Level 1 indicates the main anatomical group and consists of one letter. Level 2 indicates the therapeutic subgroup and consists of two digits. Level 3 indicates the therapeutic/pharmacological subgroup and consists of one letter. Level 4 indicates the chemical/therapeutic/pharmacological subgroup and consists of one letter, and Level 5 indicates the chemical substance and consists of two digits.

4.6.1.2 Summary statistics of the variables

In this section, we give a summary of the key variables used in our analysis.

Table 4.1: Summary statistics of the variables

	Market share in shortage	No. of API	No. of expipients	Tendered market share	Total sales	No. of alternative suppliers	Normalized HHI	Price
#	158524	158524	158524	158524	158524	158524	158524	158524
min	0.00	1.00	1.00	0.00	1.00	1.00	0.00	0.10
max	1.00	12.00	27.00	1.00	415309	12.00	1.00	4311.09
mean	0.08	1.18	6.82	0.17	6710.98	2.04	0.71	39.20
S.D.	0.26	0.65	3.70	0.26	19087.31	1.48	0.38	134.53

4.6.2 Appendix B: Detailed results

We now present the detailed results of the main model presented in Equation 4.1. Table 4.2 shows the effect sizes and standard errors for the main model, price, and normalized HHI as dependent variables.

Table 4.2: Results of the model for market share in shortage, price, and normalized HHI

Dependent Variables:	Market share shortage	Log weighted price	Normalized HHI
Variables			
Relative time = -12	-0.0336*	-0.0101	0.0303
	(0.0190)	(0.0340)	(0.0322)
Relative time = -11	-0.0246	-0.0205	0.0357
	(0.0193)	(0.0339)	(0.0303)
Relative time = -10	-0.0341*	-0.0201	0.0470*
	(0.0194)	(0.0320)	(0.0279)
Relative time = -9	-0.0249	0.0075	0.0236
	(0.0179)	(0.0323)	(0.0226)
Relative time = -8	-0.0342**	0.0041	0.0121
	(0.0168)	(0.0259)	(0.0208)
Relative time = -7	-0.0387**	-0.0009	0.0185
	(0.0170)	(0.0270)	(0.0204)
Relative time = -6	-0.0412***	-0.0359	0.0088

	(0.0154)	(0.0239)	(0.0173)
Relative time = -5	-0.0327**	-0.0059	0.0162
	(0.0162)	(0.0228)	(0.0161)
Relative time = -4	-0.0291*	-0.0220	0.0003
	(0.0152)	(0.0210)	(0.0143)
Relative time = -3	-0.0058	0.0020	0.0021
	(0.0155)	(0.0182)	(0.0111)
Relative time = -2	0.0015	-0.0076	0.0147*
	(0.0123)	(0.0139)	(0.0080)
Relative time = 0	-0.0267	-0.1007***	0.0667***
	(0.0177)	(0.0302)	(0.0184)
Relative time = 1	0.0411**	-0.0379	0.0496***
	(0.0190)	(0.0318)	(0.0161)
Relative time = 2	0.0432**	-0.0563*	0.0444***
	(0.0199)	(0.0304)	(0.0167)
Relative time = 3	0.0818***	-0.0348	0.0478***
	(0.0232)	(0.0326)	(0.0183)
Relative time = 4	0.0498**	-0.0512	0.0426**
	(0.0206)	(0.0325)	(0.0186)
Relative time = 5	0.0554***	-0.0561	0.0459**
	(0.0214)	(0.0344)	(0.0186)
Relative time = 6	0.0197	-0.0775**	0.0712***
	(0.0212)	(0.0373)	(0.0192)
Relative time = 7	0.0433*	-0.0730*	0.0639***
	(0.0223)	(0.0381)	(0.0196)
Relative time = 8	0.0601***	-0.0655*	0.0701***
	(0.0230)	(0.0391)	(0.0198)
Relative time = 9	0.0442*	-0.0444	0.0551**
	(0.0234)	(0.0364)	(0.0217)
Relative time = 10	0.0464**	-0.0479	0.0733***
	(0.0228)	(0.0345)	(0.0202)
Relative time = 11	0.0192	-0.0523	0.0732***
	(0.0217)	(0.0351)	(0.0203)
Relative time = 12	0.0064	-0.0739**	0.0553***
	(0.0214)	(0.0344)	(0.0213)
Tendered market share × Relative time = -12	-0.0013***	-0.0062***	-0.0012**
	(0.0004)	(0.0009)	(0.0006)
Tendered market share × Relative time = -11	-0.0015***	-0.0060***	-0.0013**

	(0.0004)	(0.0009)	(0.0006)
Tendered market share × Relative time = -10	-0.0013***	-0.0060***	-0.0015**
	(0.0004)	(0.0009)	(0.0006)
Tendered market share × Relative time = -9	-0.0014***	-0.0064***	-0.0011**
	(0.0004)	(0.0009)	(0.0005)
Tendered market share × Relative time = -8	-0.0013***	-0.0062***	-0.0010**
	(0.0004)	(0.0009)	(0.0005)
Tendered market share × Relative time = -7	-0.0012***	-0.0062***	-0.0011**
	(0.0004)	(0.0008)	(0.0005)
Tendered market share × Relative time = -6	-0.0012***	-0.0056***	-0.0010**
	(0.0004)	(0.0008)	(0.0005)
Tendered market share × Relative time = -5	-0.0013***	-0.0061***	-0.0012**
	(0.0004)	(0.0008)	(0.0005)
Tendered market share × Relative time = -4	-0.0012***	-0.0058***	-0.0009**
	(0.0004)	(0.0007)	(0.0004)
Tendered market share × Relative time = -3	-0.0016***	-0.0063***	-0.0010**
	(0.0004)	(0.0008)	(0.0004)
Tendered market share × Relative time = -2	-0.0014***	-0.0059***	-0.0011***
	(0.0004)	(0.0008)	(0.0004)
Tendered market share × Relative time = -1	-0.0013***	-0.0059***	-0.0009**
	(0.0004)	(0.0007)	(0.0004)
Tendered market share × Relative time = 0	-0.0012***	-0.0042***	-0.0019***
	(0.0003)	(0.0005)	(0.0003)
Tendered market share × Relative time = 1	-0.0018***	-0.0050***	-0.0017***
	(0.0004)	(0.0007)	(0.0004)
Tendered market share × Relative time = 2	-0.0019***	-0.0048***	-0.0016***
	(0.0004)	(0.0007)	(0.0004)
Tendered market share × Relative time = 3	-0.0026***	-0.0054***	-0.0016***
	(0.0004)	(0.0007)	(0.0004)
Tendered market share × Relative time = 4	-0.0022***	-0.0052***	-0.0016***
	(0.0004)	(0.0007)	(0.0003)
Tendered market share × Relative time = 5	-0.0022***	-0.0051***	-0.0017***
	(0.0004)	(0.0007)	(0.0004)
Tendered market share × Relative time = 6	-0.0018***	-0.0048***	-0.0021***
	(0.0004)	(0.0006)	(0.0004)
Tendered market share × Relative time = 7	-0.0022***	-0.0049***	-0.0020***
	(0.0004)	(0.0006)	(0.0004)
Tendered market share × Relative time = 8	-0.0025***	-0.0050***	-0.0021***

	(0.0004)	(0.0007)	(0.0004)
Tendered market share × Relative time = 9	-0.0023***	-0.0055***	-0.0019***
	(0.0004)	(0.0007)	(0.0004)
Tendered market share × Relative time = 10	-0.0023***	-0.0055***	-0.0022***
	(0.0004)	(0.0007)	(0.0004)
Tendered market share × Relative time = 11	-0.0020***	-0.0054***	-0.0022***
	(0.0004)	(0.0006)	(0.0004)
Tendered market share × Relative time = 12	-0.0018***	-0.0051***	-0.0018***
	(0.0004)	(0.0006)	(0.0004)
No. of exipients	0.0114	0.0399	0.0098
	(0.0156)	(0.0264)	(0.0203)
Total sale	-3.4×10^{-8}	-5.53×10^{-6}***	2.92×10^{-8}
	(6.23×10^{-7})	(1.48×10^{-6})	(4.87×10^{-7})
ATC L207	-0.2649***	-0.0140	0.0085
	(0.0079)	(0.0166)	(0.0079)
ATC L3B	-0.0168	-0.2179***	0.0345***
	(0.0377)	(0.0661)	(0.0089)
ATC L4B	0.2492***	-0.1926	0.0496***
	(0.0469)	(0.1752)	(0.0080)
ATC L4J	-0.0606	0.1043	0.1935***
	(0.0376)	(0.0650)	(0.0100)
ATC L4X	0.0334	0.8246***	0.2086***
	(0.0371)	(0.0638)	(0.0070)
Fixed effects			
ID	Yes	Yes	Yes
Month	Yes	Yes	Yes
Fit statistics			
Observations	246,633	246,633	246,633
R^2	0.48796	0.96070	0.80808
Within R^2	0.00761	0.08564	0.02224

Clustered (Prescription cluster) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

4.6.3 Appendix C: Detailed results of robustness checks

Here we provide the detailed results of the robustness checks.

