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Business Model Choice under Right to Repair: Economic and Environmental Consequences

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Problem Definition: Right to Repair (RTR) regulations require producers to supply necessary information and parts for consumers to independently undertake repairs. Although these regulations intend to prolong the useful life of products through repairs, benefit consumers and the environment; the ease of access to proprietary information and spare parts through RTR can facilitate the infringement of intellectual property rights (IPR) by third parties. We analyze whether and when retaining product ownership (instead of selling) helps producers avoid IPR infringement and competition. Considering the business model choice, we study the consequences of RTR for producers, consumers, and the environment. **Methodology/Results:** Using a game-theoretic model, we find that RTR regulations can encourage producers to keep ownership if the production cost is low and/or the IPR infringement risk under RTR is significant. As a result, RTR reduces producer profits in many cases. However, it is interesting that producers of high-cost products can benefit from RTR if the risk of infringement of IPR is limited and independent repair options help increase the valuation of new products. Furthermore, RTR can reduce the total environmental impact of products with a high production cost and low use-phase impact. However, for other products, especially those with low production costs, RTR can effectively decrease reuse volumes and hurt the environment. Our results also suggest a trade-off between the effects of RTR for the environment and consumers, as well as a potential decrease in product innovation and durability. **Managerial and Policy Implications:** From a managerial perspective, retaining product ownership appears to be a viable response for firms faced with RTR. From a policy perspective, the impact of RTR goes beyond creating more efficient repair markets. Anticipating strategic producer responses to the risk of IPR violation and competition is crucial in understanding the economic and environmental implications of RTR.

Keywords: Right to Repair; Circular Economy; Non-ownership; Business Model Choice; Intellectual Property

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1. Introduction

The Right to Repair (RTR) movement posits that end-users should be able to repair the products they own or use the services of any independent repairer they choose (iFixit 2021). As the idea gains popularity, regulations have recently required producers to design easy-to-repair products, make repair information (e.g., manuals, documentation, and schematics), diagnostic tools, and spare parts available to independent repairers and consumers (The Repair Association 2020). In the EU, household appliances such as washing machines and vacuum cleaners are subject to the RTR regulations (European Commission 2023). In the US, to date, 41 states have introduced

RTR bills and New York, California, and Colorado have passed RTR legislation for consumer electronics (Wiens 2022, Lopatto 2023). At the federal level, RTR bills for automobiles and farming equipment have been introduced (Ghosh 2022, Koebler 2023) and the Federal Trade Commission have investigated the ability of manufacturers to restrict independent repairs (Wiens 2021).

RTR regulations intend to prolong product lifetimes by facilitating repairs and preventing consumers from discarding products that are still valuable. The popular opinion is that this will be beneficial to consumers and the environment: consumers will be able to use products longer; and longer product lifetimes will result in lower new production, waste and environmental impact.

In this paper, we study the business implications of RTR from a novel perspective: the extent to which RTR can lead producers to reconsider their business model choice around product ownership. Our research question is motivated by the impact of RTR on intellectual property rights (IPR) and secondary markets; and builds on arguments in various streams of literature (law, durable goods, sustainable operations) as well as observations of recent business practice. In what follows, we provide detailed background evidence for this position and a brief overview of our study.

1.1. RTR and IPR: A Legal Perspective

While RTR is presumed to benefit the environment and consumers, some producers argue that supplying repair information, spare parts and tools would allow third-party access to a product's *proprietary* architecture (DigitalEurope 2017, Electronic Products Manufacturers Coalitions 2018, Wharton Public Policy Initiative 2019, Polly 2021). These arguments have received support from the law literature which acknowledges that RTR can conflict with a producer's IPR (e.g., on repair manuals, spare parts, software) (Grinvald and Tur-Sinai 2019, Terryn 2019, Montello 2020, Rosborough et al. 2023). Some scholars also warn that manufacturers can assert these rights to legally thwart independent repairs (Terryn 2019, Samuelson 2022, Rosborough et al. 2023). Consequently, as part of the RTR laws, some countries are considering eliminating producers' IPR where it conflicts with independent repairs. For example, The Promoting Automotive Repair, Trade and Sales Act in the U.S. would, if enacted, exclude consumer repair of automobiles from patent infringement (Grinvald and Tur-Sinai 2019, Ghosh 2022). Similar regulations are under discussion in Germany (Purdy 2019, Meindel and Witteman 2021), Canada (Rosborough et al. 2023), and Australia (Rosborough et al. 2023, Tyacke et al. 2023). At the same time, RTR proponents call for an EU-wide legislation that would allow independent repairers to use third-party parts without IPR concerns (Rosborough et al. 2023, Right to Repair Europe 2023).

From a legal perspective, repairs can be excluded from patent protection, because “the *purchaser* of a patented product is entitled to maintain the product... either by repairing it themselves or engaging someone else to do so" (Tyacke et al. 2023). That is, repair is the *legal right* of the product *owner* (Terryn 2019, Hatta 2020, Ghosh 2022, Tyacke et al. 2023). The advocates of RTR assert that upon purchasing, the consumer becomes the sole decision maker about the use and repair of a product: “You bought it. You own it... Ownership means you should be able to open, hack, repair, upgrade, or tie bells on it." (iFixit 2021). In turn, a producer who sells a product also sells the authority to use, maintain, and repair it; and under RTR, must supply the necessary repair information and parts. In contrast, a producer who maintains ownership of the product also maintains authority over repairs and can legally circumvent the regulation (Ghosh 2022). Thus, from a legal perspective, a discussion of product ownership appears crucial in crafting the RTR regulations. However, to our knowledge, this discussion is so far lacking in (model) RTR laws, and the ambiguity around product ownership (i.e., what counts as a sale vs. use) complicates the interpretation of RTR regulations in practice (Ghosh 2022). Unsurprisingly, some producers are aware of this complication and already use ownership arguments against RTR: In a lawsuit about preventing independent repairs, John Deere argued that their consumers do not own the product, but only have a license to use it (Wiens 2015, Montello 2020, Gordon-Bryne and Brighton 2022). This observation suggests that RTR has a direct impact on how a producer evaluates transferring ownership to consumers, the consequences of which require research to inform policy.

1.2. RTR and Secondary Markets: A Non-Ownership Perspective

RTR has an impact on a producer’s ownership decision not only due to its IPR implications, but also due to its intended effect on secondary markets. By extending a product’s useful life, RTR regulations effectively increase secondary market availability of products, business implications of which (e.g., producers preempting secondary market competition by keeping product ownership) have long been studied in the durable goods literature (Waldman 2003). We adopt the term “non-ownership" to describe a business model in which consumers do not own a product but are only entitled to use it through a pay-per-period (e.g., operational leasing) or a pay-per-use (e.g., servicizing) model. For a taxonomy of other terms used in the literature, see Agrawal and Bellos (2016).

Non-ownership business models have recently become more prevalent due to the Circular Economy (CE) movement, which advocates for transitioning from selling to business models in which products are shared, leased, repaired, and reused (Ellen MacArthur Foundation 2016, Atasu et al. 2021). As a key strategy towards a circular economy (Ellen MacArthur Foundation 2013), RTR regulations aim to encourage “more sustainable business models" (Terryn 2019, Mikolajczak 2020); and non-ownership models are increasingly common in the industries at the center of RTR discussions. For example, in consumer electronics, the Apple ‘iPhone Upgrade Program’ allows consumers to pay monthly fees and upgrade to a new model every year (Apple 2022). Apple is also reportedly working on a subscription service for iPhones (Gartenberg 2022, Gurman 2022). Fairphone, a company that actively supports RTR, has offered a monthly subscription model for phones with the ‘Fairphone Easy’ model (Fairphone 2023). In consumer durables, various companies offer subscription options for vacuum cleaners (Electrolux 2020), washing machines, coffee machines (Bundles 2023, Homie 2023), and home sound systems (Sonos 2023).

1.3. Overview of the Study and Results

In light of these arguments, we posit that the producer concerns around IPR and secondary market activity under RTR, combined with the CE momentum, imply a natural connection between RTR and non-ownership business models. Accordingly, we study a producer’s choice between ownership and non-ownership under RTR and the implications of this choice for producers, consumers, and the environment. To do so, we use a game-theoretic analytical model that builds on the established approaches in the durable goods literature and captures the salient features of our observations above.

Our analyses suggest that RTR can drive producers towards non-ownership (selling) business models when production is cheap (costly) and RTR implies a significant (negligible) threat of IPR violation. Consequently, given an endogenous business model choice, RTR achieves its environmental goals (that is, lower new production, higher availability of used products, lower environmental impact), for products with a high production cost and low use-phase environmental impact. However, for products with low production cost and use-phase impact, the environmental consequences of RTR can be contrary to its goals if RTR effectively results in lower reuse volumes. In particular, RTR-driven non-ownership business model choices may allow producers to prevent repairs and limit secondhand use; resulting in higher new production, lower secondhand use, and worse environmental impact.

In terms of the welfare implications of RTR, we find that RTR generally reduces producer profits. Nevertheless, some producers can benefit from RTR if they choose to sell products. We never observe a positive effect on producers and the environment simultaneously, that is, there is always a trade-off between economic and environmental implications of RTR. In addition, we show that RTR does not necessarily benefit consumers; as a result of the producer’s business model choice, consumers may observe higher prices and lower (new and used) product availability. We further show that these results are robust to endogenous repair and usage decisions. In terms of product design, we find that RTR can curtail product innovation and durability.

Taken together, these findings suggest that the implications of RTR can go beyond its expected effects on repair markets, and strategic producer responses to IPR concerns can produce unintended outcomes. Thus, we believe that a forward-looking approach such as ours is necessary to anticipate such strategic responses to RTR and evaluate intuitive claims on its economic and environmental consequences.

2. Related Literature

2.1. Durable Goods

RTR regulations apply to durable products whose useful life can be extended through repairs. Therefore, we build our research on the durable goods literature. This literature shows that producers can maintain ownership of their products and avoid competition from secondary markets by reducing availability of used products. See Waldman (2003) for a review. A stream of papers identifies the conditions under which retaining product ownership is more profitable than selling. For example, leasing, as a non-ownership business model, can be more profitable under different durability or disposal costs between leasing and selling (e.g., Desai and Purohit 1998, Agrawal et al. 2012), or when complementary product externalities are present (Bhaskaran and Gilbert 2005). We contribute to this stream by focusing on the RTR regulations as a potential driver of a firm's business model choice between selling and non-ownership. In the context of RTR, we show that retaining product ownership can preempt not only secondary market competition but also increased IPR infringement risks.

2.2. Sustainable Operations Management

Whereas the durable goods literature analyzes the drivers behind a firm's business model choice, the sustainable operations literature investigates the economic and environmental consequences of that choice. A growing number of papers examine the implications of non-ownership business models such as leasing (Agrawal et al. 2012, Lim et al. 2015), servicizing (Agrawal and Bellos 2016, 2017, Bellos et al. 2017), and shared-savings contract services (Corbett and DeCroix 2001). See Girotra and Netessine (2013) and Agrawal et al. (2019) for reviews. In contrast to the popular opinion of the CE proponents (Ellen MacArthur Foundation 2016), an important conclusion from these papers is that non-ownership business models are not necessarily more profitable or more environmentally friendly. For example, Agrawal et al. (2012) find that leasing can be environmentally worse than selling even if all off-lease products are remarketed and used until the end of lifetime, or it can be greener than selling even if some off-lease products are prematurely discarded. The interaction of business model choice and product design (Agrawal et al. 2021), and the presence of a government subsidy (Agrawal et al. 2022) have also been investigated in this stream of literature. We complement this stream by analyzing the impact of RTR regulations on business model choice.

We contribute to the sustainable operations literature also through our focus on an environmental regulation. There is a vast literature on business responses to environmental regulations (Atasu et al. 2016, Drake and Just 2016), and the consequences of those responses for various stakeholders. In particular, this literature has investigated the implications of the Extended Producer Responsibility laws (Plambeck and Wang 2009, Atasu and Souza 2013, Alev et al. 2020), environmental taxes and green technology (Krass et al. 2013, Drake 2018, Sunar and Birge 2019, Sunar and Swaminathan 2021), and emissions regulations (Drake et al. 2016, Sunar and Plambeck 2016, Sunar 2016). See Sunar and Birge (2019) and Atasu et al. (2020) for recent reviews.

Despite the extensive literature on various environmental regulations, our understanding of the implications of RTR is nascent. In the operations management literature, two recent papers by Chowdhury and Verma (2024) and Jin et al. (2022) discuss RTR. Chowdhury and Verma (2024) investigate when, in the absence of regulations, a firm would voluntarily adopt RTR by selling spare parts. Unlike Chowdhury and Verma (2024), we consider the IP risks associated with the sale of spare parts (and the sharing of information), as well as a strategic response to these risks when the regulations are mandated on the producer. Jin et al. (2022) analyze the pricing response of a monopolist and find that RTR can trigger an increase in the prices of new products. As a result, even though RTR reduces independent repair costs and increases repair quantities; producers, consumers, and the environment can be worse-off. We identify a fundamentally different mechanism through which RTR can affect businesses (IP violation risks and business model choice) and find that the business model implications of RTR can lead to substantially different outcomes than those studied in Jin et al. (2022). In particular, our results suggest that some producers can benefit from RTR, and the regulation does not necessarily increase repair volumes even for low-cost products. We detail these arguments in §6.2 and §7.1.

3. Model

We develop a discrete-time, infinite-horizon, dynamic game to model the decisions of a durable good producer, a third-party competitor, and consumers. In this model, a legislator decides whether or not to impose RTR regulations on the producer. The producer then chooses her business model, that is, whether to sell products (hence transfer ownership) or offer them through a non-ownership model. In our main analysis, we model the non-ownership offer as a pay-per-period model (e.g., leasing) in which the producer offers the use of new and used products for one period to consumers. In §7.2 we analyze the robustness of our insights to an alternative model with endogenous usage decisions (e.g., pay-per-use model). Depending on the presence of RTR regulations and the producer's corresponding business model choice, the third-party competitor may be able to leverage the producer's proprietary information to improve his product offering.

Before formally introducing the model that captures these interactions, we discuss our key assumptions.

3.1. Model Assumptions

In our model, the impact of RTR is two-fold: it increases product lifetimes by facilitating repairs, and it also increases the risk of IPR infringement. We capture RTR's effect on product lifespan in the following way: in the absence of RTR, if the producer chooses to sell, some consumers cannot access the necessary information and parts to repair the product. We reflect this by assuming that absent the regulations, only a fraction $f \in (0, 1)$ of new products can be resold in a secondhand market. That is, a product with a high secondhand availability f achieves a long lifetime through reuse. This may be the case, for example, for products with simpler architectures and in countries with a well-developed (independent) repair market. A low f indicates that a high fraction of products are discarded instead of repaired, and RTR can help extend the lifetime of such products. To model the effect of RTR on product lifetimes in a tractable manner, we assume without loss of generality that under RTR, all products can be repaired and resold by consumers (i.e., effectively, $f = 1$).

To model RTR's effect on facilitating IPR infringement, as suggested by some producers (DigitalEurope 2017, 2022, Montello 2020, Gordon-Bryne and Brighton 2022), we assume that RTR regulations allow a third-party competitor (who produces a lower-end product) to leverage the producer's proprietary information and parts to improve his product and hence its consumer valuation. Further, if the producer chooses to offer the product through a non-ownership model, she bears the cost and responsibility of repairs and avoids sharing repair information and spare parts. Therefore, the competitor is not able to improve his product.

3.2. Model Description

We now formalize the model. Periods are indexed by $t \geq 0$. Subscripts s, no denote selling and non-ownership, respectively; n, u denote new and used products, respectively; and c denotes the competing product. Superscripts R and NR denote the presence and absence of RTR, respectively.

The timeline of events is as follows: at $t = 0$, the legislator announces whether the RTR regulation is imposed on the producer. Given this announcement, the producer chooses her business model, and then determines the production quantity.

If the producer chooses to sell in the absence of RTR, in every period $t > 0$, she chooses the quantity $q^{NR}_{s,n,t}$, and the competitor chooses the quantity of the competing product to sell[1], $q^{NR}_{s,c,t}$. Used products are traded in the secondhand market by consumers, and $q^{NR}_{s,u,t}$ denotes the available quantity of used products. Without RTR, only a fraction $f \in (0, 1)$ of products of the producer are available in the secondhand market, i.e., $q^{NR}_{s,u,t+1} \leq f q^{NR}_{s,n,t}$.

On the other hand, if the producer chooses selling under RTR, in every period $t > 0$, the producer and the competitor choose the quantities to sell, $q^{R}_{s,n,t}$ and $q^{R}_{s,c,t}$, respectively, and, due to RTR, $q^{R}_{s,u,t+1} \leq q^{R}_{s,n,t}$.