4.6.3.1 Limiting the number of treatment moments

Figure 4.7 shows the main effect sizes when we allow for a different maximum number of initiations per prescription cluster.

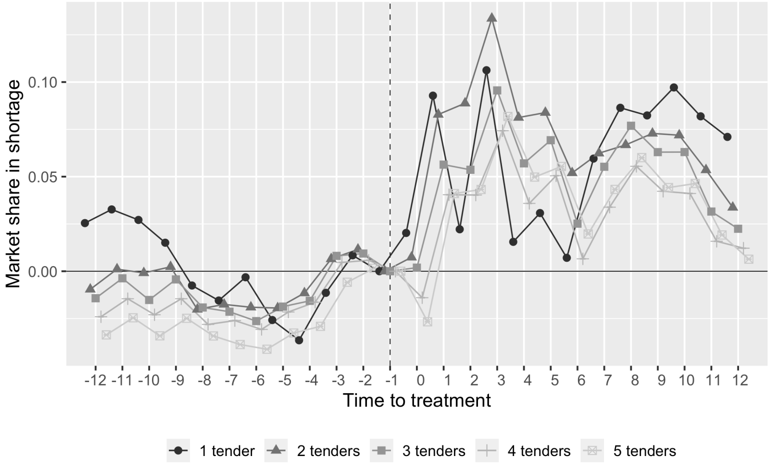


Figure 4.7: The main results when allowing for different maximum number of tenders per prescription cluster over the timespan

4.6.3.2 Two-period aggregation

Table 4.3 shows the summary of results for the two-period aggregation test. Please note that the number of observations in Table 4.3 decreased compared to the base results in Figure 4.3a since we reduced the number of periods from 25 to two. However, this was not possible for the control group.

Table 4.3: The two-period aggregation results

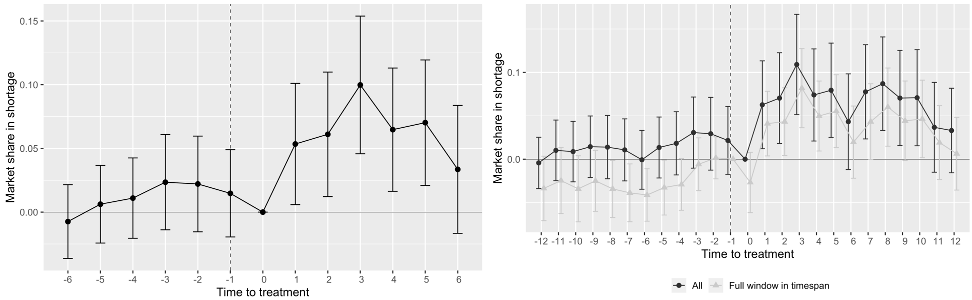
Dependent Variables:	Market share shortage
Variables	
After	0.1102^{***}

	(0.0182)
Tendered market share × Treatment	-0.0003
	(0.0003)
No. of exipients	0.0092
	(0.0202)
Total sales	1.23×10^{-6}
	(9.34×10^{-7})
ATC L207	-0.2689***
	(0.0104)
ATC L3B	-0.0459
	(0.0463)
ATC L4B	0.1985***
	(0.0406)
ATC L4J	-0.0501
	(0.0451)
ATC L4X	0.0316
	(0.0444)
Fixed effects	
ID	Yes
Month	Yes
Fit statistics	
Observations	104,744
R^2	0.48179
Within R^2	0.00321

Clustered (Prescription cluster) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

4.6.3.3 Relative time windows

Here we present the detailed results of manipulating the relative time windows. Figure 4.8a shows the results if we assume a 12-month time window. Figure 4.8b shows the results when we only include those units for which the entire time window is within our study's timespan.



(a) Impact of tendering on drug shortages with a 12-month time window

(b) Impact of tendering on drug shortages for clusters for which the full pre- and post-treatment period is within the timespan of the data

Figure 4.8: Time window robustness check

4.6.3.4 Using never-treated clusters as the control group

Here we present the results of the main model when only using the never-treated units as control. Figure 4.9 compares the results of this analysis and the base results.

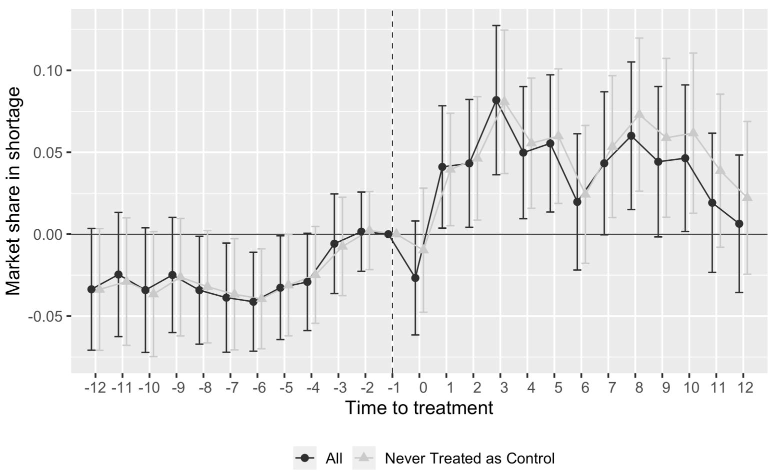
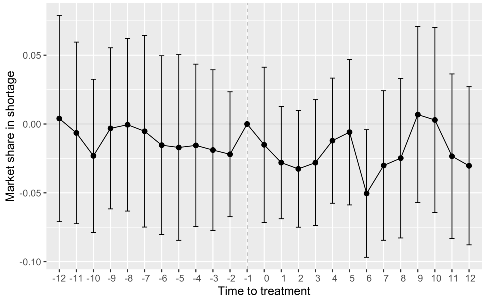


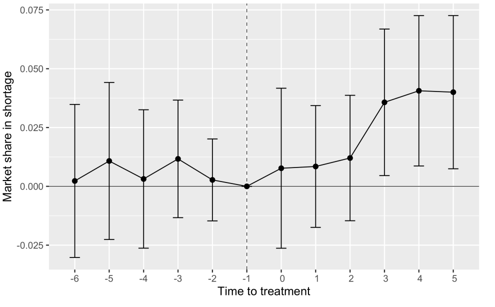
Figure 4.9: Impact of tendering on drug shortages when using only never-treated prescription clusters as the control group

4.6.3.5 Placebo tests

Here, we present the detailed results of the placebo tests. Figure 4.10a and Figure 4.10b depict the results of the treatment and time placebo tests, respectively.



(a) Treatment placebo test (Only control groups with fake treatments)



(b) Time placebo test (Only pre-treatment periods with a fake treatment period)

Figure 4.10: Placebo tests

5 Conclusions and Future Outlook

This dissertation examines opportunities for promoting sustainable business practices that prioritize profit, people, and planet. In the Introduction chapter, we introduce the concept of creating shared value (CSV) and the importance of shifting stakeholders' mindsets to consider all three objectives simultaneously. We then introduce two areas - servicizing and drug shortages - that require this mindset shift. Chapter 2 and Chapter 3 concentrate on servicizing, which differs significantly from the traditional sales model and has been adopted by several businesses. Despite its growing popularity, little is known about the optimal design of servicizing business models. We contribute to the literature by providing insights on pricing policies and other elements of the business model, offering valuable guidance on how to create a successful servicizing business.

Our attention then shifts to the problem of drug shortages, which is a serious global issue. This primarily focuses on the social aspect of CSV, i.e., people, among the three objectives of profit, people, and planet. Despite much speculation on the reasons for this problem (see de Vries et al., 2021; van Oorschot et al., 2022), we focus on one of the most heavily discussed potential causes of the problem. Tendering was introduced to improve the affordability of drugs but, in its current form, it does not adequately consider business profit, which can lead to social issues such as drug shortages. We explore ways to modify the tendering process to improve the balance between affordability and availability. In this concluding chapter, we summarize the key findings and insights from our research and discuss possible directions for future studies.

5.1 Conclusions

Chapter 2 explores the pricing policy as an essential element of a servicizing business model. The nature of servicizing allows for more complicated pricing structures than a single upfront payment like in traditional purchasing. Two of the most popular pricing structures are pay-per-use and pay-per-period. The choice of these structures significantly impacts both the SP's revenue and operational costs. In contrast to a pay-per-period scheme, a pay-per-use pricing can regulate and lower the consumer usage level. A pay-per-use pricing scheme discourages usage through the so-called 'ticking meter' effect and the per-use fee. We, therefore, seek to find the optimal pricing policy for each segment of the consumers, which is formed based on the value they assign to usage. It could also be that the SP benefits from excluding one segment of the consumers from the service. We keep environmental impact and consumer welfare in mind on top of maximizing profit to find pricing policies that can improve all three objectives. The primary contributions of this study are as follows:

1. We are the first to compare the performance of different pricing policies. The literature compares one servicizing business model (usually pay-per-period) with traditional sales, as we show, the choice of the pricing scheme itself can influence the performance of the servicizing business model in all objectives.
2. We allow for discretionary usage by consumers. This has not been considered in prior research, the exception being the study by Agrawal & Bellos (2016).
3. We are the first to capture the impact of the ticking meter effect and SP usage monitoring costs on its own and its users' decisions to generate useful insights.
4. Our research differs from the existing literature on pricing information goods in that we take into account the additional operational challenges associated with physical product handling. Unlike information goods, the SP offering a physical-product servicizing is responsible for operational costs, which creates a noticeable link between usage and environmental performance. In contrast, the usage level of information goods does not significantly impact the SP's environmental footprint.

We begin by analyzing a single product scenario, where the SP determines pricing schemes for each consumer segment, and consumers select their usage level. We model this problem as a dynamic game of incomplete information, where the SP is only aware of the distribution of consumer types. The primary objective is maximizing profit. We then assess the efficacy of optimal pricing policies in terms of consumer welfare and total environmental impact, ultimately seeking a win-win-win situation. Next, we expand the model to encompass a product line, consisting of a green and a regular product. In this scenario, we segment consumers into green and non-green groups, and conduct a similar analysis to the single-product scenario. Finally, we investigate the SP's ability to influence the size of the green segment through investments in awareness-raising, determining optimal consumer awareness levels for various pricing schemes. Additionally, we consider a scenario where the SP can adjust the product's greenness in two stages of its lifecycle: usage and production/disposal phases. We derive the following results and managerial insights:

- A pay-per-period policy results in higher usage levels, while a pay-per-use pricing scheme discourages usage through the ticking meter effect and per-use fee. SPs should try to constrain customer usage when their operational costs are high through offering a pay-per-use scheme. However, if the ticking meter effect is also high, the SP benefits from offering the pay-per-period scheme instead.
- A higher fraction of high usage-valuation customers motivates the SP to offer the service exclusively to these customers.

- When offering a pay-per-period scheme to the high usage-valuation customers, the choice of the scheme to offer to the low usage-valuation segment also depends on the size of the high usage-valuation segment in the market. If the high usage-valuation segment size is sufficiently small, it is optimal to offer a pay-per-period scheme to the low usage-valuation customers as well.
- SPs with sufficiently high operational costs can realize a *win-win* strategy (profit and planet) when offering a pay-per-use option to high usage-valuation customers if they form a sufficiently large majority of the market. Additionally, offering a pay-per-period scheme to all customers always maximizes the consumer surplus. This implies that when offering a single product, there is no *win-win-win* strategy possible.
- If the SP begins offering "green" customers an alternative eco-friendly version of its product, this will cause a higher usage level by discounting usage costs in the user mindset. Here, results mirror the single-product case. However, offering a single product through a pay-per-period scheme no longer proves optimal. In this case, though, no single win-win strategy exists. In this case, even the pay-per-period policy might generate the least environmental impact when this impact is extremely low during the usage phase. Consumer welfare, however, does not depend on the pricing policy, in this case.

Chapter 3 expands the analysis beyond the pricing aspect and consider other design attributes of a servicizing business model, such as payment schemes (pay-per-use vs. pay-per-period), price, and minimum contract duration. However, despite the growing popularity of servicizing and PSS in general, many firms lack a comprehensive understanding of how these attributes affect consumer choices. Also they lack the evidence how these attributes influence the perception of product-related characteristics, such as energy efficiency, selling price, and quality (Kreye & van Donk, 2021). This knowledge gap can lead to PSS offerings that do not align with consumer preferences, resulting in low adoption rates. To ensure market success, businesses must identify which attributes strongly impact consumer choices, how changes in these attributes affect choices, and how consumer characteristics drive these choices. By doing so, businesses can tailor their PSS offerings to specific market segments and increase their chances of success. In this study, we address this gap. The primary contributions of this study are as follows:

1. We are the first to quantify and compare the relative importance of payment scheme, price, MCD, and energy efficiency in the choice of consumers between purchase and PSS.
2. We shed light on the mechanisms explaining consumer choices. While these mechanisms are well established in the consumer behavior literature, we specifically show how they explain the choice among various payment schemes.

3. Our cluster analysis helps SPs better understand the market and choices on attributes based on the existing clusters in the market.

We develop a choice-based conjoint experiment for washing machines among 298 Dutch adults to measure the relative importance of the attributes of the PSS. We analyze the data using Hierarchical Bayes (HB) method to calculate the relative importance of the payment scheme (purchase, pay-per-use, and pay-per-period), price (low, medium, and high), MCD (one year, three, and five years), and energy efficiency (labels A and C). Our follow-up survey measures participants' characteristics. These characteristics include the ticking meter effect, psychological ownership, need for flexibility, insurance effect, and greenness. We also measure the usage of consumers and the breakdown probability perception. We argue that these characteristics also influence the relative importance of the PSS attributes. We also conduct a cluster analysis, using K-means clustering method, in which we find four segments with homogeneous choices in the market. The implications of our main findings are illustrated through simulation analysis where we predict market shares for different PSS and purchasing offerings. We derive the following results and managerial insights:

- Consumers consider the payment scheme to be the most important attribute. The other three attributes were considered almost equally important. This suggests that many people strongly prefer one of the payment schemes and that it differs significantly across consumers. An important implication is that there appears to be space for multiple business models in the market. The equal relative importance of the other attributes suggests that companies have multiple strong levers for gaining market share.
- Among the three payment schemes, purchase is the most preferred option for washing machines, followed by pay-per-use and pay-per-period. Thus, businesses that would like to invest in a PSS should be aware that consumers are still more likely to purchase a washing machine than to adopt a PSS. On average, people also strongly prefer pay-per-use to pay-per-period. This could also be why Bundles, one of the pioneers in PSS in the Netherlands, removed the pay-per-period option from their offering (Bundles, 2021).
- Consumers' price sensitivity depends on the payment scheme. Specifically, consumers are less sensitive to the price of PSS compared to the purchase price.
- Consumers' choices are influenced by their characteristics. People with a high *ticking meter effect* tend to choose the pay-per-period option over the pay-per-use option. Those with a lower *psychological ownership* level are more likely to adopt a PSS. The *insurance effect* makes the pay-per-period more attractive to risk-averse consumers. People with a higher *need for flexibility* or who are "tech-savvy" prefer a shorter MCD.

- Although greener consumers are more likely to choose a PSS (i.e., a perceived greener option) than purchasing (Tukker, 2004; EMF, 2013, 2019)), this relationship and the evidence behind it is weak.
- According to our cluster analysis, consumer preferences are highly varied and can be categorized into four clusters of similar consumers, where each attribute is the most important for one cluster. These clusters represent significant market segments, indicating that there is room for several payment schemes and product offerings in the market, considering the tradeoffs between different attributes.

In Chapter 4, the issue of drug shortages is investigated, which is becoming more prevalent worldwide. The FDA has labeled drug shortages as a ”persistent problem” (FDA, 2019), while the European Commission views it as a ”major problem for the quality and continuity of patient care” (EC, 2021). The consequences of drug shortages can be severe, leading to increased mortality rates (Vail et al., 2017; Yurukoglu et al., 2017), medication errors (Fox & Tyler, 2003), and less effective treatment. Additionally, shortages have significant economic consequences, such as sourcing from expensive small-scale local producers (EAHP, 2019) or providing different, more costly alternatives (Caulder et al., 2015). Handling shortages also places a considerable burden on pharmacies. To resolve this issue, it is key to understand the causes. We focus on one of the most heavily debated economic causes: the use of tendering. There are conflicting views on the impact of tendering on drug shortages. Thus, it urges us to examine the net impact of tendering on market-wide drug shortages. The primary contributions of this study are as follows:

1. We are the first to quantitatively evaluate the short- and long-term effects of tendering on drug shortages.
2. We are the first that consider drug shortages at the prescription cluster level instead of the article level. This captures reality better since within a prescription cluster, drugs are substitutable.
3. We quantitatively evaluate the *mechanisms* that explain the link between tendering and shortages. Prior academic and grey literature solely *hypothesized* those mechanisms.
4. We contribute to the scarce but growing literature on (1) public policy and operations management (Helper et al., 2021) and (2) the impact of procurement on supply security or resilience. While prior literature has mainly explored this at the firm level, we investigate this at the market level.
5. We derive conditions in which tendering has a relatively strong vs. weak impact on shortages.