If the producer chooses to offer products through a non-ownership model, in every period $t > 0$, she determines the new $(q_{no,n,t})$ and used $(q_{no,u,t})$ product quantities to market, while the competitor determines the quantity to sell, $q_{no,c,t}$.

Finally, we do not differentiate between the scenarios of retaining ownership under or without RTR, because non-ownership allows the producer to avoid the effects of RTR on competition and secondhand availability.

3.3. Product Characteristics

Costs. We assume that the producer's product lasts for two periods, while the low-end competing product lasts for one period (and cannot be resold in the secondary market). It costs $\kappa > 0$ to produce a new product and $\kappa_c \leq \kappa$ to produce a low-end competing product. We normalize $\kappa_c = 0$ for simplicity. Following (Agrawal et al. 2012), we allow the non-ownership model to have a different unit cost than selling, by assuming that non-ownership is associated with an additional per-unit disposal cost, γ .

Environmental Impact. A product's per-unit environmental impact in each life-cycle phase (production, use, disposal) is found using life-cycle analysis (U.S. Environmental Protection Agency 2008). Consistent with the literature (White et al. 1999, Agrawal et al. 2012, 2021), we represent the total environmental impact of each scenario (non-ownership, selling without RTR, selling under

RTR) by the environmental impact of each phase, multiplied by the number of products in that phase in each period. Let i_p and i_d denote the per-unit environmental impact during the production and disposal phases, respectively. Let also i_{u2} and i_{u1} denote the per-unit environmental impact during the first and second use periods, respectively[2]. We allow the competing product to have a different environmental impact by defining i_{pc}, i_{dc}, i_{uc} for the per-unit environmental impact of a competing product during the production, disposal and use phases, respectively.

3.4. Consumer Characteristics

The consumer population is normalized to 1. Consumers are heterogeneous in their valuation of the product, characterized by a finite and time-independent taste parameter $\theta \sim \text{Uniform}[0,1]$. Consumer type θ's gross utility from using a new producer's product, a used producer's product, or a competing product are denoted respectively by $U_n(\theta)$, $U_u(\theta)$, and $U_c(\theta)$. Consumers derive zero utility from staying inactive, and prefer consuming any product to staying inactive. Ceteris paribus, consumers prefer a new product to a used one, and a used product to a competing product[3], i.e., $U_n(\theta) \geq U_u(\theta) \geq U_c(\theta) \geq 0$. As in the literature (Desai and Purohit 1998, Agrawal et al. 2012), we adopt the following specification for the consumer utility from consuming new and used products: $U_n(\theta) = \theta$, $U_u(\theta) = \delta\theta$ where $\delta \in (0,1)$ represents the relative consumer willingness to pay (WTP) for the used product compared to the new product. That is, δ is the decrease in consumer WTP due to performance deterioration (physical decay) of the product after a period of use.

If the producer chooses selling under RTR, the competitor can leverage RTR to improve the features of his product. Therefore the consumer utility from consuming the competing product depends on the presence of RTR and the producer's business model. In the absence of RTR, consumer θ's gross utility from consuming a competing product is $U_c(\theta) = \delta_{c0}\theta$ where $\delta_{c0} \in [0,\delta)$ denotes the relative WTP for a competing product compared to that of a new product. If the producer sells in the presence of RTR, this relative consumer WTP increases to $\delta_c \in (\delta_{c0}, \delta)$. However, the producer can avoid this increase under RTR by keeping ownership of the product and preventing IP leakage to the competitor, in which case the relative WTP for the competing product remains at δ_{c0}.

Under selling, we let $p_{s,n,t}$, $p_{s,u,t}$ and $p_{s,c,t}$ denote the price of the new product, the market-clearing price for the used product in the secondary market, and the competing product at time t, respectively. Under non-ownership, we let $p_{no,n,t}$ and $p_{no,u,t}$ denote the one-period use fees for a new and a used product. In our model, consumers are forward-looking and have rational expectations: in the absence of RTR, a consumer who purchases a new product anticipates that it may break down and he will only be able to repair and resell it in the secondhand market with probability f. In contrast, under RTR, he expects to be able to resell all products he purchases. Note that when the producer retains ownership, she remains responsible for repairs. We further assume that all information regarding consumer preferences is common knowledge and that all players have a common per-period discount factor, ρ.

3.5. Solution Approach

We assume that consumer utility from selling a product after one period of use and buying another in the secondhand market is the same as keeping the product (See Hendel and Lizzeri (1999) pp. 1099-1100 for an explanation). Consequently, under any business model, there are at most four undominated consumer strategies: (i) consume (through purchasing or a non-ownership model) new products in every period, (ii) consume (through purchasing on the secondary market or a non-ownership model) used products in every period, (iii) purchase a competing product in every period (if available), and (iv) stay inactive.

For simplicity, we take the discount factor $\rho = 1$. Following the literature (Hendel and Lizzeri 1999, Huang et al. 2001, Agrawal et al. 2012, 2021, Huang et al. 2019, 2023), we restrict our attention to a “focal point", that is, an equilibrium that has a steady limit (i.e., $t \to \infty$) in which all players’ actions are constant in time (See Huang et al. (2001) p. 1521 for an explanation). This approach is effectively equivalent to a model where all players maximize their average per-period utility. Thus, the time dependence can be dropped out with a steady-state interpretation. In what follows, we omit the subscript t.

Moreover, we assume a positive disposal cost, $\gamma > 0$. This assumption is necessary in our model so that selling can be a viable option in the absence of RTR. Otherwise, keeping ownership is always more profitable for the producer than selling. Note that there are various reasons why a producer may not prefer a non-ownership model, such as administration and maintenance costs (Van Loon et al. 2018), and consumer preferences towards non-ownership models (White et al. 1999, FinanCE 2016, Gülserliler et al. 2022). The positive disposal cost assumption is meant to capture such drawbacks of non-ownership via an increase in the marginal unit cost. Lastly, we assume that the production and disposal costs are sufficiently low such that production is profitable in each scenario.

4. Preliminaries

In this section, we lay the foundation for our analysis by deriving the equilibrium strategies for consumers, the producer, and the competitor under the three scenarios of interest: selling without

RTR, selling under RTR, and non-ownership. The details of the model derivation are in Appendix A and all proofs in the paper are relegated to the Electronic Companion (EC). Due to page limitations, we provide some additional analyses in a Supplemental Material (SM) for peer review.

4.1. Selling without RTR

In the absence of RTR, the producer and the competitor simultaneously choose the quantity of new products and competing products to sell in each period. Used products are traded in the secondhand market at a market-clearing price. The producer's profit maximization problem is: $\max_{q_{s,n}^{NR}} \ \Pi_s^{NR} = q_{s,n}^{NR}(p_{s,n}^{NR} - \kappa)$ s.t. $q_{s,n}^{NR} \geq 0,\ q_{s,u}^{NR} \geq 0,\ p_{s,n}^{NR} \geq 0,\ p_{s,u}^{NR} \geq 0,\ q_{s,n}^{NR} + q_{s,u}^{NR} + q_{s,c}^{NR} \leq 1$. In this formulation and those that follow for the different scenarios, the constraints respectively ensure that the quantity and price of new and used products in the market are non-negative, and that the sizes of all consumer segments sum up to 1. Similarly, the competitor's profit maximization problem is: $\max_{q_{s,c}^{NR}} \ \Pi_{s,c}^{NR} = q_{s,c}^{NR} p_{s,c}^{NR}$ s.t. $q_{s,c}^{NR} \geq 0,\ p_{s,c}^{NR} \geq 0,\ q_{s,n}^{NR} + q_{s,u}^{NR} + q_{s,c}^{NR} \leq 1$. The complete characterization of the stationary equilibrium is in Appendix A.1, and shows that there exist unique optimal quantities $q_{s,n}^{NR*}, q_{s,u}^{NR*}, q_{s,c}^{NR*}$. The total steady-state, per-period environmental impact of the selling strategy without RTR is given by: $E_s^{NR} = (i_p + i_d + i_{u1}) q_{s,n}^{NR*} + i_{u2} q_{s,u}^{NR*} + (i_{pc} + i_{dc} + i_{uc}) q_{s,c}^{NR*}$.

4.2. Selling under RTR

This scenario is simply a replication of that in §4.1, with $f \to 1$ and $\delta_{c0} \to \delta_c$ [4]. The details of this analysis are in Appendix A.2, and show that there exist unique optimal quantities $q_{s,n}^{R*}, q_{s,u}^{R*}, q_{s,c}^{R*}$. The total steady-state, per-period environmental impact of the selling strategy without RTR is given by: $E_s^R = (i_p + i_d + i_{u1}) q_{s,n}^{R*} + i_{u2} q_{s,u}^{R*} + (i_{pc} + i_{dc} + i_{uc}) q_{s,c}^{R*}$.

4.3. Non-ownership

When the producer chooses to retain ownership, she maintains control over the quantity of used products in the market. In this case, the producer's profit maximization problem is: $\max_{q_{no,n}, q_{no,u}} \ \Pi_{no} = q_{no,n}(p_{no,n} - \kappa - \gamma) + q_{no,u} p_{no,u}$ s.t. $q_{no,n} \geq q_{no,u},\ q_{no,u} \geq 0,\ q_{no,n} + q_{no,u} + q_{no,c} \leq 1$. The competitor's problem is: $\max_{q_{no,c}} \ \Pi_{no,c} = q_{no,c} p_{no,c}$ s.t. $q_{no,c} \geq 0,\ q_{no,n} + q_{no,u} + q_{no,c} \leq 1$. The complete characterization of the equilibrium is in Appendix A.3, and shows that there exist unique optimal quantities $q_{no,n}^*, q_{no,u}^*, q_{no,c}^*$. The total steady-state, per-period environmental impact under the non-ownership model is given by: $E_{no} = (i_p + i_d + i_{u1}) q_{no,n}^* + i_{u2} q_{no,u}^* + (i_{pc} + i_{dc} + i_{uc}) q_{no,c}^*$.

We now discuss the optimal equilibrium strategy of the producer in this scenario, which lays the foundation for our results in the following sections. In equilibrium, we find that the producer always offers both new and used products. At low levels of production and disposal costs (if $\frac{1-\delta}{2} \geq \kappa + \gamma > 0$), the producer may prefer to dispose a fraction of used products instead of marketing them for another period (i.e., partial remarketing strategy) (Agrawal et al. 2012). Such premature disposal of used products allows the producer to reduce cannibalization and increase demand for new products. This is only attractive to the producer if the cost of disposing a product and producing new instead is not too high, that is, at low levels of κ and γ. Otherwise (if $1 + \delta - \delta_{c0} > \kappa + \gamma > \frac{1-\delta}{2}$), the producer chooses to market all products in both periods of their useful lifetime (i.e., full remarketing strategy).

5. Business Model Choice under RTR

For ease of exposition, hereafter we refer to the producer's product as an original, and the competing product as a counterfeit. We also assume $\delta_{c0} = 0$. This effectively means that in the absence of RTR the producer is not subject to competition, and under RTR a third-party offers a low-end counterfeit[5]. Finally, for readability, we slightly abuse the notation and denote the thresholds in all propositions the same way, e.g. $\hat{\kappa}$. The closed-form expressions for these thresholds are different for each proposition, provided in EC.1.

Proposition 1 provides an answer for our first research question, i.e., if and when RTR drives producers towards non-ownership. The results are illustrated in Figure 1.

Proposition 1 (Business Model Choice)**.** *There exist thresholds $\hat{\kappa}$ and $\hat{\delta}_c(f)$ such that RTR increases producer incentives for non-ownership if: (i) The production cost is low, $\kappa \leq \hat{\kappa}$, or (ii) Both the production cost and the relative consumer WTP for the counterfeit (as a function of the secondhand availability f) are high, $\kappa > \hat{\kappa}$ and $\delta_c > \hat{\delta}_c(f)$. Otherwise, RTR increases producer incentives to sell.*

Proposition 1 suggests that under certain conditions, RTR regulations can increase a producer's incentives to retain ownership. This depends on the production cost κ, the level of secondhand availability (i.e., how developed the independent repair market is) in the absence of RTR f, and the consumers' relative WTP for the counterfeit δ_c. The intuition behind Proposition 1 is as follows.

Absent RTR, when choosing her business model, the producer faces a trade-off between the disposal cost (under non-ownership) and the competition with used products in the secondary market (under selling). Under RTR, the trade-off is more involved between the disposal cost (under non-ownership) and competition with both the secondary market and the third-party (under selling). Consequently, the producer can find non-ownership more attractive under RTR if the selling profits are reduced due to higher competition with the third-party and the secondary market.

The producer always loses profits due to the third-party competition. Interestingly, however, the RTR-driven increase in the secondary market availability presents a double-edged sword for the

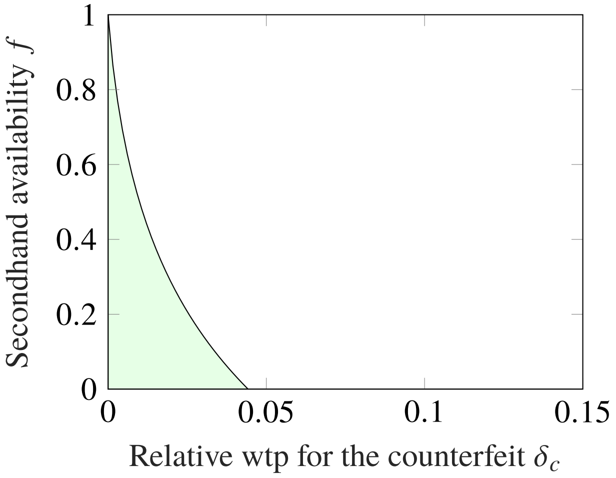
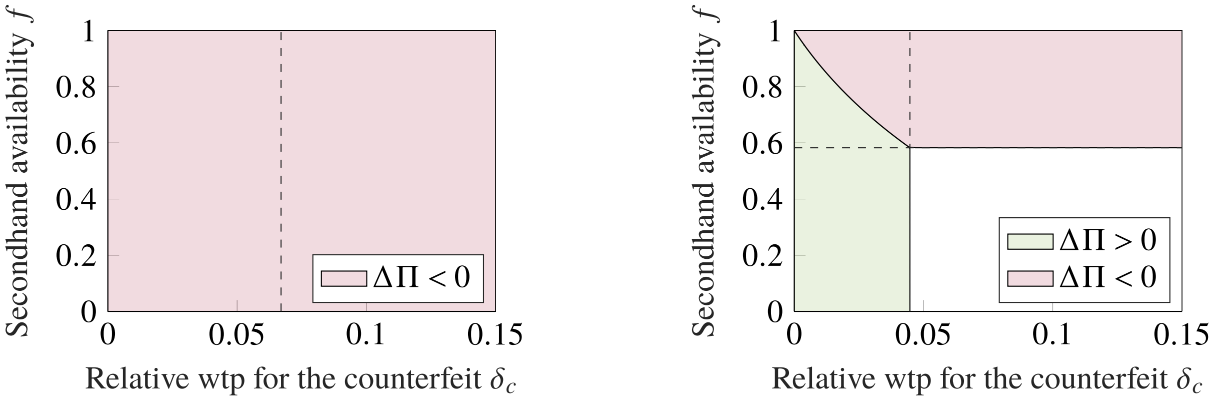


Figure 1 **The impact of RTR on business model choice. The curve plots $\hat{\delta}_c(f)$ with $\kappa = 0.3, \delta = 0.5$. RTR makes non-ownership (selling) more attractive in the blank (shaded) region.**

producer. On the one hand, the producer can benefit from the increase in the secondhand availability (i.e., a more efficient independent repair market), because consumers expect with a higher probability to have a functional product after one period of use. This expectation increases their WTP for a new product, allowing the producer to raise prices. On the other hand, an increase in the secondary market quantity cannibalizes new product sales. Thus, a higher secondhand availability due to RTR results in lower selling profits if the producer is hurt more by the cannibalization than she gains from the price increase. Note that this implies that the switch to non-ownership can be a viable strategy under RTR even in the absence of IP concerns. As a result, as Proposition 1 states, RTR can drive producers towards non-ownership if the product is cheap to make or if RTR brings a significant improvement in the counterfeit (the blank region in Figure 1).

Given its effects on third-party and secondary market competition, it is intuitive that RTR can create incentives for producers to keep ownership of their products. Somewhat surprisingly, however, Proposition 1 clarifies that this is not always the case: RTR can also create incentives for a producer to transition from non-ownership models towards selling. This is because the producer can prefer a higher secondhand quantity, provided that the product is expensive to make and RTR's effect on the third-party competition is limited (the shaded region in Figure 1).