6. Our work yields and discusses actionable insights for policymakers and organizations running tenders on how to modify tendering or selectively apply it to improve the balance between affordability and availability.
7. Finally, our paper serves the United Nations Sustainable Development Goal 3 in general and Target 3.8 specifically: to achieve *"(...) access to safe, effective, quality and affordable essential medicines and vaccines for all"*.

We use a panel data staggered DiD framework, a state-of-the-art method in policy evaluation (Roth et al., 2023). This setup enables us to compare drugs affected by initiating a tendered contract (treatment group) to unaffected drugs (control group). Our data enables us to study shortages at the prescription cluster level – a cluster of identical articles except for the pack size and/or the supplier or manufacturer. It also allows for a holistic analysis of the impact of tendering – how it affects the capability of *the entire market* to ensure the availability of articles in a given prescription cluster. Our analyses cover both short-term and long-term impacts. The short-term analysis assumes a time window starting from 12 months before the initiation of the contract until 12 months after that. The long-term analysis expands this window to 48 months before until 48 months after the initiation. Since it is key for policymakers to understand *under what conditions* tendering enhances shortages, we also investigate three potential *moderators*: 1) the number of alternative suppliers in the prescription cluster, 2) the magnitude of change in the tendered market share, and 3) the market concentration within the prescription cluster. We do the moderation analysis using sample splits based on the corresponding moderators. From these analyzes, we derive the following results and insights:

- We find that tendering for a prescription cluster reduces the average price of articles from that cluster, confirming its effectiveness in improving drug affordability. Additionally, we observe an increase in market concentration, as evidenced by an upward jump in the normalized Herfindahl-Hirschman index (HHI) following the initiation of tendered contracts.
- Tendering significantly increases drug shortages, with an expected 7.0 percentage point increase in market share in shortage for a given prescription cluster following the initiation of a tendered contract. This amounts to an extra 26 days of market-wide shortage annually. These findings are significant considering that the estimated yearly costs of drug shortages in the Netherlands range from €60 to €135 million (Ministerie van VWS, 2019b), suggesting an additional cost of €4.2 to €9.45 million due to a 7% increase in shortages.
- We also find that tendering leads to more *extreme* shortages, i.e., when the market share in shortage exceeds a given critical threshold.
- Shortages are partly caused by the incumbent and the new supplier facing difficulties ramping down and ramping up their supply line (Jagtenberg et al., 2021; EFPIA, 2022;

Biedermann, 2022). The market share in shortage steadily increases in the months before contract initiation and is particularly high in the months after. Three months after initiation, the expected market share in shortage is 8.1% higher compared to the month before.

- Our results confirm that tendering increases the expected market share in shortage in the long term.
- After a tendered contract is initiated, the market share lost due to market exits slightly decreases over 2.5 years, and while there is a slight increase afterwards, it is not statistically significant. Therefore, we find little support for the “market exit mechanism”, which aligns with recent doubts about its validity (Biedermann, 2022). This also supports the argument that the prospect of serving a major share of the market can *attract* and keep suppliers in the market, and that many can hedge the uncertainty associated with tenders.
- Tendering has a relatively minor impact on drug shortages when there are many suppliers or when the market is highly fragmented. The impact increases when the market becomes more concentrated or when fewer suppliers are present. Interestingly, this trend seems to reverse at some point. The impact decreases again when the market is highly concentrated or when very few suppliers are present. The latter is in line with the observation that suppliers feel a strong sense of responsibility in such circumstances (Francas et al., 2023).
- The impact of tendering on shortages increases when a larger market share is granted through the tender. Granting a larger market share can induce more complexities due to the ramp-up and ramp-down of supply chains and a larger change in market concentration. Importantly, tendering appears to have a negligible impact on shortages when less than 20% of the market is granted through the tender.

Using price as the sole or dominant criterion triggers disruptions when initiating a tendered contract and permanently enhances the risk of shortages. While this does not mean that tendering should be abandoned altogether, it does call upon policymakers and practitioners to redesign the tendering system to mitigate these risks. The mechanisms we study offer following directions:

- Consider redesigning the tendering system to prioritize *supply chain reliability.* This can be achieved by incorporating reliability as a criterion in tenders, as the UK is already doing by considering diverse API sources, suppliers’ business continuity plans, supplier past performance, and buffer stock as additional criteria for selecting a tender winner (Selviaridis et al., 2022). Furthermore, policymakers could strengthen incentives for reliability *within the contract* by offering extended contract terms, as one Dutch insurance company has done, conditional on supply reliability.

- Policymakers could implement solutions that mitigate the market concentration mechanism. Examples include appointing multiple tender winners, only allowing suppliers with a relatively small market share to participate in tenders, and running separate tenders per region (Medicine for Europe, 2018; EC, 2021). Several countries and insurance companies are experimenting with these solutions (e.g., see Boogaard, 2023).
- The apparent increase in shortages *around* the start of the contract term emphasizes the need to reserve enough time between the tendering period and the beginning of the contract term (Medicine for Europe, 2018). This reduces uncertainty and allows for careful planning of the supply chain ramp-up.
- To avoid the outgoing incumbent from ramping down the supply chain too quickly, we need to disincentivize by assigning a weight to past shortages in future tenders, penalizing failures to supply (Jia & Zhao, 2017), or increasing future stock obligations after a shortage, as happens in France (GD Advocats, 2022).
- Our moderation analysis indicates that tendering can be employed safely in various settings, including hospital procurement. For many drugs, hospital care represents only a minor market share, and tendering for hospital care often occurs through procurement groups, each representing only a minor market share (Jagtenberg et al., 2021).
- Insurers need to coordinate the timing of their tenders. Insurers presently initiate many tendered contracts in January, causing significant jumps in the tendered market share. Spacing out tendering activities throughout the year can reduce such jumps, and measures can be implemented to avoid highly concentrated markets.

5.2 Future Outlook

This dissertation explored two topics: design of servicizing business models, and impact of tendering on drug shortages. In both topics, we focused on specific research questions and provided valuable insights for firms and policymakers. Based on our findings and what is still lacking in the literature, we provide future research topics below.

Servicizing

There are several further OM related research opportunities in the servicizing industry. In addition to the pricing, the contract between the SP and the customers includes termination clauses and conditions. Some companies offer lenient cancellation terms (EMF, 2018d) to avoid keeping customers captive, whereas other companies may offer a waiver or discount the deposit in turn for a minimum length of contracts (Bundles, 2020; Reid, 2020). Termination terms may have implications for consumer purchase behaviour as well as the revenue of companies. It seems relevant to explore the suitability of cancellation mechanisms depending on the product, consumer and company characteristics.

Additionally, many of these companies have limited capacity (inventory) of products offered to consumers because of the large investment required. This may require dynamic pricing and capacity (inventory) decisions to respond to evolving consumer demand behaviours (Özdemir-Akyıldırım et al., 2014). More specifically, SPs have to decide how to allocate the limited capacity to different consumer segments and how to update the price to match the demand and supply more effectively. This becomes more relevant and interesting in a multi-period setting where capacity/inventory decisions at one period have operational implications for the subsequent periods. To follow a circular economy approach, SPs also often offer refurbished products (see for example (Bundles, 2021)). This is another dimension of dynamic capacity that should be decided jointly with the pricing decisions of services considering the possible impact they have on consumer behaviour.

Furthermore, with a growing number of servicizing companies, another interesting extension of the current model is taking competition into account. It would require a different modelling framework such that the market shares depend on the prices offered by service providers. Competition models could generate valuable insights on how optimal pricing schemes should change under competition and what are the consequent impacts of competition on the triple bottom-line of people, planet and profit.

Our insights from Chapter 3 cannot be trivially generalized to other products. We chose washing machines because currently both PSS and purchase options exist for this product. However, attributes of PSS may differ depending on the product nature. Bikes, for example, are mobile and the accessibility should be considered when comparing PSS and purchasing. Future studies, thus, could repeat our analyses for bikes, cell phones, and other products. Our work can be also extended by examining other commonly used payment schemes. Examples include three-part tariff schemes and quantity-dependent types of schemes, which could trigger different consumer behaviors and interact with consumer characteristics differently. Future studies could also consider remanufactured and new products or include competing SPs offering PSS and purchasing. Our study considers how certain attributes affect consumer preferences and market shares. Future research could integrate costs and environmental impacts.

A potential future direction is to incorporate the findings from Chapter 3 into the model developed in Chapter 2. The analytical model in Chapter 2 relies on a simple utility function focused on price. The experiment in Chapter 3 highlights the importance of other attributes of the PSS as well. By using the utility function built based on the results of the experiment, the analytical model can produce a more realistic and practical pricing policy.

Drug shortages

The impact of tendering is likely affected by many moderating factors. We only consider the number of suppliers, market concentration, and the jump size. Other potential moderators include the total annual revenue corresponding to a prescription cluster, how distinct the supply chains of suppliers are, the extent to which suppliers can hedge risks, and the inventory policy of the suppliers. Future research examining these moderators would help identify KPIs indicating how a tender for a prescription cluster would affect availability, informing whether or not to subject it to tendering. We lack detailed data on drug suppliers' supply chains, including inventories, production, sourcing, and transportation information. As such, we lack a detailed understanding of how a firm's supply chain reacts to winning or losing a tender. Future research could analyze the impact of tenders on granular supply chain data and study how policymakers can mitigate the adverse effects of tendering on supply chains.

Another potential avenue for further research on drug shortages is examining the effects of *price ceilings*. Some countries, such as the Netherlands and Germany, establish a price ceiling for drugs based on an average of prices from a select group of countries. However, this policy may also activate one or more of the mechanisms identified in our study, e.g., by putting suppliers' margin under pressure, potentially contributing to drug shortages.

Chapter 4 presented empirical evidence that tendering causes market-wide drug shortages and suggested several modifications. The next step in this line of research is to determine the *optimal* redesign and modification of the tendering system. This could be achieved through a mechanism design framework that adjusts the system to achieve the ultimate goals of affordability and availability simultaneously. The design elements in such a model could include the administrative level at which tenders are launched, such as international, national, or regional, as well as the frequency of tendering, such as bi-annually, annually, every six months, or less.

The role of *API suppliers* is an important area for further research in the field of drug shortages. A risk management perspective could help policymakers avoid situations where multiple suppliers appear to be in the market, as winners of the tender, for a given prescription cluster, while in reality, the upstream supply chain of these suppliers is common, thereby increasing the risk of shortages. Accordingly, some KPIs should be developed to incorporate *product* and *supply chain* characteristics of suppliers as part of the winning criteria in tendering to avoid such situations. Empirical evidence is needed to determine whether such situations lead to more shortages. Another way of avoiding these situations would be implementing supply chain transparency policies (see e.g., Lee et al., 2021). Following the implementation of such policies, a DiD study could be conducted to assess whether they lead to fewer drug shortages.

As we conclude this dissertation, we have explored the topics of servicizing and drug shortages through the lens of creating shared value. Through our research, we have uncovered valuable insights that can aid businesses and governments in balancing their objectives towards people, profit, and planet. But the journey doesn't end here. We urge fellow researchers to continue exploring the pathways we have paved to further promote sustainable operations management and address societal challenges.

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About the author

Hamed Vafa Arani was born on June 11th, 1991 in Aran-o-Bidgol, Iran. He pursued his studies in Industrial Engineering at the University of Tehran, Iran. In August 2015, he earned his M.Sc. degree, after which he worked as a Business Process Analyst for two years. In 2017, Hamed joined the Department of Technology and Operations Management at Rotterdam School of Management, Erasmus University, under the supervision of Professor René De Koster and Dr. Harwin de Vries, to pursue his Ph.D. Dr. Erwin van der Laan also supervised his research during his doctoral studies.

Hamed's research interests revolve around incentive design and evaluation for all business stakeholders to foster socially responsible supply chains by optimizing business model elements, designing experiments, and performing statistical analysis. His research work is primarily focused on two areas: designing product-service systems and addressing drug shortages. His work has been published in the European Journal of Operational Research and has also been presented at various international conferences.

Portfolio

Publications

Publications in Journals:

Vafa Arani, H., Pourakbar, M., and De Koster, R. (2023). How to charge in servicizing: Per period or per use?. *European Journal of Operational Research*, 304(3), 981-996.

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Working Papers:

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PhD Courses

Micro Economics
Statistical Methods
Programming and Data Management
Game Theory and its Applications
Stochastic Dynamic Optimisation
Microeconomics III (Info. and Contract Theory)
Panel Data Econometrics: Theory and Practice
Behavioural Decision Theory
Algorithmic Game Theory
Stochastic Programming

Data Driven Decision Models	Sustainable Operations Management
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Research Methods and Skills 2022

Tutorial Lecturer:

Operations Management 2018
Global Sustainable Supply Chains 2020-2021
Quantitative Decision Making 2019-2020

Conferences Attendance and Invited Sessions

Eeorpean workgroup on sutainable operations management 2018, oslo, Norway
CEMS Research Seminar 2020, Riezlern, Austria
POMS Internation conference 2019, Brighton, UK

Summary

Focusing solely on maximizing short-term profits has led to various social, environmental, and economic issues. To counteract this problem, some have suggested implementing corporate social responsibility practices. However, this approach has proven ineffective as it treats social and environmental concerns as a separate objective, leading them to be viewed as expenses rather than opportunities for growth. Alternatively, the idea of creating shared value aims to integrate profitability with social and environmental objectives, providing a more holistic solution to the problem.

This dissertation examines two distinct areas where the integration of profit with social and environmental objectives is crucial for achieving long-term solutions to significant challenges. The first topic explores the optimization and design of servicizing business models to facilitate the transition from a linear economy to a more circular one, emphasizing the environmental benefits of such models while simultaneously maximizing firm profitability. In the second topic, we investigate the issue of drug shortages, a major social problem. We specifically examine the impact of tendering on market-wide shortages. In this topic, our focus centers on social aspects, and we recommend policy modifications that also consider business profit as a means of resolving this issue.

Servicizing falls under the category of product-service systems (PSS), whereby a service provider offers the functionality of a product rather than the product itself. These types of systems are considered business models that can lead to a more circular economy. Such business models offer a range of environmental benefits, including reduced usage, a streamlined product return flow, and incentivizing durable product designs. These business models include a significant service component that requires an ongoing relationship with customers. This, in turn, demands new design elements such as payment schemes, pricing, and minimum contract duration. The use of such business models may also affect how customers perceive product attributes such as energy labeling. To support the transition to sustainable business practices, companies must design these attributes in a way that maximizes profit while also addressing environmental and social objectives.

Chapter 2 delves into the pricing policy of servicizing business models, aiming to identify win-win-win strategies that meet profit, planet, and people objectives. When providers charge consumers based on usage (pay-per-use) versus a regular flat fee (pay-per-period), the economic, environmental, and welfare implications of such strategies are unclear. To

address this issue, we utilize a stylized game-theoretic model where service providers first design pricing policies, and consumers respond by adjusting usage. Our findings reveal that pay-per-use schemes outperform pay-per-period when service providers are cost-inefficient or small-scale when offering a single product. Additionally, providers tend to exclude low usage-valuation users when per-use consumers are not very sensitive to payment frequency. Pay-per-use also outperforms pay-per-period when the proportion of low-use consumers is sufficiently small. Our research shows that a win-win (profit and planet) strategy can be achieved by offering a pay-per-use policy to high usage-valuation consumers, but a win-win-win strategy is unachievable. We also analyze the problem when the service provider offers a product line consisting of green and regular products, identifying possible win-win-win strategies that depend on the environmental impact of different phases of a product's lifecycle.

In Chapter 3, we extend our analysis beyond pricing policies and examine how different attributes of a servicizing business model influence consumer behavior. Designing a PSS involves several significant choices, such as payment scheme, contract duration, and energy efficiency, yet little is known about how these attributes impact consumer choices. To investigate this issue, we conduct a choice-based conjoint experiment with 300 Dutch adults, in which we present various options for a washing machine that vary in four attributes: payment scheme, price, energy label, and minimum contract duration. We compare three payment schemes: pay-per-use, pay-per-period, and purchase. Our results show that consumer preferences vary considerably, with payment scheme being the most influential factor. Purchasing the product is the most popular payment option, followed by pay-per-use. We find that consumers are more price-sensitive when purchasing a product compared to when they adopt PSS. Moreover, we identify four distinct consumer segments with almost equal market shares, indicating the potential for multiple business models in the market. We also explore how consumers' characteristics, including greenness, usage, the ticking meter effect, the insurance effect, and psychological ownership, affect their choices. Surprisingly, we find that greenness does not significantly impact consumers' choices. Finally, to support businesses in their design choices, we simulate how different attributes affect market shares.