The observation that RTR can drive a producer's ownership choice in either direction has important implications on its broader economic and environmental impacts, as we discuss in detail in the next chapter.



(a) Mobile phones. Under RTR, it is optimal to sell if $\delta_c < 0.067$ and keep ownership otherwise. Without RTR, it is optimal to sell for all $f \in [0, 1]$.

(b) Washing machines. Under RTR, it is optimal to sell if $\delta_c < 0.045$ and keep ownership otherwise. Without RTR, it is optimal to keep ownership if $f < 0.58$ and sell otherwise.

Figure 2 **Change in producer profits due to RTR for mobile phones and washing machines. The dashed lines indicate the business model change.**

6. Economic and Environmental Consequences of RTR

Having characterized a producer's business model choice under RTR, we now analyze the consequences of this choice on producers, consumers, and the environment. We calibrate our model with data and visualize our insights for two products at the center of RTR discussions: mobile phones and washing machines. For data calibration, we follow the approach of Agrawal and Bellos (2017) (See Appendix B for details).

6.1. Producer Profits

Proposition 2 (Producer Profits)**.** *Let* $\Delta\Pi$ *denote the change in producer profits due to RTR:* $\Delta\Pi = \Pi^{R*} - \Pi^{NR*}$*. There exists* $\hat{\delta}_c$ *such that RTR increases profits,* $\Delta\Pi > 0$*, if: (i) it results in a change from non-ownership to selling, or (ii) it is optimal to sell both under and without RTR and the relative WTP for the counterfeit is low,* $\delta_c < \hat{\delta}_c$*. Otherwise, RTR decreases profits,* $\Delta\Pi \leq 0$*.*

Proposition 2 allows us to make a key observation: RTR need not be bad news for producers. In fact, RTR can lead to higher producer profits, provided that the producer sells under RTR. The intuition behind this result follows from the discussion in §5, and is based on the argument by the RTR advocates that releasing repair information will improve the efficiency of independent repairs (Montello 2020, Ramirez and Duffy 2021). This argument effectively implies that the producer benefits from a cost-less increase in the efficiency of independent repairs, which boosts the lifetime utility and the consumer WTP for a new original product (This result continues to hold as long as

RTR renders the independent repair market more cost-efficient than producer repairs. Please see §7.1 for a detailed analysis).

Yet, for producers to enjoy a profit boost under RTR, this efficiency improvement must be large enough to justify the cannibalization losses due to the secondary market and intensified third-party competition. Proposition 2 shows that this is the case only when the original product is expensive to make and RTR's effect on improving the counterfeit is minimal. Figure 2 plots the change in profits for our calibrated examples and demonstrates that an increase in profits can be observed only for washing machines satisfying these conditions. More specifically, the bottom left corner of Figure 2b represents conditions under which a producer would choose selling under RTR, even if she prefers non-ownership in the absence of RTR. In contrast, the upper left corner of Figure 2b represents conditions where the producer always chooses selling (with or without RTR) and the relative WTP for the counterfeit is sufficiently low.

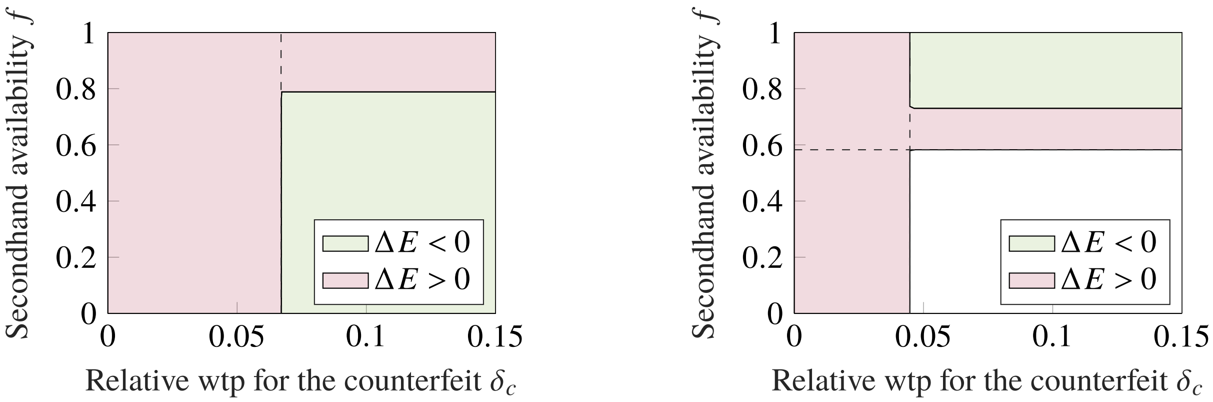
While some producers can observe higher profits due to RTR, it is important to emphasize that RTR reduces producer profits in general. For our calibrated examples, this is the case for mobile phones (Figure 2a) due to the low production cost, and for washing machines when the producer switches to non-ownership and pays additional disposal costs (upper right corner of Figure 2b).

6.2. Environmental Impact

Proposition 3 (Environmental Impact)**.** *Let* ΔE *denote the difference in total environmental impact under and without RTR:* $\Delta E = E^R - E^{NR}$*. For simplicity, assume that* $i_{pc} = i_p, i_{dc} = i_p, i_{uc} = i_{u1}$*. There exist thresholds* $\hat{\Omega}$*,* $\hat{f}$*,* $\hat{\kappa}$*, and* $\hat{\delta}_c$ *such that RTR benefits the environment, i.e.,* $\Delta E < 0$ *if either: (i) selling is optimal under RTR,* $\delta_c \geq \hat{\delta}_c$*, and* $\Omega = i_{u2}/(i_{u1} + i_p + i_d) > \hat{\Omega}$*; or (ii) RTR results in a switch from selling to non-ownership and one of the following holds: (ii.a.)* $f < \hat{f}$ *and* $\Omega < \hat{\Omega}$*; or (ii.b.)* $f > \hat{f}$*,* $\kappa \leq \hat{\kappa}$*, and* $\Omega > \hat{\Omega}$*; or (ii.c.)* $f > \hat{f}$ *and* $\kappa > \hat{\kappa}$*. Otherwise, RTR (weakly) hurts the environment,* $\Delta E \geq 0$.

Proposition 3 effectively offers one critical insight: RTR need not bring environmental benefits. It also suggests that the endogenous business model choice under RTR can reverse our understanding of RTR's environmental impact. That is, while RTR can improve environmental impact under selling, a switch to non-ownership can reverse this position, as we detail below.

The intuition behind Proposition 3 is as follows. The impact of RTR on the environment depends on how the producer's business model choice drives new production (original and counterfeit) and used product volumes in the secondary market. As the analysis up to this point indicates, the



(a) Mobile phones. Under RTR, it is optimal to sell if $\delta_c < 0.067$ and keep ownership otherwise. Without RTR, it is optimal to sell for all $f \in [0, 1]$.

(b) Washing machines. Under RTR, it is optimal to sell if $\delta_c < 0.045$ and keep ownership otherwise. Without RTR, it is optimal to keep ownership if $f < 0.58$ and sell otherwise.

Figure 3 Change in total environmental impact due to RTR for mobile phones and washing machines. The dashed lines indicate the underlying business model change.

business model choice and these volumes are determined by the relative WTP for the counterfeit, used product availability and production costs.

More specifically, an increase in the new production quantity increases the production (i_p) and disposal impacts (i_d), as well as the use impact due to new products (i_{u1}). Similarly, an increase in the used product quantity increases the use impact due to used products (i_{u2}). Therefore, when RTR increases the new production quantity but reduces the used quantity, it results in a lower total environmental impact only for products with a high impact in the second use phase, i_{u2}, i.e., $\Omega = i_{u2}/(i_p + i_d + i_{u1}) > \hat{\Omega}$, such that the increase in i_p, i_d, i_{u1}, is dominated by the decrease in i_{u2}. Effectively, this Ω ratio determines the balance between new production and secondhand use effects. The condition for a low Ω is more easily met by products with a low total use-phase impact, such as mobile phones (Apple 2020). In contrast, products with a high total use-phase impact, such as washing machines (Rosa-Aquino 2020, Agrawal et al. 2012, Fishbein et al. 2000), are more likely to satisfy the condition for a high Ω. Our insights below follow from this intuition, which we illustrate in Figure 3 for our calibrated numerical examples.

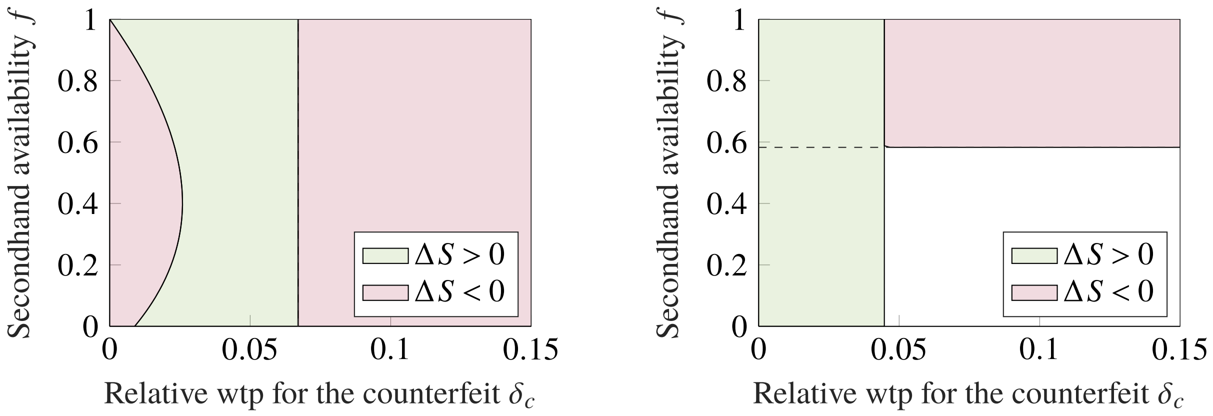
First, we observe that the business model implications of RTR can override its intended effects on the environment. In particular, for products with a low production cost and use-phase impact (e.g., mobile phones), the producer has an incentive to keep ownership of products under RTR, and discard some items before the end of their useful lifetime. Depending on the secondhand availability before RTR, this premature removal can lead to higher new production and *lower* reuse volumes, hence *higher* total environmental impact (upper right corner of Figure 3a). This result is in contrast to previous literature (Jin et al. 2022), and highlights the importance of business model choice as a response to RTR. As further explained in §7.1, with endogenous business model choice, we find that RTR can reduce the total environmental impact of mobile phones only if, absent the regulations, a high percentage of products are scrapped due to the unavailability of repair options (lower right corner of Figure 3a).

Proposition 3 also suggests that the intensified third-party competition under RTR can benefit the environment, even though it increases total new production (original and counterfeit). This is because if consumers have a high valuation for the counterfeit, the competitor can capture a substantial market share from the producer, limiting the original production and hence the used product volume[6]. This reduces the total environmental impact for products with a high use-phase impact. Yet, this potential environmental benefit of increased competition under RTR depends crucially on the level of consumer WTP for the counterfeit: it must be low enough that the producer still chooses to sell products, but high enough that it can steal a significant market share from original products. If the counterfeit has a limited consumer WTP, RTR increases both total new production and used product quantities, leading to a higher environmental impact for all types of products (left hand side of the dashed lines in Figures 3a, 3b). Taken together, these results imply that for mobile phones, the presumed environmental benefits of RTR can only be obtained in markets with limited independent repair options. Otherwise (e.g., for washing machines), RTR can be harmful for the environment especially when it implies limited benefit to third-party competitors.

Finally, it is interesting to note that these potential environmental benefits of RTR come at a cost to producer profits. Combining our results on the economic and environmental consequences of RTR, we see that there is no “win-win" region for the producer and the environment: the regions with $\Delta\Pi > 0$ in Figure 2 and $\Delta E < 0$ in Figure 3 do not overlap. In fact, for a range of scenarios, RTR may be harmful for both the producer and the environment.

6.3. Consumer Surplus

Proposition 4 (Consumer Surplus)**.** *Let* ΔS *denote the change in consumer surplus due to RTR:* $\Delta S = S^R - S^{NR}$*. There exist thresholds* $\hat{\kappa}, \hat{f}, \hat{\delta}_c$ *such that RTR benefits consumers, i.e.,* $\Delta S > 0$ *if one of the following holds: (i) RTR leads to a switch from non-ownership to selling; (ii) RTR leads to a switch from selling to non-ownership,* $\kappa > \hat{\kappa}$*, and* $f < \hat{f}$*; (iii) It is optimal to sell both under and without RTR and* $\delta_c > \hat{\delta}_c$*. Otherwise, RTR hurts consumers,* $\Delta S \leq 0$*.*



(a) Mobile phones. Under RTR, it is optimal to sell if $\delta_c < 0.067$ and keep ownership otherwise. Without RTR, it is optimal to sell for all $f \in [0, 1]$.

(b) Washing machines. Under RTR, it is optimal to sell if $\delta_c < 0.045$ and keep ownership otherwise. Without RTR, it is optimal to keep ownership if $f < 0.58$ and sell otherwise.

Figure 4 Change in consumer surplus due to RTR for mobile phones and washing machines. The dashed lines indicate the underlying business model change.

Proposition 4 indicates that RTR can benefit consumers, but through a different mechanism (IP and business model implications) than its presumed first-order effects (increasing reuse). In fact, due to its business model implications, RTR can benefit consumers even when it decreases reuse volumes, and vice versa. This is because, RTR affects consumer surplus not only through the quantity of used products, but also through total new production (original and counterfeit) and the prices (or per-period fees) of these products under different business models. The following insights build on this intuition, and the resulting effect is illustrated for our calibrated numerical examples in Figure 4.

Proposition 4 highlights that consumers can benefit from RTR if the producer sells under RTR. Intuitively, consumers enjoy the competition between the third-party and the producer, as well as an increased efficiency in the repair market (left-hand side of Figures 4a and 4b). Nevertheless, if the IP implications of RTR are significant such that it encourages producers to retain ownership, it can hurt consumers even when it boosts reuse volumes. This is because, the costs incurred under non-ownership (i.e., γ) could push the producer to make fewer new products and price them higher – effectively reducing consumer surplus (right-hand side of Figures 4a and 4b).

Taken together, our insights so far suggest a trade-off between the economic and environmental consequences of RTR, for both mobile phones and washing machines. The IP implications of RTR can increase total new production (original and counterfeit). While this increase harms the environment, it may serve consumers.

7. Extensions

In this section, we investigate the robustness of our main findings to alternative modeling choices on endogenous repair (§7.1) and usage (§7.2) decisions, and analyze the impact of RTR on the innovation and durability choices of a producer (§7.3). Where these additions render the model analytically intractable, we resort to extensive numerical analyses and provide details in the EC.

7.1. Endogenous Repair Decisions

In this extension, following Jin et al. (2022)'s approach, we allow consumers and producers to make repair decisions, and model RTR as a force that reduces the independent repair cost. See EC.2.1 for details.

In general, our insights continue to hold. We find that producers of items with high production cost can benefit from the increased efficiency of the independent repair market under RTR. This increase in profit is observed if RTR makes independent repairs more cost-effective than producer repair services and if the RTR-driven improvement in the counterfeit is negligible. Considering that many producers of consumer electronics and durables (e.g., Apple, John Deere) are conglomerates with high overhead and transportation costs; small independent repair shops, which are closer to consumers, may be able to handle repairs at a lower cost. In this case, all consumers repair their products independently under RTR, and the producer enjoys the increase in the consumer valuation of a new product. However, this increase in profits disappears if the product is cheap to produce or if, even under RTR, independent repairs are costlier than producer repairs (as assumed in Jin et al. (2022)).

In addition, as alluded to in §6.2, we find that the decrease in independent repair costs under RTR does not necessarily come with an increase in repair volume for low-cost products. Maintaining ownership of low-cost products can be a strategic lever for the producer to thwart repairs, potentially leading to lower repair volumes, higher new production, and worse environmental impact. This is in contrast to Jin et al. (2022) who find that for such products, RTR increases repair volumes: the producer eliminates repairs without RTR and repairs all broken products under RTR. This finding is independent of the repair cost structure and is due to the business model choice we study as a response to RTR.

Lastly, as in our main model, considering the producer's business model choice points to a trade-off between the implications of RTR for consumers and the environment. Faced with a strong competitor under RTR, the producer of a high-cost product switches to non-ownership and repairs and remarkets all broken products. In line with our previous findings and different from Jin et al.