Drug shortages have become a significant problem that is receiving increasing attention from both academia and practitioners due to its potential impact on national security and the persistence of the issue. The causes of drug shortages are often attributed to two main categories, including manufacturing/supply issues such as poor inventory management and active pharmaceutical ingredient (API) supply disruptions, and economic factors such as regulations and policies. Among these causes, tendering has been the most extensively debated. Tendering involves competitive bidding for procuring products or services and is a commonly used policy in Europe to contain the drug prices. However, the concrete evidence of whether and how tendering contributes to market-wide drug shortages remains unclear. Therefore, the focus of this study is on exploring this question.

Chapter 4 investigates the impact of using tendering as a procurement method for drugs on nationwide drug shortages. While tendering can enhance affordability, it is also argued to undermine availability by squeezing suppliers' margins, prompting them to leave the market, increasing market concentration, and inducing supplier switching. Nevertheless, tendering may also attract new suppliers, provide financial security to the winner, and create a greater sense of responsibility for the winner. As a result, many are uncertain about the significance or even existence of tendering's effect on drug shortages. Our study utilizes a staggered difference-in-difference approach and examines three datasets from the Netherlands to address this issue. Our results indicate that tendering lowers drug prices, but it also concentrates the market and substantially increases drug shortages. Shortages tend to surge at the start of a tendered contract, possibly because suppliers have difficulty adapting their supply chains. Tendering maintains high levels of drug shortages even in the long term. However, the effect of tendering on shortages is minimal when there are numerous alternative suppliers, the market is relatively fragmented, and the share of the market that is being tendered is low. Our research offers policymakers practical insights on how to apply tenders selectively and address the mechanisms linking tendering to shortages. Specifically, we propose allowing multiple winners, regionalizing the tenders, allowing more time between the tender and initiation of the contract, and including a reliability measure as a winning criterion.

In the concluding chapter, we summarize the key results and insights from our research in the two topics of servicizing and drug shortages and discuss several directions for future research.

Samenvatting (Summary in Dutch)

Uitsluitend de focus leggen op het maximaliseren van kortetermijnwinsten heeft tot verschillende sociale, economische en milieukwesties geleid. Er zijn mensen die hebben voorgesteld om maatschappelijk verantwoord ondernemen in te voeren om dit probleem tegen te gaan. Zo'n benadering is echter ineffectief gebleken omdat dan sociale en milieukwesties als een aparte doelstelling worden neergezet, waardoor ze als kostenposten worden gezien in plaats van mogelijkheden om te groeien. Aan de andere kant probeert men met het idee van gemeenschappelijke waarde creëren de winstgevendheid te integreren met sociale en milieudoelstellingen. Dit biedt een holistischere oplossing van het probleem.

Dit proefschrift onderzoekt twee verschillende gebieden waarbinnen de integratie van winstdoelen met sociale en milieudoelstellingen essentieel is om op de lange termijn grote uitdagingen het hoofd te bieden. Het eerste onderwerp verkent de optimalisatie en opzet van bedrijfsmodellen op basis van verdiensting om de transitie van een lineaire naar een meer circulaire economie mogelijk te maken. Hierbij wordt de nadruk gelegd op de milieuvoordelen van dergelijke modellen, terwijl tegelijkertijd de winstgevendheid van het bedrijf wordt gemaximaliseerd. In het tweede deel onderzoeken we de kwestie van geneesmiddelentekorten, een groot sociaal probleem. We onderzoeken voornamelijk het effect van aanbestedingen op tekorten op de gehele markt. Bij dit onderwerp ligt onze focus op de sociale aspecten en we adviseren beleidsaanpassingen te doen waarbij ook de bedrijfswinst wordt meegenomen als een middel om dit probleem op te lossen.

Verdiensting valt onder product-dienstsystemen (PDS), waarbij een dienstverlener de functionaliteit van een product aanbiedt in plaats van het product zelf. Deze systeemtypen worden beschouwd als bedrijfsmodellen die tot een meer circulaire economie kunnen leiden. Dergelijke bedrijfsmodellen bieden een aantal milieuvoordelen, waaronder verminderd gebruik, een gestroomlijnde retourstroom van producten en het stimuleren van duurzaam productontwerp. Deze bedrijfsmodellen dragen een aanzienlijke dienstencomponent in zich die een bestendige relatie met klanten vereist. Dit vraagt op zijn beurt om nieuwe elementen in de opzet, zoals betalingsplan, prijsstelling en minimale contractduur. Het gebruik van dergelijke bedrijfsmodellen kan ook effect hebben op hoe klanten producteigenschappen beoordelen zoals energielabels. Om de transitie naar een duurzame bedrijfsvoering te ondersteunen, moeten bedrijven deze eigenschappen zo aanpassen dat de winst wordt gemaximaliseerd en tegelijkertijd de sociale en milieudoelstellingen worden gehaald.

In hoofdstuk 2 duiken we in het prijsbeleid van verdienstingsbedrijfsmodellen om win-win-win-strategieën vast te stellen waarmee de doelstellingen voor winst, planeet en mensen kunnen worden gehaald. Wanneer dienstverleners consumenten laten betalen op basis van gebruik (pay-per-use) in plaats van een regulier tarief (pay-per-period), zijn de economische, milieu- en maatschappelijke effecten van dergelijke strategieën onduidelijk. Voor de aanpak van dit probleem gebruiken we een gestileerd speltheoretisch model waarin dienstverleners eerst het prijsbeleid opstellen en consumenten vervolgens reageren door hun gebruik aan te passen. Onze resultaten laten zien dat pay-per-use-regelingen beter presteren dan pay-per-period, wanneer dienstverleners niet-kostenefficiënt of kleinschalig opereren bij het aanbieden van een enkel product. Daarnaast lijken dienstverleners de gebruikers die op laag gebruik worden ingeschat uit te sluiten wanneer per-use-consumenten niet erg ontvankelijk zijn voor de betalingsfrequentie. Pay-per-use presteert ook beter dan pay-per-period wanneer het aandeel consumenten met laag gebruik klein genoeg is. Uit ons onderzoek blijkt dat een win-win-strategie (winst en planeet) kan worden bereikt door een pay-per-use-regeling aan te bieden aan consumenten die op hoog gebruik worden ingeschat, maar waar een win-win-win-strategie onhaalbaar is. We analyseren ook het probleem wanneer de dienstverlener een productlijn aanbiedt dat uit groene en reguliere producten bestaat, door de mogelijke win-win-win-strategieën vast te stellen die afhankelijk zijn van het milieu-effect van de verschillende fasen in de levenscyclus van een product.

In hoofdstuk 3 gaat onze analyse verder dan het prijsbeleid en onderzoeken we hoe verschillende eigenschappen van een verdienstingsbedrijfsmodel het consumentengedrag beïnvloed. Het opzetten van een PDS behelst een aantal belangrijke keuzes, zoals betalingsplan, contractduur en energie-efficiëntie. Toch is er maar weinig bekend over hoe deze eigenschappen consumentenkeuzes beïnvloeden. Om dit te onderzoeken voeren we een conjunct keuze-experiment uit onder 300 Nederlandse volwassenen, waarin we verschillende opties voor een wasmachine presenteren met vier verschillende eigenschappen: betalingsregeling, prijs, energielabel en minimale contractduur. We vergelijken drie betalingsregelingen: pay-per-use, pay-per-period en aankoop. Onze resultaten laten zien dat consumentenvoorkeuren aanzienlijk kunnen verschillen, waarbij de betalingsregeling de meest doorslaggevende factor is. Het product kopen is de meest populaire betalingsoptie, gevolgd door pay-per-use. We stellen vast dat consumenten prijsgevoeliger zijn bij de aankoop van een product dan wanneer ze PDS toepassen. Bovendien signaleren we vier aparte consumentensegmenten met bijna een gelijk marktaandeel, hetgeen wijst op het potentieel voor meerdere bedrijfsmodellen in de markt. We verkennen ook hoe de kenmerken van consumenten, waaronder milieuvriendelijkheid, gebruik, ticking meter effect (het effect van de tikkende meter), het effect van de verzekering en psychologisch eigendom, hun keuzes beïnvloeden. Verrassend genoeg concluderen we dat milieuvriendelijkheid geen significante invloed heeft op de keuzes van consumenten. Ten slotte bootsen we na - om bedrijven in hun opzetkeuzes te ondersteunen - hoe verschillende eigenschappen marktaandelen beïnvloeden.

Geneesmiddelentekorten zijn een aanzienlijk probleem geworden dat steeds meer aandacht krijgt vanuit de academische wereld en vanuit de praktijk, vanwege de mogelijke gevolgen voor de nationale veiligheid en het feit dat het probleem blijft bestaan. De oorzaken van geneesmiddelentekorten worden vaak toegeschreven aan twee hoofdcategorieën: productie-/leveringsproblemen zoals slecht voorraadbeheer en verstoringen in de levering van werkzame stoffen (active pharmaceutical ingredients, API's), en economische factoren zoals regelgeving en beleid. Van deze oorzaken is aanbesteden het meest besproken onderwerp. Aanbesteden is concurrerend bieden voor het inkopen van producten of diensten en is een veelgebruikt beleid in Europa om geneesmiddelenprijzen te beheersen. Maar het concrete bewijs of en hoe aanbesteden bijdraagt aan geneesmiddelentekorten in de gehele markt blijft echter onduidelijk. Daarom ligt de focus van dit onderzoek op het beantwoorden van deze vraag.

In hoofdstuk 4 wordt de impact van het gebruik van aanbesteden als inkoopmethode voor geneesmiddelen op landelijke geneesmiddelentekorten onderzocht. Hoewel aanbesteden kan bijdragen tot een betere betaalbaarheid, wordt er ook beweerd dat het de beschikbaarheid kan ondermijnen door de marges van leveranciers te verkleinen, waardoor leveranciers geneigd zijn de markt te verlaten, de marktconcentratie toeneemt en bedrijven overstappen naar een andere leverancier. Toch kan aanbesteden ook nieuwe leveranciers aantrekken, de geselecteerde leverancier financiële zekerheid bieden en hem meer verantwoordelijkheidsgevoel geven. Daarom bestaat er veel twijfel over het belang of zelfs het bestaan van het effect van aanbesteden op geneesmiddelentekorten. In ons onderzoek gebruiken we een gespreide verschil-in-verschilmethode en onderzoeken we drie datasets uit Nederland om deze kwestie te behandelen. Onze resultaten geven aan dat aanbesteden de geneesmiddelenprijzen verlaagt, maar ook de markt concentreert en de geneesmiddelentekorten aanzienlijk doet toenemen. Bij de start van een aanbestedingscontract ontstaan er vaak grote tekorten, waarschijnlijk omdat leveranciers moeite hebben om hun toeleveringsketens aan te passen. Aanbesteden houdt de mate van geneesmiddelentekorten hoog, zelfs op de lange termijn. Echter, het effect van aanbesteden op tekorten is minimaal wanneer er veel alternatieve leveranciers zijn, de markt relatief gefragmenteerd is en het aandeel van de markt dat wordt aanbesteed klein is. Ons onderzoek biedt beleidsmakers praktische inzichten over hoe aanbestedingen selectief kunnen worden toegepast en hoe de mechanismen die aanbestedingen koppelen aan tekorten kunnen worden aangepakt. Meer bepaald stellen we voor om meerdere bedrijven als winnaar uit de bus te laten komen, de aanbestedingen te regionaliseren, meer tijd te reserveren tussen de aanbesteding en de start van het contract en een betrouwbaarheidsfactor mee te laten wegen in het toekennen van de aanbesteding.

In het afsluitende hoofdstuk vatten we de belangrijkste resultaten en inzichten samen uit ons onderzoek naar de twee onderwerpen van verdiensting en geneesmiddelentekorten en behandelen we verschillende richtingen voor toekomstig onderzoek.

چکیده (Summary in Farsi)

تمرکز صرف بر حداکثرسازی سود کوتاه مدت، منجر به مشکلات اجتماعی، زیست‌محیطی و اقتصادی مختلف شده است. برای مقابله با این مشکل، برخی پیشنهاد می کنند که اقدامات مسئولیت اجتماعی شرکتی پیاده سازی شوند. با این حال، این رویکرد غیرموثر واقع شده است زیرا نگرشی جداگانه به مسائل اجتماعی و زیست‌محیطی دارد و آن‌ها را به عنوان هزینه به جای فرصت رشد می‌بینند. به عنوان گزینه‌ای دیگر، ایده ایجاد ارزش مشترک که هدف آن ترکیب سودآوری با اهداف اجتماعی و زیست‌محیطی است راهکاری جامع‌تر برای حل مشکل ارائه می‌دهد.

این پایان‌نامه دو حوزه متمایزی را مورد بررسی قرار می‌دهد که ادغام سود با اهداف اجتماعی و زیست‌محیطی در آن‌ها برای دستیابی به راهکارهای بلندمدت برای چالش‌های مهم ضروری است. موضوع اول به بهینه‌سازی و طراحی مدل‌های کسب و کار خدمات سازی می‌پردازد که جهت تسهیل گذر از اقتصاد خطی به اقتصادی چرخشی با تاکید بر فواید زیست‌محیطی این مدل‌ها با حفظ سودآوری شرکت استفاده می شوند. در موضوع دوم، مشکل کمبود دارو که یک مشکل اجتماعی جدی است، مورد بررسی قرار می‌گیرد. به طور خاص، تأثیر مناقصه‌گذاری بر کمبود دارو بررسی می‌شود. در این موضوع، تمرکز ما بر جوانب اجتماعی است و ما تغییرات سیاستی را معرفی می کنیم که می توانند این مشکل را با درنظرگرفتن توامان سود شرکت برطرف کنند.

رویکرد "خدمات‌سازی" زیرمجموعه‌ای از سیستم‌های محصول-خدمات است که در آن ارائه‌دهنده خدمات عملکرد یک محصول را به جای خود محصول ارائه می‌دهد. این نوع سیستم‌ها به‌عنوان مدل‌های کسب و کاری مورد توجه قرار می‌گیرند که به اقتصادی چرخشی منجر می‌شوند. این مدل‌های کسب و کار فواید زیست‌محیطی متعددی از جمله کاهش مصرف، بهینه سازی جریان بازگشت محصول و طراحی محصولات بادوام را دربردارند. این مدل‌های کسب و کار شامل یک عنصر مهم خدمات هستند که نیاز به رابطه مداوم با مشتری دارند. این امر نیاز به عناصر طراحی جدیدی مانند طرح‌های پرداخت، قیمت‌گذاری و حداقل مدت قرارداد دارد. استفاده از این مدل‌های کسب و کار ممکن است نحوه دید مشتریان نسبت به ویژگی‌های محصولات مانند برچسب انرژی را نیز تحت تأثیر قرار دهد. برای حمایت از گذر به مدل های کسب و کار پایدار، شرکت‌ها باید این ویژگی‌ها را به نحوی طراحی کنند که سودآوری را حداکثر کنند و در عین حال به اهداف زیست‌محیطی و اجتماعی دست یابند.

در فصل دوم، به سیاست قیمت‌گذاری در مدل‌های کسب و کار خدمات‌سازی می‌پردازیم و هدف ما شناسایی استراتژی‌هایی است که همه منافع سودآوری، محیط زیست و افراد را برآورده می‌کنند. در این مدل کسب و کار وقتی ارائه دهندگان بر اساس استفاده مشتریان (پرداخت بر اساس استفاده) در مقابل یک هزینه ثابت معمولی (پرداخت بر اساس دوره) هزینه می‌گیرند، پیامدهای اقتصادی، زیست‌محیطی و رفاهی این استراتژی‌ها مبهم است. برای پرداختن به این مسئله، ما از یک مدل نظریه بازی ها استفاده می‌کنیم که در آن ابتدا ارائه دهندگان سرویس سیاست‌های قیمت‌گذاری را طراحی می‌کنند و سپس مشتریان با تنظیم میزان استفاده خود به آن پاسخ می‌دهند. یافته‌های ما نشان می‌دهد که روش‌های پرداخت بر اساس استفاده در مقایسه با پرداخت بر اساس دوره زمانی بهتر عمل می‌کنند که ارائه دهندگان سرویس ناکارایی در کاهش هزینه‌ها داشته باشند یا به صورت کوچک مقیاس با ارائه یک محصول واحد فعالیت کنند.