(2022), this change in the business model can lead to lower new production (due to additional disposal costs), potentially improving the environmental impact but hurting consumers.

7.2. Endogenous Usage Decisions

In our main analysis, we model a pay-per-period (e.g., leasing) system in which consumers pay a fixed fee for each period, regardless of their usage. In this section, following Agrawal and Bellos (2017)'s approach, we explore a pay-per-use (e.g., servicizing) model in which the consumers' utility depend on their usage decisions. Such models have been argued to encourage consumers to reduce their usage and lead to better environmental results (Agrawal and Bellos 2016, 2017). In a pay-per-use system, if consumer requests do not overlap, the producer can pool and satisfy the demand from consumers with fewer products than the number of consumers who adopt the model, which is referred to as pooling efficacy (Agrawal and Bellos 2017). The details are provided in the SM.

Our numerical observations suggest that, in general, our main insights hold under this extension. For example, we find that the producer may be incentivized to retain ownership of products and offer them through a pay-per-use model under RTR if the production cost is low. This incentive is higher at high levels of pooling efficacy. Similar to our main results, the change to a pay-per-use model leads to premature disposal of cheap-to-make products, hence higher new production (and usage) and lower used product quantity (and usage). Different from our main insights, however, if pay-per-use allows the producer to meet consumer demand with very few products, the producer may choose to discard products prematurely even when the production cost is high. In that case, the switch to pay-per-use under RTR is likely to result in a lower new and used product quantity, but a higher new product usage. This is because, while the pay-per-use system encourages an individual consumer to decrease their usage, it enlarges the consumer segment that can access high-end products (as also identified in (Agrawal and Bellos 2017)).

7.3. Innovation and Durability Decisions

7.3.1. Innovation. An interesting argument some producers use against RTR is that releasing proprietary repair information and spare parts would reduce their incentives to innovate (DigitalEurope 2017, Polly 2021, Gordon-Bryne and Brighton 2022). To investigate this argument, we follow Purohit (1994) and allow the producer to innovate and improve the consumer valuation of its product. The producer introduces a new generation product in each period, which depreciates and becomes an old generation product after the first period of use. Under RTR the competitor can introduce a counterfeit of either the new or the old generation. See EC.2.2.1 for details.

The impact of RTR on innovation depends on how quickly the competitor can access proprietary product design information under RTR. RTR can increase the innovation incentives of a selling producer if the counterfeit is of the old generation. The increased competition with the counterfeit further drives the producer to innovate, because innovation helps differentiate the new original product from counterfeits and secondhand products, both of which are old generation. From this perspective, the claims about the effect of RTR on innovation may seem unfounded. However, RTR can curtail innovation if it allows a third party to quickly imitate a new generation product. In this case, innovation does not help differentiate the original product from the counterfeit, and the competitor also benefits from the innovation investments of the producer. Therefore, if, as some producers argue, RTR allows third parties to produce a counterfeit quickly after the original has been released, it can discourage producers from innovating.

7.3.2. Durability. One of the goals of RTR is to encourage more durable product designs (European Parliament 2022). To analyze the potential effects of RTR on a producer's durability choice, we extend our model to allow the producer to choose product durability. See EC.2.2.2 for details.

The impact of RTR on durability depends on how long a product will be in use. RTR can increase (decrease) product durability if the baseline production cost is high (low) and IP risk is low (high). At low baseline production costs and when RTR implies a highly competitive counterfeit, the producer switches to non-ownership. This means a decrease in her durability investment because some products will be prematurely disposed. In contrast, if the product is expensive to make and the increase in the WTP for the counterfeit is limited, RTR can improve product durability. This is because the producer sticks with selling and expects more products to remain in use for a long time due to the increase in the efficiency of the repair market.

8. Conclusion

RTR regulations require producers to supply necessary information and parts for consumers to independently repair their products. Although these regulations are presumed to benefit consumers and the environment, the ease of access to proprietary information and spare parts can facilitate IPR infringement by third parties. In this paper, we investigate whether and when retaining ownership of products (instead of selling them) helps producers prevent IPR violation and competition under RTR. We use a game-theoretic model to analyze a producer's business model choice under RTR, and the economic and environmental consequences of this choice.

Our results suggest that keeping product ownership can be a viable strategy for producers to protect themselves against intensified competition with third parties and secondary markets under

RTR. This is especially the case for firms operating in markets where production is cheap and RTR has significant IP infringement implications. Interestingly, we find that RTR can also imply a stronger preference towards selling. This happens for firms operating in markets where production is expensive, RTR's effect on IP leakage is minimal, and independent repair options help increase consumer valuation of new products.

Although business model choice is an effective strategy to cope with RTR-induced competition, in general, it is likely not sufficient to eliminate the fall in producer profits. Surprisingly, however, some producers can benefit from RTR if they choose to sell under such regulations. Specifically, producers of high-cost items can enjoy the increased efficiency of independent repair markets provided that this increase does not present a major cost to the producer (i.e., the IPR violation risks are limited).

As a result of this business model choice, RTR does not necessarily increase repair volumes or bring environmental benefits. We find that RTR regulations can, in fact, reduce repair volumes, even for products with a low production cost. This result presents a departure from the current understanding in the literature (Jin et al. 2022) and is mainly due to the business model implications of RTR. That is, maintaining product ownership allows the producer to remove products off the market before the end of their useful life, effectively thwarting repair and reuse. As a result, for our case study products, we find that RTR can benefit the environment for mobile phones *only if* the reuse levels absent the regulation are significantly low (such that RTR effectively increases reuse even with premature disposal of products). In contrast, for washing machines, RTR is likely to increase new production (original and counterfeit) and harm the environment if the producer sticks to selling.

Our results also suggest a trade-off between the implications of RTR for consumers and the environment. For example, for mobile phones, the switch to non-ownership models under RTR can imply an environmental benefit, but also higher prices to consumers. For washing machines, a non-ownership business model would only be welcomed from an environmental perspective if it effectively reduces repair and reuse volumes, which implies a decrease in consumer surplus. Further numerical analyses suggest that these insights are robust to including endogenous repair and usage decisions in our model. In addition, we observe that RTR can curtail a producer's investment into innovation and product durability. Thus, additional economic levers (e.g., subsidies) may be necessary for policy effectiveness.

In light of these observations, we caution against blanket legislation such as the model RTR legislation in the U.S. (The Repair Association 2020). Instead, we recommend an analysis per product category (such as mobile phones and washing machines) considering production and disposal costs, the life-cycle environmental impact, and reuse volumes absent RTR regulation. We also recommend that RTR laws be crafted considering the competitive ecosystem in which firms operate and their potential strategic response in the form of business model choice. To our knowledge, this discussion is so far lacking in the (model) legislation, and the ambiguity around product ownership can complicate the interpretation of RTR regulations in practice (Ghosh 2022). We believe that forward-looking research such as ours is necessary to provide policymakers with the input they need today.

In closing, we note some directions for future research. In terms of the business model implications under RTR, we consider pure business models in this paper (i.e., the producer either sells or keeps ownership of all products), and it would be interesting to examine whether a hybrid business model (as in Huang et al. 2001) would be a viable option under RTR. In addition, there are concerns that under RTR, producers can use new business models to attract consumers to rapidly upgrade to a new product (Hollister 2022), which could be worth further investigation. Moreover, while this paper addresses IP implications, RTR may also have implications on the quality and safety of repairs. Some producers argue that allowing consumers and independent repairers without the necessary technical training to perform repairs would compromise the quality and safety of repairs and damage the brand image. Producers may also lose information on breakdowns that can be used to design newer versions of the product (DigitalEurope 2017).

Notes

[1] We also considered a case in which the competitor offers his product through a non-ownership model; the results are provided in the Supplemental Material for peer review.

[2] Due to decrease in efficiency with depreciation, used items may have a higher environmental impact than new items: $i_{u2} \geq i_{u1}$ (Intlekofer 2009, Agrawal et al. 2012).

[3] This is because competing products that infringe the IP of original equipment manufacturers are typically counterfeits, which is a growing problem in sectors affected by RTR, such as consumer electronics (OECD & EUIPO 2016).

[4] Since $\delta_{c0} \in [0, \delta_c)$, note that this could also capture a case where a non-existing competitor enters the market by producing a counterfeit.

[5] We have conducted a detailed numerical analysis (provided in the SM) which suggests that this assumption is without loss of generality. Our qualitative insights continue to hold for $\delta_{c0} > 0$. As expected, for a given δ_c, as δ_{c0} increases, the impact of RTR on increasing IPR infringement and third-party competition becomes less pronounced.

[6] This result rests on our modeling assumption that the low-end counterfeit has a shorter lifetime than the original product. Although realistic in many cases, if this assumption does not hold (i.e., the counterfeit has the same lifespan as the original product, two periods in our model), then the IP leakage under RTR increases both total new and used product quantities (original and counterfeit), and always hurts the environment.

Appendix A: Derivation of Optimal Decisions

For ease of exposition, in what follows, we use the same notation for the thresholds $\theta, \hat{f}, \hat{\delta_c}, \hat{\Omega}$ and the Lagrangian multipliers λ in each derivation and proof. These are in fact associated with different closed-form expressions, provided below.

A.1. Selling without RTR

Let $V_{s,n}^{NR}(\theta), V_{s,u}^{NR}(\theta), V_{s,c}^{NR}(\theta), V_i^{NR}(\theta)$ denote the net utility of consumer θ from purchasing a new original product, a used original product, and a counterfeit; and staying inactive, respectively. Without RTR, the consumers' willingness to pay for the counterfeit is a fraction δ_{c0} of that for a new product, and only a fraction f of all new products can be resold in the secondary market. There are at most four undominated consumer strategies: (i) buy new products in every period (N), (ii) buy used products in every period (U), (iii) buy a counterfeit in every period (C), (iv) stay inactive (I), with the following respective net utilities: (i) $V_{s,n}^{NR}(\theta) = \theta - p_{s,n}^{NR} + \rho f p_{s,u}^{NR}$,(ii) $V_{s,u}^{NR}(\theta) = \delta\theta - p_{s,u}^{NR}$, (iii) $V_{s,c}^{NR}(\theta) = \delta_c\theta - p_{s,c}^{R}$, (iv) $V_i^{NR}(\theta) = 0$. The differences $V_{s,n}^{NR}(\theta) - V_{s,u}^{NR}(\theta)$, $V_{s,u}^{NR}(\theta) - V_{s,c}^{NR}(\theta)$, and $V_{s,c}^{NR}(\theta) - V_i^{NR}(\theta)$ are increasing in θ. Therefore, there exist thresholds $\theta_1, \theta_2, \theta_3 \in [0,1]$ such that consumers of type $\theta \in (\theta_1, 1]$ always buy new, $\theta \in (\theta_2, \theta_1]$ always buy used, $\theta \in (\theta_3, \theta_2]$ always buy the counterfeit, and others remain inactive. Taking $\rho = 1$ and solving $V_{s,n}^{NR}(\theta_1) - V_{s,u}^{NR}(\theta_1) = 0, V_{s,u}^{NR}(\theta_2) - V_{s,c}^{NR}(\theta_2) = 0, V_{s,c}^{NR}(\theta_3) - V_i^{NR}(\theta_3) = 0$, we get these thresholds as: $\theta_1 = \frac{p_{s,n}^{NR} - (1+f)p_{s,u}^{NR}}{1-\delta}, \theta_2 = \frac{p_{s,u}^{NR} - p_{s,c}^{NR}}{\delta - \delta_{c0}}, \theta_3 = \frac{p_{s,c}^{NR}}{\delta_{c0}}$.

Solving $q_{s,n}^{NR} = 1 - \theta_1$, $q_{s,u}^{NR} = f q_{s,n}^{NR} = \theta_1 - \theta_2$, $q_{s,c}^{NR} = \theta_2 - \theta_3$ together, we get the inverse demand functions: $p_{s,n}^{NR} = 1 + f\delta - q_{s,n}^{NR}(1 + f(2+f)\delta) - (1+f)q_{s,c}^{NR}\delta_{c0}, p_{s,u}^{NR} = (1 - (1+f)q_{s,n}^{NR})\delta - q_{s,c}^{NR}\delta_{c0}, p_{s,c}^{NR} = \delta_{c0}(1 - q_{s,c}^{NR} - (1+f)q_{s,n}^{NR})$.

The competitor's problem. $\max_{q_{s,c}^{NR}} \; q_{s,c}^{NR} p_{s,c}^{NR}$, s.t. $q_{s,c}^{NR} \geq 0$, $1 - q_{s,n}^{NR} - q_{s,u}^{NR} - q_{s,c}^{NR} \geq 0$, $p_{s,n}^{NR} \geq 0$, $p_{s,u}^{NR} \geq 0$, $p_{s,c}^{NR} \geq 0$. It is easy to show that with $1 - q_{s,n}^{NR} - q_{s,u}^{NR} - q_{s,c}^{NR} \geq 0$, the constraints $p_{s,c}^{NR} \geq 0$ and $p_{s,u}^{NR} \geq 0$ are redundant. It can also be shown that the objective function is concave in $q_{s,c}^{NR}$. The Lagrangian function of this problem is: $\mathcal{L} = q_{s,c}^{NR} p_{s,c}^{NR} + \lambda_1(q_{s,c}^{NR}) + \lambda_2(1 - q_{s,n}^{NR} - q_{s,u}^{NR} - q_{s,c}^{NR}) + \lambda_3(p_{s,n}^{NR})$, with dual variables $\lambda_1, \lambda_2, \lambda_3 \geq 0$. In addition to the constraints, the optimal solution to this problem must satisfy the following first-order conditions and complementary slackness constraints: $\frac{\partial \mathcal{L}}{\partial q_{s,c}^{NR}} = 0, \lambda_1(q_{s,c}^{NR}) = 0, \lambda_2(1 - q_{s,n}^{NR} - q_{s,u}^{NR} - q_{s,c}^{NR}) = 0, \lambda_3(p_{s,n}^{NR}) = 0$. It follows that the optimal quantity is: $q_{s,c}^{NR*} = \frac{1-(1+f)q_{s,n}^{NR}}{2}$ where $1 \geq (1+f)q_{s,n}^{NR} \geq 0$.

The producer's problem. $\max_{q_{s,n}^{NR}} \; \Pi_s^{NR} = q_{s,n}^{NR}(p_{s,n}^{NR} - \kappa)$ s.t. $q_{s,n}^{NR} \geq 0$, $1 - q_{s,c}^{NR} - q_{s,n}^{NR} - q_{s,u}^{NR} \geq 0$, $p_{s,n}^{NR} \geq 0$, $p_{s,u}^{NR} \geq 0$, $p_{s,c}^{NR} \geq 0$. It can be shown that the constraint $p_{s,c}^{NR} \geq 0$ is redundant, and the producer's profit function is concave in $q_{s,n}^{NR}$. To solve for the Nash equilibrium, we plug $q_{s,c}^{NR*} = \frac{1-(1+f)q_{s,n}^{NR}}{2}$ into the producer's problem. The Lagrangian function of the producer's problem is $\mathcal{L} = q_{s,n}^{NR}(p_{s,n}^{NR} - \kappa) + \lambda_1(q_{s,n}^{NR}) + \lambda_2(1 - q_{s,c}^{NR} - (1+f)q_{s,n}^{NR}) + \lambda_3(p_{s,n}^{NR}) + \lambda_4(p_{s,u}^{NR})$ with the dual variables $\lambda_1, \lambda_2, \lambda_3, \lambda_4 \geq 0$. The optimal solution must satisfy the following first-order conditions and complementary slackness constraints: $\frac{\partial \mathcal{L}}{\partial q_{s,n}^{NR}} = 0,\ \ \lambda_1(q_{s,n}^{NR}) = 0,\ \ \lambda_2(1 - q_{s,c}^{NR} - (1+f)q_{s,n}^{NR}) = 0,\ \ \lambda_3(p_{s,n}^{NR}) = 0,\ \ \lambda_4(p_{s,u}^{NR}) = 0$. We assume that $2(\kappa - f\delta - 1) + (1+f)\delta_{c0} < 0$, so that production is profitable for the producer and the competitor, i.e. $q_{s,n}^{NR*}, q_{s,c}^{NR*} > 0$. In equilibrium, the new original and counterfeit quantities are:$q_{s,n}^{NR*} = -\frac{2\kappa+\delta_{c0}+f(\delta_{c0}-2\delta)-2}{4\delta f(f+2)-2\delta_{c0}(f+1)^2+4}$ and $q_{s,c}^{NR*} = \frac{1}{2}\left(\frac{(f+1)(2\kappa+\delta_{c0}+f(\delta_{c0}-2\delta)-2)}{4\delta f(f+2)-2\delta_{c0}(f+1)^2+4} + 1\right)$.

A.2. Selling under RTR

The equilibrium quantities and profits in this case can be derived simply by plugging in $f = 1$ and $\delta_{c0} = \delta_c$ in the equilibrium strategy under selling without RTR given in A.1. We assume that $\kappa < 1 + \delta - \delta_c$, so that production is profitable. This gives the following optimal quantities: $q_{s,n}^{R*} = \frac{\kappa+\delta-\delta_c+1}{6\delta-4\delta_c+2}$, $q_{s,c}^{R*} = \frac{\kappa+2\delta-\delta_c}{6\delta-4\delta_c+2}$.

A.3. Non-ownership

Let $V_{no,n}(\theta), V_{no,u}(\theta), V_{no,c}(\theta), V_i(\theta)$ denote the net utility of consumer θ from using a new and a used original product without ownership, purchasing a counterfeit, and staying inactive, respectively. There are at most four undominated consumer strategies: (i) consume new products in every period without ownership (N), (ii) consume used products in every period without ownership (U), (iii) buy a counterfeit in every period (C), (iv) stay inactive (I). The consumer strategies (i)-(iv) have the following respective net utilities: (i) $V_{no,n}(\theta) = \theta - p_{no,n}$,(ii) $V_{no,u}(\theta) = \delta\theta - p_{no,u}$, (iii)$V_{no,c}(\theta) = \delta_{c0}\theta - p_{no,c}$,(iv) $V_i(\theta) = 0$. The differences $V_{no,n}(\theta) - V_{no,u}(\theta)$, $V_{no,u}(\theta) - V_{no,c}(\theta)$, and $V_{no,u}(\theta) - V_i(\theta)$ are increasing in θ. There exist $\theta_1, \theta_2, \theta_3 \in [0,1]$ such that consumers of type $\theta \in (\theta_1, 1]$ always consume new products, $\theta \in (\theta_2, \theta_1]$ always consume used products, $\theta \in (\theta_3, \theta_2]$ always purchase counterfeits, and others remain inactive. Moreover, the threshold consumer is indifferent between the two options, that is: $V_{no,n}(\theta_1) = V_{no,u}(\theta_1)$, $V_{no,u}(\theta_2) = V_{no,c}(\theta_2)$, and $V_{no,u}(\theta_3) = V_i(\theta_3)$. This analysis gives $\theta_1 = \frac{p_{no,n}-p_{no,u}}{1-\delta}$, $\theta_2 = \frac{p_{no,u}-p_{no,c}}{\delta-\delta_{c0}}$, $\theta_3 = \frac{p_{no,c}}{\delta_{c0}}$.

The producer and the competitor compete in Cournot fashion. The inverse demand functions for the per-period fees of new and used products and the purchase price of the counterfeit are found by solving $q_{no,n}(p_{no,n}) = 1 - \theta_1$, $q_{no,u}(p_{no,u}) = \theta_1 - \theta_2$, and $q_{no,c}(p_{no,c}) = \theta_2 - \theta_3$ together: $p_{no,n} = 1 - q_{no,n} - q_{no,u}\delta - q_{no,c}\delta_{c0}$, $p_{no,u} = (1 - q_{no,n} - q_{no,u})\delta - q_{no,c}\delta_{c0}$, $p_{no,c} = (1 - q_{no,c} - q_{no,n} - q_{no,u})\delta_{c0}$.

The competitor's problem. $\max_{q_{no,c}}\ q_{no,c}p_{no,c}$ s.t. $q_{no,c} \geq 0,\ 1 - q_{no,n} - q_{no,u} - q_{no,c} \geq 0,\ p_{no,n} \geq 0,\ p_{no,u} \geq 0,\ p_{no,c} \geq 0$. It can be shown that the constraints $p_{no,n} \geq 0,\ p_{no,u} \geq 0,\ p_{no,c} \geq 0$ are redundant, and the objective function is concave in $q_{no,c}$. The Lagrangian function of the resulting problem is: $\mathcal{L} = q_{no,c}p_{no,c} + \lambda_1 q_{no,c} + \lambda_2(1 - q_{no,n} - q_{no,u} - q_{no,c})$, with the dual variables $\lambda_1, \lambda_2 \geq 0$. The optimal solution to this problem must satisfy the following first-order conditions and complementary slackness constraints: $\frac{\partial \mathcal{L}}{\partial q_{no,c}} = 0, \lambda_1 q_{no,c} = 0, \lambda_2(1 - q_{no,n} - q_{no,u} - q_{no,c}) = 0$. It follows that the optimal quantity of low-end product quantity in the market is $q_{no,c}^* = \frac{1-q_{no,n}-q_{no,u}}{2}$ where $1 \geq q_{no,n} + q_{no,u} \geq 0$

The producer's problem. $\max_{q_{no,n}, q_{no,u}}\ \Pi_{no} = q_{no,n}(p_{no,n} - \kappa - \gamma) + q_{no,u}p_{no,u}$, s.t. $q_{no,n} \geq q_{no,u},\ \ q_{no,u} \geq 0,\ \ 1 - q_{no,c} \geq q_{no,n} + q_{no,u}$. We assume that $\kappa + \gamma < 1 + \delta - \delta_{c0}$, such that production is profitable. It can be shown that the producer's profit function is concave in $q_{no,n}$. To solve for the Nash equilibrium, we plug $q_{no,c} = \frac{1-q_{no,n}-q_{no,u}}{2}$ into the producer's problem. Then the last constraint simplifies to $1 \geq q_{no,n} + q_{no,u}$. The Lagrangian function of this problem is $\mathcal{L} = q_{no,n}(p_{no,n} - \kappa - \gamma) + q_{no,u}p_{no,u} + \lambda_1(q_{no,n} - q_{no,u}) + \lambda_2 q_{no,u} + \lambda_3(1 - q_{no,n} - q_{no,u})$ with the dual variables $\lambda_1, \lambda_2, \lambda_3 \geq 0$. The optimal solution must satisfy the following first-order conditions and complementary slackness constraints: $\frac{\partial \mathcal{L}}{\partial q_{no,n}} = 0$, $\frac{\partial \mathcal{L}}{\partial q_{no,u}} = 0, \lambda_1(q_{no,n} - q_{no,u}) = 0, \lambda_2(q_{no,u}) = 0, \lambda_3(1 - q_{no,n} - q_{no,u}) = 0$. In equilibrium, the optimal strategy for the producer and the competitor depends on the production cost as follows. If $\frac{1-\delta}{2} \geq \kappa + \gamma > 0$, then partial remarketing is optimal (i.e. $q^*_{no,u} < q^*_{no,n}$): $q^*_{no,n} = \frac{1-\delta-\kappa-\gamma}{2(1-\delta)}, q^*_{no,u} = \frac{\kappa+\gamma}{2(1-\delta)}, q^*_{no,c} = 1/4$. If $1 + \delta - \delta_{c0} > \kappa + \gamma > \frac{1-\delta}{2}$, then full remarketing is optimal: $q^*_{no,n} = q^*_{no,u} = \frac{1+\delta-\delta_{c0}-\kappa-\gamma}{2(1-3\delta-2\delta_{c0})}, q^*_{no,c} = \frac{\kappa+\gamma+2\delta-\delta_c}{2(1-3\delta-2\delta_{c0})}$.

Appendix B: Calibrated Numerical Study

iPhones: We first determine the highest value for consumers' willingness to pay, θ. According to a survey in 2019, 10% of consumers are willing to make an upfront payment of \$2000 for the new iPhone (Simon-Kucher & Partners 2019). We therefore take $\theta = 2000$. We choose the iPhone 12 128GB as a representative product, with the price tag of \$849 at the time of writing (Apple 2021). We calculate the production cost by subtracting the profit margin from the price. Apple reports a 42.5% gross margin (Statista 2021), which gives (1-0.425)*849=\$488 as the production cost. Since our parameters are between 0 and 1, we divide them by θ to normalize, which gives $\kappa = 488/2000 = 0.244$. For the durability parameter δ, we use Alev et al. (2020)'s estimate of 0.15. We take the disposal cost parameter $\gamma = 0.035$. We use data from Apple to calculate the relative environmental impact in the second-period of use for an iPhone. 85% of total carbon emissions for an iPhone 12 are created during production and transportation phases, 14% during use, and 1% during disposal (Apple 2020). Taking $i_{u1} + i_{u2} = 0.14$ and assuming $i_{u1} = i_{u2}$, we get $\Omega = i_{u2}/(i_{u1} + i_p + i_d) = 0.075$. Due to lack of estimates, we plot the comparisons for various levels of f and δ_c.

Washing Machines: We first determine the highest value for consumers' willingness to pay, θ. The prices for washing machines vary highly between approximately \$250 to \$2500, with machines around the \$1000 price range being most popular. Due to lack of better estimates, we take $\theta = \$2000$. We choose LG WM4000H Black Steel as a representative product in the average price range, \$1100 at the time of writing (Yang et al. 2021). We calculate the production cost by subtracting the profit margin from the price. LG Electronics reports a 26.9% gross margin (Wall Street Journal 2021), which gives (1-0.269)*1100=\$803 as the production cost. Since our parameters are between 0 and 1, we normalize these estimates by dividing them by θ, which gives $\kappa = 803/2000 = 0.4015$. We estimate the durability parameter from the new and used product costs. To do this, we searched for posts for LG WM4000H on Ebay. On 8.07.2021, there was one such post, with a bid of \$450. We calculate the relative value of a used washing machine (\$450) to a new machine (\$1100): $\delta = 450/1100 = 0.409$. For washing machines, non-ownership is more common than it is for mobile phones, which suggests that the barriers for non-ownership instead of selling should be lower. In our model, this is represented by the additional disposal cost, hence we assume a lower disposal cost for a washing machine than an iPhone, $\gamma = 0.025$. The use-phase impact of a washing machine is 80-90% of total (Fishbein et al. 2000). Taking $i_{u1} + i_{u2} = 0.8$ and assuming $i_{u1} = i_{u2}$, we get $\Omega = i_{u2}/(i_{u1} + i_p + i_d) = 0.66$. Due to lack of estimates, we plot the comparisons for various levels of f and δ_c.

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E-Companion to: Business Model Choice under Right to Repair

Appendix EC.1: Proofs of Propositions

EC.1.1. Proof of Proposition 1

To prove Proposition 1, we first define the thresholds for the disposal cost below which non-ownership is more profitable than selling. We then compare these thresholds.

Lemma EC.1 (Disposal Cost Thresholds). *There exist thresholds* $\hat{\gamma}_j^i$ *for the disposal cost such that* $\Pi_{no}^* - \Pi_s^{i*} > 0$ *if* $\gamma < \hat{\gamma}_j^i$*, where* $i \in \{R, NR\}$ *denote the cases under and without RTR regulation and* $j \in \{1, 2\}$ *denote partial and full remarketing, respectively.*

Proof. Assume the production cost κ is sufficiently low that production in all scenarios is profitable. It can be shown that $\Pi_{no}^* - \Pi_s^{i*}$ is decreasing in γ for all $i \in \{R, NR\}$. Therefore, there exist thresholds $\hat{\gamma}_j^i, i \in \{R, NR\}, j \in \{1, 2\}$ that solve $\Pi_{no}^* = \Pi_s^{i*}$, and below which the producer prefers non-ownership. With $\delta_{c0} = 0$, these thresholds $\hat{\gamma}_j^i$ are given by $\hat{\gamma}_1^{NR} = \frac{X}{1+\delta f(f+2)}$ where $X = -1 + \delta + \kappa(1 + \delta f(f + 2)) - 1\delta f^2 + \delta^2 f^2 - 2\delta f + 2\delta^2 f + \sqrt{(1-\delta)(1+\delta f(f+2))\left(\kappa^2 - 2\kappa(1+\delta f) + (1-\delta)(1+2\delta f)\right)}$, $\hat{\gamma}_2^{NR} = 1 - \frac{\sqrt{(1+3\delta)(1+\delta f(f+2))(1-\kappa+\delta f)^2}}{1+\delta f(f+2)} - \kappa + \delta$, $\hat{\gamma}_1^R = 1 - \frac{\sqrt{(1-\delta)(1+3\delta-\delta_c)^2 y}}{(1+3\delta-\delta_c)^2} - \kappa - \delta$, $\hat{\gamma}_2^R = -\frac{\delta_c(\kappa+2\delta)}{-1-3\delta+\delta_c}$ where $Y = \left(\delta\left(16 + 3\kappa^2 - 8\kappa + 6\kappa\delta_c + 2\delta_c^2 - 6\delta_c\right) + \delta^2(1-6\kappa) + (-1+\kappa+\delta_c)^2 - 6\delta^3\right)$ □.

Having defined the disposal cost thresholds under and without RTR, we now prove Proposition 1 by comparing these thresholds to determine the conditions under which RTR makes non-ownership more attractive, i.e. $\hat{\gamma}_j^R > \hat{\gamma}_j^{NR}$, $j \in \{1, 2\}$.

Comparison of Disposal Cost Thresholds. The thresholds under RTR $\hat{\gamma}_j^R$ are functions of δ_c. The thresholds without RTR $\hat{\gamma}_j^{NR}$ are functions of f. It can be shown that $\hat{\gamma}_j^R$ are increasing in δ_c. Hence the differences $\hat{\gamma}_1^R(\delta_c) - \hat{\gamma}_1^{NR}(f)$, and $\hat{\gamma}_2^R(\delta_c) - \hat{\gamma}_2^{NR}(f)$ are increasing in δ_c. At the boundaries of $\delta_c \in (0, \delta)$ and $f \in (0, 1)$, we have the following: (i) $\hat{\gamma}_1^R(0) - \hat{\gamma}_1^{NR}(0) < 0$ if $\kappa > \frac{2-\sqrt{1+3\delta}}{3}$ and $\hat{\gamma}_2^R(0) - \hat{\gamma}_2^{NR}(0) < 0$. (ii) $\hat{\gamma}_1^R(0) - \hat{\gamma}_1^{NR}(1) = 0$ and $\hat{\gamma}_2^R(0) - \hat{\gamma}_2^{NR}(1) = 0$. (iii) $\hat{\gamma}_1^R(\delta) - \hat{\gamma}_1^{NR}(0) > 0$ and $\hat{\gamma}_2^R(\delta) - \hat{\gamma}_2^{NR}(0) > 0$. (iv) $\hat{\gamma}_1^R(\delta) - \hat{\gamma}_1^{NR}(1) > 0$ and $\hat{\gamma}_2^R(\delta) - \hat{\gamma}_2^{NR}(1) > 0$. There exist $\hat{\delta}_{c,j} \in (0, \delta)$ such that $\hat{\gamma}_j^R(\delta_c) - \hat{\gamma}_j^{NR}(f) = 0$ for all $f \in (0, 1)$. Above $\hat{\delta}_{c,j}$, $\hat{\gamma}_j^R(\delta_c) - \hat{\gamma}_j^{NR}(f) > 0$, hence RTR makes non-ownership more attractive. These $\hat{\delta}_{c,j}(f)$ are given by: $\hat{\gamma}_1^R(\delta_c) - \hat{\gamma}_1^{NR}(f) = 0$ if $\hat{\delta}_{c,1}(f) = \frac{(1+3\delta)\left(-\kappa^2+\kappa\left(1-\delta f^2\right)+\delta\left(1+f^2+2\delta f\right)\right)}{\left(-\kappa^2+2\kappa(1+\delta f)+\delta\left(1\left(f^2+3\right)+2\delta f(f+3)\right)\right)} - \frac{\sqrt{(1+3\delta)(\kappa+2\delta)^2(1+\delta f(f+2))(1-\kappa+\delta f)^2}}{\left(-\kappa^2+2\kappa(1+\delta f)+\delta\left(1\left(f^2+3\right)+2\delta f(f+3)\right)\right)}$. It can be shown that $\hat{\delta}_{c,1}(f) < 0$ if $\kappa < \frac{f(1-\delta)}{1+f}$ and $\frac{\partial \delta_{c,1}}{\partial f} < 0$ if $\kappa > \frac{f(1-\delta)}{1+f}$. That is, the level of δ_c at which the disposal costs are equal is less than zero, thus RTR makes non-ownership more attractive for all feasible values of δ_c and f. Under full remarketing, $\hat{\gamma}_2^R(\delta_c) - \hat{\gamma}_2^{NR}(f) = 0$ if $\hat{\delta}_{c,2}(f) = \frac{(1-\kappa+\delta)(1+\delta f(f+2))+(1-\kappa+\delta f)\sqrt{(1+3\delta)(1+\delta f(f+2))}}{(1+\delta f(f+2))-(1-\kappa+\delta f)\sqrt{(1+3\delta)(1+\delta f(f+2))}}$.