علاوه بر این، ارائه دهندگان در صورتی که مشتریان به پرداخت هزینه بلافاصله بعد از استفاده حساس نباشند، کاربران کم مصرف را حذف می‌کنند. روش پرداخت بر اساس استفاده همچنین وقتی درصد کمی از مشتریان کم مصرف باشند در مقایسه با پرداخت بر اساس دوره بهتر عمل می‌کند. پژوهش ما نشان می‌دهد که استراتژیی هم پیروزی (بهبود همزمان سود و محیط زیست) با ارائه یک سیاست پرداخت بر اساس استفاده به مشتریان پرمصرف قابل دستیابی است، اما استراتژی پیروزی همه جانبه (سود، محیط زیست و رفاه) قابل دستیابی نیست. ما همچنین مسئله را زمانی مورد تحلیل قرار می‌دهیم که ارائه دهنده سرویس یک خط محصول از محصولات سبز و معمولی داشته باشد و استراتژی‌های پیروزی همه جانبه احتمالی را که وابسته به تأثیر زیست محیطی مراحل مختلف چرخه عمر محصول هستند، شناسایی می‌کنیم.

در فصل سوم، ما تحلیل خود را فرای سیاست‌های قیمت‌گذاری گسترش می‌دهیم و تأثیر ویژگی‌های مختلف یک مدل کسب و کار خدمات‌سازی بر رفتار مصرف‌کننده را بررسی می‌کنیم. طراحی یک سیستم محصول-خدمات شامل چندین انتخاب مهم مانند سیستم پرداخت، مدت قرارداد و برچسب انرژی است، اما اطلاعات کمی درباره اینکه این ویژگی‌ها چگونه بر تصمیمات مصرف‌کننده تأثیر می‌گذارند، وجود دارد. برای بررسی این مسئله، ما یک آزمایش مبتنی بر انتخاب با 300 نفر بالغ در هلند انجام دادیم. در این آزمایش ما گزینه‌های مختلفی برای یک ماشین لباسشویی ارائه دادیم که در چهار ویژگی متفاوت بودند: سیستم پرداخت، قیمت، برچسب انرژی و حداقل مدت قرارداد. ما سه سیستم پرداخت را مقایسه می‌کنیم: پرداخت بر اساس استفاده، پرداخت بر اساس دوره، و خرید مستقیم. نتایج ما نشان می‌دهد که ترجیحات مصرف‌کنندگان به طرز قابل توجهی ناهمگون است و سیستم پرداخت به عنوان عاملی که بیشترین تأثیر را دارد، شناخته می‌شود. خرید مستقیم محصول، محبوب‌ترین گزینه پرداخت است، و بعد از آن پرداخت بر اساس استفاده گزینه محبوب است. ما دریافتیم که مصرف‌کنندگان در زمان خرید محصول از حساسیت بیشتری نسبت به زمانی که از سیستم های محصول-خدمات استفاده می‌کنند، برخوردار هستند. علاوه بر این، ما چهار گروه جداگانه از مصرف‌کنندگان با سهم بازار تقریباً مساوی شناسایی می‌کنیم، که نشان‌دهنده پتانسیل وجود چندین مدل کسب و کاری در بازار است. همچنین، ما بررسی می‌کنیم که صفات مصرف‌کنندگان، از جمله سبزبودن، میزان استفاده، اثر متر روان‌شناختی و مالکیت روانی، چه تأثیری بر تصمیمات آن‌ها دارد. به طرز غیرمنتظره‌ای، نتایج ما نشان می دهد که سبزبودن تأثیر معناداری در تصمیمات مصرف‌کنندگان ندارد. در پایان، ما برای کمک به کسب و کارها در انتخاب پیشنهادهای خود، اثر ویژگی‌های مختلف بر تقسیم سهم بازار را شبیه سازی می کنیم.

کمبود دارو به دلیل تأثیرات بالقوه‌ای که بر امنیت ملی دارد و تداوم این مسئله در بسیاری کشورها به مشکلی مهم تبدیل شده است. توجه به این مساله هم از سوی دانشگاه‌ها و هم از سوی سیاست گزاران درحال افزایش است. علل کمبود دارو معمولاً به دو دسته اصلی نسبت داده می‌شوند، شامل مسائل تولید/تامین مانند مدیریت موجودی ناکاآمد و خلل در عرضه مواد موثره دارویی، و عوامل اقتصادی مانند ضوابط و سیاست‌ها. در میان این علل، مناقصه‌گذاری بحث برانگیزترین مشکل بوده است. مناقصه‌گذاری شامل مناقصه رقابتی برای تأمین محصولات یا خدمات است و در اروپا به عنوان یک سیاست معمول برای کنترل قیمت داروها استفاده می‌شود. با این حال، شواهد قطعی درباره اینکه مناقصه‌گذاری چگونه به کمبود دارو منجر می‌شود وجود ندارد. بنابراین، تمرکز این مطالعه بررسی این سؤال است.

فصل چهارم تأثیر استفاده از مناقصه‌گذاری به عنوان روش تامین دارو را بر کمبود سراسری داروها بررسی می‌کند. در حالی که مناقصه‌گذاری می‌تواند قدرت خرید را تقویت کند، برخی معتقدند که این روش می‌تواند دسترس پذیری را تضعیف کند و با تحت فشار قراردادن حاشیه سود تامین کنندگان و ترغیب آنها به خروج از بازار، باعث افزایش تمرکز بازار و تغییر در تأمین‌کننده شود. با این حال، مناقصه‌گذاری ممکن است هم تأمین‌کنندگان جدید را جذب کند، هم به برنده مناقصه امنیت مالی بدهد و هم احساس مسئولیت پذیری بیشتری را در برنده ایجاد کند. به همین دلیل، بسیاری درباره اهمیت یا حتی وجود تأثیر مناقصه‌گذاری بر کمبود دارواطمینان ندارند. ما در

این مطالعه از یک روش پیشرفته اقتصادسنجی استفاده می‌کنیم و سه مجموعه داده از هلند را برای پاسخ به این سؤال بررسی می‌کنیم. نتایج ما نشان می‌دهد که مناقصه‌گذاری قیمت داروها را کاهش می‌دهد، اما باعث تمرکز بازار و افزایش چشمگیر کمبود دارو می‌شود. کمبودها در ابتدای یک قرارداد مناقصه‌گذاری شدیداً افزایش می‌یابند، احتمالاً به این دلیل که تأمین‌کنندگان در سازماندهی زنجیره تأمین خود دچار مشکل می شوند. مناقصه‌گذاری حتی در طولانی مدت نیز موجب حفظ سطح بالایی از کمبود دارو می‌شود. با این حال، تأثیر مناقصه‌گذاری بر کمبودها در صورتی که تأمین‌کنندگان جایگزین فراوانی وجود داشته باشد، و یا بازار نسبتاً متمرکز نباشد و سهم بازار در مناقصه کم باشد، حداقل است. پژوهش ما برای سیاست‌گذاران نکات عملی را در مورد چگونگی برگذاری مناقصه‌گذاری برای رفع یا کمرنگ شدن ارتباط بین مناقصه‌گذاری و کمبودها ارائه می‌دهد. به طور خاص، ما پیشنهاد می‌دهیم که اجازه وجود چند برنده برای هر گروه دارویی داده شود، مناقصه‌ها به صورت منطقه‌ای باشند، فاصله زمانی بیشتری بین مناقصه و شروع قرارداد گذاشته شود و یک معیار قابلیت اطمینان به عنوان معیار برنده‌شدن در نظر گرفته شود.

در فصل پایانی، ما نتایج کلیدی و نکات مهم مطالعات در دو موضوع خدمات سازی و کمبود داروها را خلاصه می‌کنیم و چندین مسیر را برای تحقیقات آینده مورد بحث قرار می دهیم.

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Focusing solely on short-term profits has caused social, environmental, and economic problems. Creating shared value integrates profitability with social and environmental objectives, offering a holistic solution. This dissertation examines two areas where this integration is crucial. The first topic explores servicizing business models for a transition to a more circular economy, emphasizing environmental benefits and firm profitability. Initially, we focus on pricing policies, comparing pricing schemes across consumer segments to identify win-win-win strategies that meet all people, planet, and profit objectives. Our research reveals that pay-per-use schemes outperform pay-per-period schemes for cost-inefficient or small-scale providers. A win-win (profit and planet) strategy can be achieved by offering a pay-per-use policy to high usage-valuation consumers, but a win-win-win strategy is unattainable. We then investigate consumer choices in servicizing models by conducting a conjoint experiment on payment scheme, price, minimum contract duration, and entry label attributes. The payment scheme emerges as the most influential attribute, with purchasing and pay-per-use schemes being popular options. The second topic focuses on drug shortages. Specifically, we examine the impact of tendering on shortages. Our findings demonstrate that tendering reduces prices but increases shortages, particularly at the beginning of contracts. However, shortages are less severe when alternative suppliers are available, and the market is less concentrated. To address this issue, we propose allowing multiple winners, regionalizing tenders, increasing the time between tender and contract initiation, and incorporating a reliability measure as a winning criterion to mitigate shortages.

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