EC.1.2. Proof of Proposition 2

The change in producer profits due to RTR depends on the producer's business model choice without and under RTR as follows: (i) If $\gamma < \min(\hat{\gamma}^{NR}, \hat{\gamma}^{R})$, non-ownership domimates selling both without and under RTR, there is no change in producer profits due to RTR: $\Delta\Pi = \Pi_{no}^{*} - \Pi_{no}^{*} = 0$. (ii) If $\hat{\gamma}^{R} > \gamma > \hat{\gamma}^{NR}$, the producer chooses selling without RTR and non-ownership under RTR. This means that without RTR, non-ownership dominates selling , i.e. $\Pi_{s}^{NR*} > \Pi_{no}^{*}$, and hence $\Delta\Pi = \Pi_{no}^{*} - \Pi_{s}^{NR*} < 0$. (iii) If $\hat{\gamma}^{NR} > \gamma > \hat{\gamma}^{R}$, the producer chooses non-ownership without RTR and selling under RTR. This means that under RTR, selling dominates non-ownership, i.e. $\Pi_{s}^{R*} > \Pi_{no}^{*}$ and hence $\Delta\Pi = \Pi_{s}^{R*} - \Pi_{no}^{*} > 0$. (iv) If $\gamma > \max(\hat{\gamma}^{NR}, \hat{\gamma}^{R})$, the producer chooses selling both without and under RTR. Π_{s}^{R*} decreases in δ_c, hence $\Delta\Pi = \Pi_{s}^{R*} - \Pi_{s}^{NR*}$ decreases. $\Delta\Pi = 0$ at $\delta_c = \hat{\delta}_c = \frac{-(3\delta+1)\left(-\kappa^2-\kappa\delta f^2+\kappa+\delta\left(f^2+2\delta f+1\right)\right)+\sqrt{(3\delta+1)(\kappa+2\delta)^2(\delta f(f+2)+1)(-\kappa+\delta f+1)^2}}{\kappa^2-2\kappa(\delta f+1)-\delta\left((2\delta+1)f^2+6\delta f+3\right)}$ and $\Delta\Pi < 0$ if $\delta_c > \hat{\delta}_c$.

EC.1.3. Proof of Proposition 3

Recall that the total environmental impact is determined by the volume of products in each life-cycle phase, and the environmental per product in that life-cycle phase. To prove Proposition 3, we first determine the change in new and used product quantities due to RTR. We then investigate the change in total environmental impact.

Lemma EC.2 (Change in New and Used Product Quantities)**.** *Let ΔQ_n denote the difference in total new production volume (original and counterfeit) in the market under and without RTR. Similarly, let ΔQ_u denote the difference in the secondary market quantity under and without RTR. (1) If $\gamma < \min(\hat{\gamma}^{NR}, \hat{\gamma}^{R})$, RTR does not lead to a change in new and used product quantities, i.e. $\Delta Q_n = q_{no,n}^{*} - q_{no,n}^{*} = 0$, $\Delta Q_u = q_{no,u}^{*} - q_{no,u}^{*} = 0$. (2) If $\hat{\gamma}^{NR} > \gamma > \hat{\gamma}^{R}$, RTR increases the total production volume, i.e. $\Delta Q_n = q_{s,n}^{R*} + q_{s,c}^{R*} - q_{no,n}^{*} > 0$. There exists a threshold $\hat{\delta}_c$ such that RTR decreases the used product quantity, i.e. $\Delta Q_u = q_{s,u}^{R*} - q_{no,u}^{*} < 0$, if $\delta_c > \hat{\delta}_c$. (3) If $\hat{\gamma}^{R} > \gamma > \hat{\gamma}^{NR}$, there exists a threshold on the secondhand availability without RTR, $\hat{f}$, such that RTR decreases the new quantity and increases the used quantity, i.e. $\Delta Q_n = q_{no,n}^{*} - q_{s,n}^{NR*} < 0$, $\Delta Q_u = q_{no,u}^{*} - q_{s,u}^{NR*} > 0$ if $f < \hat{f}$. On the other hand, if $f > \hat{f}$ and partial remarketing is optimal under non-ownership, then RTR increases the new quantity and decreases the used quantity, i.e. $\Delta Q_n > 0$, $\Delta Q_u < 0$. If $f > \hat{f}$ and full remarketing is optimal, then RTR decreases both new and used quantities, i.e. $\Delta Q_n < 0, \Delta Q_u < 0$. (4) If $\gamma > \max(\hat{\gamma}^{NR}, \hat{\gamma}^{R})$, RTR increases the total production volume, i.e. $\Delta Q_n = q_{s,n}^{R*} - q_{s,n}^{NR*} > 0$. There exists a threshold on the relative wtp for the counterfeit as a function of the secondhand availability, $\hat{\delta}_c(f)$, such that RTR decreases the used product quantity, i.e. $\Delta Q_u = q_{s,u}^{R*} - q_{s,u}^{NR*} < 0$, if $\delta_c > \hat{\delta}_c(f)$.*

Proof. (1) If $\gamma < \min(\hat{\gamma}^{NR}, \hat{\gamma}^{R})$, the producer retains ownership both under and without RTR and there is no difference in product quantities.

(2) If $\hat{\gamma}^{NR} > \gamma > \hat{\gamma}^{R}$, the producer retains ownership in the absence of RTR and sells under RTR. Thus, under RTR, the total new production quantity is the sum of new original products and counterfeits produced at each period, $q_{s,n}^{R*} + q_{s,c}^{R*} = 1/2$. Under a non-ownership business model, it can be shown that $q_{no,n}^{*} < 1/2$. Therefore, the total production quantity increases due to RTR. To compare the used quantities, note that $q_{s,u}^{R*}$ decreases with δ_c. Hence, $q_{s,u}^{R*} - q_{no,u}^{*}$ decreases with δ_c. When partial remarketing is optimal, $q_{s,u}^{R*} - q_{no,u}^{*} = 0$ at $\delta_c = \hat{\delta}_c$ and $q_{s,u}^{R*} - q_{no,u}^{*} > 0$ if $\delta_c < \hat{\delta}_c$. $\hat{\delta}_c = \frac{-1+2\kappa(1+\delta)+\delta^2+\gamma(1+3\delta)}{(-1+\kappa+\delta+\gamma)}$ when partial remarketing is optimal under non-ownership, and $\hat{\delta}_c = \frac{\gamma(1+3\delta)}{(\kappa+2\delta+\gamma)}$ when full remarketing is optimal.

(3) If $\hat{\gamma}^{R} > \gamma > \hat{\gamma}^{NR}$, the producer sells in the absence of RTR and keeps ownership under RTR. When partial remarketing is optimal, $q_{s,n}^{NR*}$ decreases in f if $\kappa < \frac{1+f(2+f\delta)}{1+f}$. This condition holds in the range of the production cost κ where partial remarketing is optimal, i.e. when $\frac{1-\delta}{2} > \kappa > 0$. $q_{no,n}^{*} - q_{s,n}^{NR*}$ hence increases in f, and equals to zero at $f = \hat{f} = -\frac{\sqrt{\delta(\delta-1)\left(4\gamma(-1+\kappa+\gamma)+\delta^2+\delta(4\gamma-1)\right)}+\delta(-1+2\kappa+\delta+2\gamma)}{2\delta(-1+\kappa+\delta+\gamma)}$ and $q_{no,n}^{*} - q_{s,n}^{NR*} > 0$ if $f > \hat{f}$. That is, the switch to non-ownership causes an increase (decrease) in the new quantity when f is high (low). $q_{s,u}^{NR*}$ increases in f, hence $q_{no,u}^{*} - q_{s,u}^{NR*}$ decreases. $q_{no,u}^{*} - q_{s,u}^{NR*} = 0$ at $f = \hat{f} = -\frac{\sqrt{1-\delta}\sqrt{\kappa^2(-(\delta-1))+\kappa(\delta(2-4\gamma)-2)-\delta\left(4\gamma^2+1\right)+1}+\kappa\delta+\kappa+\delta+2\delta\gamma-1}{2\delta(\kappa+\delta+\gamma-1)}$. Hence $q_{no,u}^{*} - q_{s,u}^{NR*} < 0$ if $f > \hat{f}$. That is, the switch to non-ownership causes a decrease (increase) in the used quantity when f is high (low). When full remarketing is optimal,$q_{s,n}^{NR*}$ decreases in f, hence $q_{no,n}^{*} - q_{s,n}^{NR*}$ increases, if $\kappa < \frac{1+f(2+f\delta)}{1+f}$. $q_{no,n}^{*} - q_{s,n}^{NR*} = 0$ at $f = \hat{f} = \frac{\sqrt{\delta\left(\delta(-1+2\kappa+\delta+2\gamma)^2-4(-1+\kappa-\delta+\gamma)(2\delta-3\kappa\delta+\gamma)\right)}+\delta-2\kappa\delta-\delta^2-2\delta\gamma}{2\delta(-1+\kappa-\delta+\gamma)}$. It follows that $q_{no,n}^{*} - q_{s,n}^{NR*} > 0$ if $f > \hat{f}$ and $\kappa < \frac{1+f(2+f\delta)}{1+f}$. $q_{s,u}^{NR*}$ increases in f, hence $q_{no,u}^{*} - q_{s,u}^{NR*}$ decreases. $q_{no,u}^{*} - q_{s,u}^{NR*} = 0$ at $f = \hat{f} = \frac{-1-\delta+\kappa(1+\delta)+2\delta^2-2\delta\gamma+x}{2\delta(\kappa+2\delta+\gamma)}$ where $x = \sqrt{(1+\delta-\kappa(1+\delta)+2\delta(\gamma-\delta))^2+4\delta(\kappa+2\delta+\gamma)(1-\kappa+\delta-\gamma)}$, and $q_{no,u}^{*} - q_{s,u}^{NR*} < 0$ if $f > \hat{f}$.

(4) If $\gamma > \max(\hat{\gamma}^{R}, \hat{\gamma}^{NR})$, the producer sells both under and without RTR. It can be shown that $q_{s,n}^{NR*} < 1/2$. Therefore, RTR leads to an increase in the total production volume, since under RTR, $q_{s,n}^{R*} + q_{s,c}^{R*} = 1/2$. For the change in the used quantity as a result of RTR, note that $q_{s,u}^{R*} - q_{s,u}^{NR*}$ decreases in δ_c since $q_{s,u}^{R*}$ decreases. $q_{s,u}^{R*} - q_{s,u}^{NR*} = 0$ at $\delta_c = \hat{\delta}_c(f) = -\frac{(f-1)\left(1+\delta-\kappa+\kappa\delta f+2\delta^2 f\right)}{(1+\kappa f-f+2\delta f)}$ and $q_{s,u}^{R*} > q_{s,u}^{NR*}$ if $\delta_c < \hat{\delta}_c(f)$.

Change in Total Environmental Impact. Assume for simplicity $i_{pc} = i_p$, $i_{dc} = i_d$, and $i_{uc} = i_{u1}$. Let $\Omega = \frac{i_{u2}}{i_p+i_d+i_{u1}}$.

(1) If $\gamma < \min(\hat{\gamma}^{NR}, \hat{\gamma}^{R})$, $\Delta E = E_{no} - E_{no} = 0$.

(2) If $\hat{\gamma}^{NR} > \gamma > \hat{\gamma}^{R}$, $\Delta E = E_s^R - E_{no}$. The total environmental impact of selling under RTR and non-ownership are given by: $E_s^R = (i_p + i_d + i_{u1})(q_{s,n}^{R*} + q_{s,c}^{R*}) + i_{u2} q_{s,u}^{R*}$ and $E_{no} = (i_p + i_d + i_{u1}) q_{no,n}^{*} + i_{u2} q_{no,u}^{*}$. From Lemma EC.2, if $\delta_c < \hat{\delta}_c$, $q_{s,n}^{R*} + q_{s,c}^{R*} > q_{no,n}^{*}$ and $q_{s,u}^{R*} > q_{no,u}^{*}$, therefore $E_s^R > E_{no}$ for all i_p, i_d, i_{u1}, i_{u2}. On the other hand, if $\delta_c > \hat{\delta}_c$, it follows from Lemma EC.2 that ΔE decreases in i_{u2}, hence in Ω. When partial remarketing is optimal under non-ownership, the difference $\Delta E = 0$ at $\Omega = \hat{\Omega} = \frac{(1+3\delta)(\kappa+\gamma)(-1-3\delta+\delta_c)}{(1-\delta)(-\kappa\delta_c-\delta_c(2\delta+\gamma)+\gamma(1+3\delta))}$ and $\Delta E < 0$ if $\Omega > \hat{\Omega}$. When full remarketing is optimal under non-ownership, the same argument follows. The difference $\Delta E = 0$ if $\Omega = \hat{\Omega} = -\frac{(\kappa+2\delta+\gamma)(-1-3\delta+\delta_c)}{\kappa\delta_c+\delta_c(2\delta+\gamma)-\gamma(1+3\delta)}$ and $\Delta E < 0$ if $\Omega > \hat{\Omega}$.

(3) If $\hat{\gamma}^{R} > \gamma > \hat{\gamma}^{NR}$, $\Delta E = E_{no} - E_s^{NR}$. The environmental impact of selling and non-ownership are given by: $E_{no} = (i_p + i_d + i_{u1}) q_{no,n}^{*} + i_{u2} q_{no,u}^{*}$ and $E_s^{NR} = (i_p + i_d + i_{u1}) q_{s,n}^{NR*} + i_{u2} q_{s,u}^{NR*}$. When $f < \hat{f}$, from Lemma EC.2 we have that $q_{no,n}^{*} < q_{s,n}^{NR*}$ and $q_{no,u}^{*} > q_{s,u}^{NR*}$. ΔE increases in i_{u2}, hence in Ω. When partial remarketing is optimal, $\Delta E = 0$ at $\Omega = \hat{\Omega} = \frac{(1+3\delta)(\delta(-(f+1))(\kappa f+\kappa-f+\delta f)-\gamma(1+\delta f(f+2)))}{(1-\delta)\left(\kappa(f-1)(\delta f-1)+\gamma(1+\delta f(f+2))+(f-1)\left(1+\delta+2\delta^2 f\right)\right)}$ and $\Delta E < 0$ if $\Omega < \hat{\Omega}_3$. When full remarketing is optimal, $\Delta E = 0$ at $\Omega = \hat{\Omega} = \frac{\kappa(f-1)(\delta f-1)-\delta+\delta\gamma f^2+2\delta\gamma f+\gamma+2\delta^2 f^2-2\delta^2 f+\delta f+f-1}{\delta(f-1)(-\kappa(f+3)+\delta f+f+2)-\gamma\left(\delta f^2+2\delta f+1\right)}$ and $\Delta E < 0$ if $\Omega < \hat{\Omega}$. When $f > \hat{f}$ and partial remarketing is optimal, from Lemma EC.2, we have $q_{no,n}^{*} > q_{s,n}^{NR*}$ and $q_{no,u}^{*} < q_{s,u}^{NR*}$. ΔE decreases in i_{u2}, hence in Ω. $\Delta E = 0$ at $\Omega = \hat{\Omega}$ and $\Delta E < 0$ if $\Omega > \hat{\Omega}$. When $f > \hat{f}$ and full remarketing is optimal, from Lemma EC.2, we have $q_{no,n}^{*} < q_{s,n}^{*}$ and $q_{no,u}^{*} < q_{s,u}^{NR*}$. $\Delta E < 0$ for all i_p, i_d, i_{u1}, i_{u2}.

(4) If $\gamma > \max(\hat{\gamma}^{R}, \hat{\gamma}^{NR})$, $\Delta E = E_s^R - E_s^{NR}$. The environmental impacts of selling under and in the absence of RTR are given by: $E_s^R = (i_p + i_d + i_{u1})(q_{s,n}^{R*} + q_c^{R*}) + i_{u2} q_{s,u}^{R*}$ and $E_s^{NR} = (i_p + i_d + i_{u1}) q_{s,n}^{NR*} + i_{u2} q_{s,u}^{NR*}$. From Lemma EC.2, if $\delta_c < \hat{\delta}_c(f)$, $q_{s,n}^{R*} + q_{s,c}^{R*} > q_{no,n}^{*}$ and $q_{s,u}^{R*} > q_{no,u}^{*}$. It follows that $\Delta E > 0$ for all i_p, i_d, i_{u1}, i_{u2}. On the other hand, if $\delta_c > \hat{\delta}_c(f)$, the difference ΔE decreases in i_{u2}, hence in Ω.The difference is zero at: $\Omega = \hat{\Omega} = \frac{(\kappa+\delta f(f+1))(-1-3\delta+\delta_c)}{-\kappa(\delta_c f+(f-1)(\delta f-1))+\delta_c((f-1)-2\delta f)-(f-1)\left(2\delta+2\delta^2 f\right)}$ and $\Delta E < 0$ if $\Omega > \hat{\Omega}$.

EC.1.4. Proof of Proposition 4

Under non-ownership, consumers with the taste parameter $\theta \in [\theta_1, 1]$ consume a new product in every period, consumers with $\theta \in [\theta_2, \theta_1)$ consume a used product in every period, and consumers with $\theta \in [0, \theta_2)$ stay inactive. From A, these thresholds are $\theta_1 = \frac{p_{no,n}-p_{no,u}}{1-\delta}$ and $\theta_2 = \frac{p_{no,u}}{\delta}$. Consumer θ gets net utility $\theta - p_{no,n}$ from consuming a new product and $\delta\theta - p_{no,u}$ from consuming a used product. Hence, under non-ownership, the total consumer surplus is given by: $S_{no} = \int_{\frac{p_{no,n}-p_{no,u}}{1-\delta}}^{1} (\theta - p_{no,n}) d\theta + \int_{\frac{p_{no,u}}{\delta}}^{\frac{p_{no,n}-p_{no,u}}{1-\delta}} (\delta\theta - p_{no,u}) d\theta$. This equals $S_{no} = -\frac{\kappa^2+2\kappa(\delta+\gamma-1)-\delta+\gamma^2+2(\delta-1)\gamma+1}{8(\delta-1)}$ under partial remarketing, and $S_{no} = \frac{(\kappa-\delta+\gamma-1)^2}{24\delta+8}$ under full remarketing.

If the producer chooses selling in the absence of RTR, plugging in the consumer segments and net utilities derived in A, the total consumer surplus is: $S_s^{NR} = \int_{\frac{p_{s,n}^{NR}-(1+f)p_{s,u}^{NR}}{1-\delta}}^{1} (\theta - p_{s,n}^{NR} + f p_{s,u}^{NR}) d\theta + \int_{\frac{p_{s,u}^{NR}}{\delta}}^{\frac{p_{s,n}^{NR}-(1+f)p_{s,u}^{NR}}{1-\delta}} (\delta\theta - p_{s,u}^{NR}) d\theta = \frac{(-\kappa+\delta f+1)^2}{8\left(\delta f^2+2\delta f+1\right)}$. Furthermore, it can be shown that S_s^{NR} increases in f if $\kappa > \frac{f(1-\delta)}{1+f}$.

If the producer chooses selling under RTR, plugging in the consumer segments and net utilities derived in A, the total consumer surplus is: $S_s^R = \int_{\frac{p_{s,n}^R-2p_{s,u}^R}{1-\delta}}^{1} (\theta - p_{s,n}^R + p_{s,u}^R) d\theta + \int_{\frac{p_{s,u}^R-p_{s,c}^R}{\delta-\delta_c}}^{\frac{p_{s,n}^R-2p_{s,u}^R}{1-\delta}} (\delta\theta - p_{s,u}^R) d\theta + \int_{\frac{p_{s,c}^R}{\delta_c}}^{\frac{p_{s,u}^R-p_{s,c}^R}{\delta-\delta_c}} (\delta_c\theta - p_{s,c}^R) d\theta$ and $S_s^R = \frac{(\delta+1)^2(3\delta+1)+(1-5\delta)\delta_c^2+\left(6\delta^2-2\right)\delta_c+\kappa^2(3\delta-3\delta_c+1)-2\kappa\left(3\delta^2+4\delta+2\delta_c^2-3(\delta+1)\delta_c+1\right)}{8(-3\delta+\delta_c-1)^2}$ Furthermore, it can be shown that S_s^R increases in δ_c.

We can now analyze the change in total consumer surplus as a result of RTR:

(1) If $\gamma < \min(\hat{\gamma}^{NR}, \hat{\gamma}^R)$, $\Delta S = S_{no} - S_{no} = 0$.

(2) If $\hat{\gamma}^{NR} > \gamma > \hat{\gamma}^R$, and partial remarketing is optimal under non-ownership, $\Delta S = S_s^R - S_{no}$ also increases in δ_c, and $\Delta S = 0$ if $\delta_c = \hat{\delta}_c = \frac{X}{2\left(\kappa^2+2\kappa(-\delta+\gamma+1)-5(\delta-1)\delta+\gamma^2+2(\delta-1)\gamma\right)}$ where $X = -6\delta^3 + 6\delta + 6\delta\gamma^2 + 2\gamma^2 + 12\delta^2\gamma - 8\delta\gamma - 4\gamma + 9\kappa^2\delta + \sqrt{\delta-1}(\kappa+2\delta) - \kappa^2 + 6\kappa\delta^2 - 8\kappa\delta + 12\kappa\delta\gamma + 4\kappa\gamma + 2\kappa + \sqrt{\kappa^2(33\delta-1) + 4\kappa\left(6\delta^2 - 7\delta + 4(3\delta+1)\gamma + 1\right) + 4\left(6\delta^3 - 4\delta^2 - \delta + (6\delta+2)\gamma^2 + 4\left(3\delta^2 - 2\delta - 1\right)\gamma - 1\right)}$. $\Delta S > 0$ if $\delta_c > \hat{\delta}_c$. It can be shown that when partial remarketing is optimal, i.e. $(1-\delta)/2 > \kappa + \gamma > 0$, $\hat{\delta}_c < 0$, therefore, $\Delta S > 0$ for all values of δ_c. Similarly, when full remarketing is optimal, the difference in consumer surplus $\Delta S = S_s^R - S_{no}$ increases in δ_c. $\Delta S = 0$ if $\delta_c = \hat{\delta}_c = X/Y$ where $X = 2\delta(\gamma^2 - 2(\delta+1)\gamma) + \kappa(3\delta+1)(2\delta + 4\gamma + 2) + (3\delta+1)\left(\kappa\left(-\sqrt{\kappa^2 - 4\kappa(2\delta+4\gamma+1) + 4\left((2\delta+1)^2 - 2\gamma^2 + 4(\delta+1)\gamma\right)}\right) - \kappa^2\right) + 2\left(\delta\left(-\sqrt{\kappa^2 - 4\kappa(2\delta+4\gamma+1) + 4\left((2\delta+1)^2 - 2\gamma^2 + 4(\delta+1)\gamma\right)} + 4\delta + 2\right)\right)$ and $Y = 2\left(\kappa^2 + 2\kappa(5\delta+\gamma+1) + 4\delta(4\delta+1) + \gamma^2 - 2(\delta+1)\gamma\right)$ and $\Delta S > 0$ if $\delta_c > \hat{\delta}_c$. It can be shown that when $1+\delta > \kappa+\gamma > (1-\delta)/2$, $\hat{\delta}_c < 0$. Thus, $\Delta S > 0$ for all permissible values of δ_c.

(3) If $\hat{\gamma}^R > \gamma > \hat{\gamma}^{NR}$, $\Delta S = S_{no} - S_s^{NR} > 0$. If partial remarketing is optimal under non-ownership, i.e. $\kappa < f(1-\delta)/(1+f)$, S_s^{NR} decreases in f, therefore ΔS increases. $\Delta S = 0$ at $f = \hat{f} = \frac{X}{\delta(\kappa+\delta+\gamma-1)^2}$ where $X = \kappa^2(-\delta) - \kappa\delta^2 + \kappa\delta - 2\kappa\delta\gamma - \delta\gamma^2 - 2\delta^2\gamma + 2\delta\gamma + \sqrt{(\delta-1)\delta\gamma\left(2\kappa^3 + \kappa^2(6\delta+5\gamma-6) + 2\kappa Y - (\delta-1)^2 + \gamma^3 + 4(\delta-1)\gamma^2 + \left(4\delta^2 - 9\delta + 5\right)\gamma\right)}$ and $Y = \left(2\delta^2 - 5\delta + 2\gamma^2 + 5(\delta-1)\gamma + 3\right)$. Then $\Delta S > 0$ if $f > \hat{f}$. It can be shown that when partial remarketing is optimal, $\hat{f} > 1$, therefore $\Delta S < 0$ for all permissible values of f. If full remarketing is optimal

under non-ownership, i.e. $\kappa > f(1-\delta)/(1+f)$, S_s^{NR} increases in f, therefore ΔS decreases. $\Delta S = 0$ at $f = \hat{f} = \frac{-\left(\kappa^2\delta+\kappa\delta(\delta+2\gamma-1)+\delta^3-\delta^2+\delta\gamma^2-2\delta^2\gamma-2\delta\gamma\right)+\sqrt{\delta(\kappa-\delta+\gamma-1)^2\left(\delta(2\kappa+\delta-1)^2+2(\delta-1)\gamma(\kappa-\delta-1)+(\delta-1)\gamma^2\right)}}{\delta\left(\kappa^2+2\kappa(-\delta+\gamma-1)-2\delta^2+\delta+\gamma^2-2(\delta+1)\gamma+1\right)}$

It can be shown that $1 > \hat{f} > 0$, for $\kappa > f(1-\delta)/(1+f)$. Therefore, $\Delta S < 0$ if $f > \hat{f}$. (4) If $\gamma > \max(\hat{\gamma}^{NR}, \hat{\gamma}^{R})$, S_s^R increases in δ_c, hence $\Delta S = S_s^R - S_s^{NR}$ increases. $\Delta S = 0$ at $\delta_c = \hat{\delta}_c(f) = \frac{x\sqrt{z}+6\kappa^2\delta+6\delta^2+6\delta+12\delta^3 f^2+2\delta^2 f^2-2\delta f^2+12\delta^3 f+12\delta^2 f-3\kappa^2\delta f^2-6\kappa^2\delta f-\kappa^2-6\kappa\delta+6\kappa\delta^2 f^2+6\kappa\delta f^2+8\kappa\delta f+2\kappa}{2\left(\kappa^2+\kappa\left(4\delta f^2+6\delta f+2\right)+\delta\left((6\delta-1)f^2+10\delta f+5\right)\right)}$ where $x = (\kappa + 2\delta)\sqrt{\delta f^2+2\delta f+1}$, $y = \kappa\left(6\delta^2 f^2+\delta\left(5f^2+6f-6\right)+1\right)$, and $z = \sqrt{\kappa^2\left(3\delta\left(3f^2+6f-8\right)+1\right)-4y+4\left(\delta^2\left(6f^2+4f+6\right)+\delta\left(3f^2+2f+2\right)+12\delta^3 f+1\right)}$. Finally, it can be shown that $\Delta S > 0$ if $\delta_c > \hat{\delta}_c(f)$.

Appendix EC.2: Extensions

EC.2.1. Endogenous Repair Decisions.

For simplicity, in the analysis below, we take $c_i^{NR} \longrightarrow \infty$ and $\delta_{c0} \longrightarrow 0$. We also assume no quality difference between producer repair and independent repair, and no transaction costs in the secondary market. For a detailed treatment of these issues, please see Jin et al. (2022).

EC.2.1.1. Selling under RTR. **Consumer Demand.** As in our main model, ceteris paribus, each consumer $\theta \in [0,1]$ prefers consuming a new product to a used one and a used one to a counterfeit, and the counterfeit to staying inactive, associated with gross utilities θ, $\delta\theta$, $\delta_c\theta$ and 0, respectively. There are at most four undominated consumer strategies with repeated actions: (i) buy a new product in every period and sell it in the secondary market with per-period net utility $V_n(\theta) = \theta - p_{s,n}^R + \rho(1-\xi)p_{s,u}^R + \rho\xi[p_{s,u}^R - \min(c_i^R, c_r^R)]^+$, (ii) buy a used product from the secondary market in every period with per-period net utility $V_u(\theta) = \delta\theta - p_{s,u}^R$, (iii) buy a counterfeit every period with per-period net utility $V_c(\theta) = \delta_c\theta - p_{s,c}^R$, and (iv) stay inactive with per-period net utility 0. A consumer who buys a new product in each period, sells their product in the secondary market if the product does not fail, with probability $(1-\xi)$. If the product fails, they decide on their repair probability $\nu \in [0,1]$ as follows: (i) if $p_{s,u}^R < \min(c_i^R, c_r^R)$, no consumers repair, $\nu = 0$; (ii) if $p_{s,u}^R > \min(c_i^R, c_r^R)$, all consumers repair, $\nu = 1$; (iii) if $p_{s,u}^R = \min(c_i^R, c_r^R)$, consumers are indifferent between repairing or scrapping the item and they play a mixed strategy where a fraction $\nu \in (0,1)$ of consumers repair.

It is straightforward to show that the differences $V_n(\theta) - V_u(\theta)$, $V_u(\theta) - V_c(\theta)$, and $V_c(\theta) - 0$ increase in θ. Therefore, there exist thresholds $\theta_1 \geq \theta_2$ where consumers with $\theta \in (\theta_1, 1]$ buy a new product every period, consumers with $\theta \in (\theta_2, \theta_1]$ buy a used product from the secondary market every period, consumers with $\theta \in (\theta_3, \theta_2]$ buy a competing product every period, and consumers with $\theta \in (0, \theta_3]$ stay inactive. Assuming $\rho = 1$, we solve for the thresholds $\theta_1, \theta_2, \theta_3$ from the indifference conditions: $V_n(\theta_1) = V_u(\theta_1), V_u(\theta_2) = V_c(\theta_2), V_c(\theta_3) = 0$. The secondary market-clearing price $p^R_{s,u}$ is determined by $(\theta_1 - \theta_2) = (1 - \theta_1)(1 - \xi + \xi\nu)$. Finally, the inverse demand functions for new products $p^R_{s,n}$ and competing products p^R_c are determined by solving $(1 - \theta_1) = q^R_{s,n}$ and $(\theta_2 - \theta_3) = q^R_c$ together.

Competitor's problem. As in our main model we assume that the production cost of the counterfeit is zero. Thus the competitor's problem is $\max_{q^R_c} \Pi^R_c = p^R_c q^R_c$ s.t. $q^R_c \geq 0, 1 - q^R_{s,n} - q^R_{s,u} - q^R_c \geq 0$.

Producer's problem. The producer aims to maximize profits by choosing the production quantity, $q^R_{s,n}$, and the repair price, c^R_r. It costs κ to produce an item and c_m to repair it. The producer's problem is $\max_{q^R_{s,n}, c^R_r} \Pi^R = (p^R_{s,n}(q^R_{s,n}) - \kappa)q^R_{s,n} + (c^R_r - c_m)q^R_{s,n}\xi\nu$. The first term is the profit from new product sales, and the second term is the profit from repairs. As in Jin et al. (2022), we assume that (i) $c_m < \delta$ and (ii) $\kappa < 1 + \delta - c_m\xi$. The first assumption eliminates the uninteresting cases where the cost of repair to producer is higher than the maximum value gained from a used product. The second assumption ensures that the production cost is sufficiently low such that the producer can make a profit.

To solve for $(q^{R*}_{s,n}, c^{R*}_r)$, we need to consider six sub-problems, with respect to the parameter space (Jin et al. 2022). **(1)** If $c^R_r > c^R_i$, no consumers prefer producer repair, **(2)** if $c^R_r \leq c^R_i$ then no consumers prefer independent repair. These two sub-problems can be further split into three categories: **(a)** If $p^R_{s,u} < \min(c^R_i, c^R_r)$, then no consumers repair, i.e. $\nu = 0$; **(b)** If $p^R_{s,u} > \min(c^R_i, c^R_r)$ then all consumers repair products, i.e. $\nu = 1$, and **(c)** If $p^R_{s,u} = \min(c^R_i, c^R_r)$, consumers play mixed strategy, i.e. $\nu \in (0, 1)$. The optimal strategy of the producer is found by comparing the optimal objective values of these sub-problems, depending on the parameters. Therefore, the optimal strategy and the related objective value under RTR is given by $\Pi^R_s = \max(\Pi^*_{1a}, \Pi^*_{1b}, \Pi^*_{1c}, \Pi^*_{2a}, \Pi^*_{2b}, \Pi^*_{2c})$ where Π^*_i denotes the optimal value of the objective function of the sub-problem $i \in \{1a, 1b, 1c, 2a, 2b, 2c\}$. We now formulate each of these sub-problems.

Problem 1a. With $c^R_r > c^R_i$ and $p^R_{s,u} < c^R_i$, no consumers repair their products upon failure, i.e. $\nu = 0$. The producer abandons the repair market. When no-one repairs, the solution to the competitor's problem is $q^{R*}_c = 1/2(1 + q^R_{s,n}(-2 + \xi))$. The secondhand price and the inverse demand functions are determined as: $p^R_{s,n} = 1 + \delta + \delta_c q^R_c(-2 + \xi) - \delta\xi + q^R_{s,n}(-1 + \delta(-3 - 2(-2)\xi + (-1)\xi^2))$, $p^R_{s,u} = -\delta_c q^R_c + \delta + q^R_{s,n}\delta(-2 + \xi)$. The producer's problem is $\max_{q^R_{s,n}, c^R_r} \Pi_{1a} = (p^R_{s,n} - \kappa)q^R_{s,n}$, s.t. $\theta_1 \geq \theta_2$, $\theta_2 \geq 0$, $p^R_{s,u} < c^R_i$, $c^R_r > c^R_i$. These constraints together imply $\frac{1}{2-\xi} \geq q^R_{s,n} > \max\left(0, \frac{\delta - c^R_i}{\delta(2-\xi)}\right)$.

Problem 1b. With $c_r^R > c_i^R$ and $p_{s,u}^R > c_i^R$, all consumers who experience a product failure repair their products independently, i.e. $\nu = 1$. The producer abandons the repair market. When everyone repairs, the solution to the competitor's problem is $q_c^{R*} = 1/2 - q_{s,n}^R$. The secondhand price and the inverse demand function are found as: $p_{s,n}^R = 1 - 2\delta_c q_c^{R*} + \delta - q_{s,n}^R(1+3\delta) - c_i\xi, p_{s,u}^R = -\delta_c q_{{}^{R*}c+\delta-2q_{s,n}^R\delta}$. The producer's problem is $\max_{q_{s,n}^R, c_r^R} \Pi_{1b} = (p_{s,n}^R(q_{s,n}^R) - \kappa)q_{s,n}^R$, s.t. $\theta_1 \geq \theta_2, \theta_2 \geq 0$, $p_{s,u}^R > c_i^R$, $c_r^R > c_i^R$. These constraints together imply $\frac{\delta - c_i^R}{2\delta} > q_{s,n}^R \geq 0$, which requires $\delta \geq c_i^R$.

Problem 1c. With $c_r^R > c_i^R$ and $p_u^R = c_i^R$, a fraction $\nu \in (0,1)$ of consumers undertake independent repairs upon failure. The manufacturer does not offer repairs. The competitor's best response function is $q_c^{R*} = 1/2(\delta_c + \delta_c q_{s,n}^R(-2 + \xi - \nu\xi))$. The secondhand price and the inverse demand function are found as: $p_{s,n}^R = 1 + \delta - \delta\xi + 1/2\delta_c(-2+\xi)(1 + q_{s,n}^R(-2+\xi-\nu\xi)) + q_{s,n}^R(-1+\delta(-3 - 2(-2+\nu])\xi + (-1+\nu)\xi^2)), p_{s,u}^R = 1/2(\delta_c - 2\delta)(-1 + q_{s,n}^R(2 + (-1+\nu)\xi))$. The producer's problem is $\max_{q_{s,n}^R, c_r^R} \Pi_{1c} = (p_{s,n}^R - \kappa)q_{s,n}^R$, s.t. $\theta_1 \geq \theta_2$, $\theta_2 \geq 0$, $p_{s,u}^R = c_i^R$, $c_r^R > c_i^R$. These constraints simplify to $q_n^R = \frac{\delta - c_i^R}{\delta(2-\xi+\nu\xi)}$ and $\delta \geq c_i^R$. Note that production is unprofitable if $\delta < c_i^R$.

Problem 2a. With $c_r^R \leq c_i^R$ and $p_u^R < c_r^R$, no consumers repair their products upon failure, i.e. $\nu = 0$, and the manufacturer does not offer repairs. The case reduces to 1a.

Problem 2b. With $c_r^R \leq c_i^R$ and $p_u^R > c_r^R$, upon failure, all consumers use the repair services offered by the producer at price c_r^R, i.e. $\nu = 1$. The competitor's best response function is the same as in 1b. The secondhand price and the inverse demand function are found as: $p_{s,n}^R = 1 - 2\delta_c q_c^R + \delta - q_{s,n}^R(1+3\delta) - c_r^R\xi, p_{s,u}^R = -\delta_c q_c^R + \delta - 2q_{s,n}^R\delta$. The producer's problem is $\max_{q_{s,n}^R, c_r^R} \Pi_{2b} = (p_{s,n}^R - \kappa)q_{s,n}^R + (c_r^R - c_m)q_{s,n}^R\xi$ s.t. $\theta_1 \geq \theta_2$, $\theta_2 \geq 0$, $p_{s,u}^R > c_r^R$, $c_r^R \leq c_i^R$. These constraints simplify to $\frac{\delta - c_r^R}{2\delta} > q_{s,n}^R \geq 0$ and $c_r^R \leq c_i^R$.

Problem 2c. With $c_r^R \leq c_i^R$ and $p_u^R = c_r^R$, upon failure, a fraction $\nu \in (0,1)$ of consumers use producer's repair services, at price $c_r^R = p_{s,u}^R$. The competitor's best response function is the same as in 1c. The secondhand price and the inverse demand function are found as: $p_{s,n}^R = 1 + \delta - \delta\xi + 1/2\delta_c(-2+\xi)(1 + q_{s,n}^R(-2+\xi-\nu\xi)) + q_{s,n}^R(-1 + \delta(-3 - 2(-2+\nu)\xi + (-1+\nu)\xi^2)), p_{s,u}^R = 1/2(\delta_c - 2\delta)(-1 + q_{s,n}^R(2 + (-1+\nu)\xi))$. The producer's problem is $\max_{q_{s,n}^R, c_r^R} \Pi_{2c} = (p_{s,n}^R - \kappa)q_{s,n}^R + (c_r^R - c_m)q_{s,n}^R\xi\nu$ s.t. $\theta_1 \geq \theta_2$, $\theta_2 \geq 0$, $p_u^R = c_r^R$, $c_r^R \leq c_i^R$. These constraints simplify to $\frac{1}{2-\xi+\nu\xi} \geq q_{s,n}^R \geq \max\left(0, \frac{\delta - c_i^R}{\delta(2-\xi+\nu\xi)}\right)$.

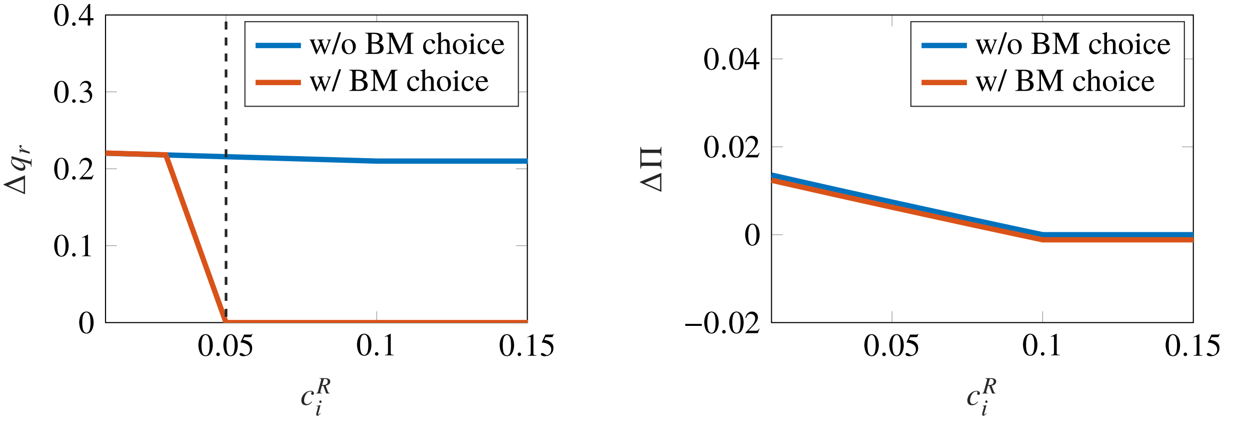
EC.2.1.2. Selling without RTR. If the producer sells without RTR, the competitor cannot improve his product valuation and the cost of independent repairs remains high. Thus, this model is a special case of the selling model under RTR where $\delta_c = \delta_{c0} \to 0$ and $c_i^{NR} \to \infty$. Therefore, $\min(c_r^{NR}, c_i^{NR}) = c_r^{NR}$ and the sub-problems 1a-1c are invalid. The optimal strategy and the related objective value without RTR is given by $\Pi_s^{NR} = \max(\Pi_{2a}^*, \Pi_{2b}^*, \Pi_{2c}^*)$ where Π_i^* denotes the optimal value of the objective function of sub-problem $i \in \{2a, 2b, 2c\}$.

EC.2.1.3. Non-ownership. The producer keeps ownership and the decision for repairing the products. The consumer segments, net utilities and the inverse demand functions $p_{no,n}, p_{no,u}$ are the same as in our main model. The producer determines the production quantity $q_{no,n}$, the used product quantity $q_{no,u}$ and the quantity to repair $q_{no,r}$, to maximize profits: $\max_{q_{no,n}, q_{no,u}, q_{no,r}} \Pi_{no} = (p_{no,n} - (\kappa + \gamma))q_{no,n} + p_{no,u}q_{no,u} - c_m q_{no,r}$ s.t. $q_{no,u} \geq 0, q_{no,r} \geq 0, 1 - q_{no,n} - q_{no,u} \geq 0, q_{no,n}\xi \geq q_{no,r}, q_{no,r} + q_{no,n}(1-\xi) \geq q_{no,u}$. The constraints together ensure that all consumer segments are non-negative, the repaired product quantity is not larger than the failed product quantity, and the remarketed product quantity is not larger than the unfailed and repaired products.

EC.2.1.4. Numerical Analysis. We ran extensive numerical experiments keeping $\delta = 0.6, \gamma = 0.05, \nu = 0.5, i_{u2} = 1, \xi = 0.8, c_m = 0.1$ constant and varying $\kappa \in \{0, 05, 0.3, 0.5\}, c_i \in \{0.05, 0.15\}, \delta_c \in \{0.01, 0.3\}, \Omega \in \{0.01, 0.5, 2\}$. For each experiment, we analyze the producer's business model choice without and under RTR, and the resulting profits as follows: $\Pi^{NR} = \max\{\Pi_s^{NR}, \Pi_{no}^*\}$ and $\Pi^R = \max\{\Pi_s^R, \Pi_{no}^*\}$. To clarify our contribution, we also analyzed the consequences of RTR overlooking the business model choice, that is, assuming that the producer always sells: $\Pi^{NR} = \Pi_s^{NR}$, and $\Pi^R = \Pi_s^R$. Due to page limitations for the EC, to demonstrate our contribution, we only present the graphs where our model leads to a different conclusion than Jin et al. (2022).

Figure EC.2.1a plots the change in repair quantity due to RTR for a product with a low production cost. Assuming that the producer sells both without and under RTR (the blue line in Figure EC.2.1) leads to the conclusion that RTR can increase repair volumes, as in Jin et al. (2022). However, factoring in the business model choice of the producer, we see that the producer can still eliminate repairs by keeping ownership of products, unless the independent repair market is highly cost-efficient under RTR ($\Delta q_r = 0$ if $c_i^R > 0.05$, right-hand side of Figure EC.2.1a).

Figure EC.2.1b plots the change in producer profits for a product with a high production cost. In this case, it is optimal for the producer to sell both without and under RTR, hence the results from both models (with and without business model choice) align. Nevertheless, as in our main model, we observe that the producer of a high-cost item can benefit from RTR if the regulations render the independent repair market to be more cost-efficient than producer's repair cost ($\Delta\Pi > 0$ if $c_i^R < c_m$, left-hand side of Figure EC.2.1b).



(a) Change in repair quantity for low-cost products, $\kappa = 0.05$. It is optimal to sell and eliminate repairs without RTR. Under RTR, it is optimal to sell (and allow consumers to use independent repairs) if $c_i^R < 0.05$, and keep ownership (without repairs) otherwise.

(b) Change in profits for high-cost products, $\kappa = 0.5$. It is optimal to sell both without and under RTR and repair all broken products. Under RTR, consumers use the independent repair services if $c_i^R < c_m = 0.1$ and the producer's services otherwise.

Figure EC.2.1 The effect of RTR on repair volume and producer profits, for both models: with and without business model (BM) choice. The dashed lines indicate the underlying business model change. In both panels, $\delta = 0.6, \delta_c = 0.01, \gamma = 0.05, c_m = 0.1, \xi = 0.8, \nu = 0.5$.

EC.2.2. Innovation and Durability Decisions.

EC.2.2.1. Innovation. We follow the same solution strategy as in A and modify the model to include $\alpha \geq 1$ as the innovation level in the new product as follows.

Selling without RTR. The net utility of consumers from buying new products with α level of innovation in every period is $V_{s,n}^{NR}(\theta) = \alpha\theta - p_{s,n}^{NR} + \rho f p_{s,u}^{NR}$. From A, we have the thresholds of consumer segments as $\theta_1 = \frac{p_{s,n}^{NR} - (1+f)p_{s,u}^{NR}}{\alpha - \delta}$ and $\theta_2 = \frac{p_{s,u}^{NR}}{\delta}$.

The market-clearing price $p_{s,u}^{NR}$ is the found as $p_{s,u}^{NR} = \frac{\delta((1+f)p_{s,n}^{NR} - f\alpha + f\delta)}{\alpha + f(2+f)\delta}$. Solving the inverse demand function, we get $p_{s,n}^{NR}(q_{s,n}^{NR}) = \alpha - \alpha q_{s,n}^{NR} + f\delta - 2f\delta q_{s,n}^{NR} - f^2\delta q_{s,n}^{NR}$. The producer's profit maximization problem is: $\max_{q_{s,n}^{NR}} \Pi_s^{NR} = q_{s,n}^{NR}(p_{s,n}^{NR} - (\kappa_0 + \kappa_i\alpha^2))$ s.t. $q_{s,n}^{NR} \geq 0$, and $1 - (1+f)q_{s,n}^{NR} \geq 0$. We assume that $\kappa < \alpha + f\delta$ such that production is profitable. The optimal new product quantity in this case is $q_{s,n}^{NR} = \frac{\alpha - (\kappa_0 + \kappa_i\alpha^2) + f\delta}{2(\alpha + f(2+f)\delta)}$. Plugging it in, the optimal profits as a function of α is: $\Pi_s^{NR^*}(\alpha) = \frac{\left(-\alpha + \kappa_0 + \alpha^2\kappa_i - \delta f\right)^2}{4(\alpha + \delta f(f+2))}$. Then we solve for $\max_\alpha \Pi_s^{NR^*}(\alpha)$ s.t. $\alpha \geq 1$ and $\kappa_0 + \kappa_i\alpha^2 < \alpha + f\delta$.

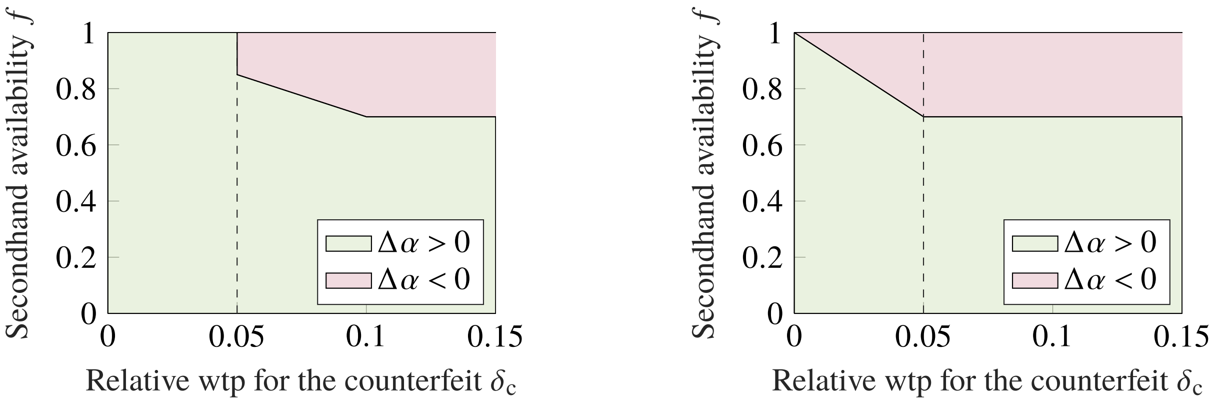
Selling under RTR. The net utility of consumers from buying a new product every period is $V_{s,n}^R(\theta) = \alpha\theta - p_{s,n}^R + \rho p_{s,u}^R$. The net utility of consumers from buying a counterfeit product every period is $V_{s,c}^R(\theta) = \delta_c k\theta - p_{s,c}^R$ where $k = \alpha$ if the counterfeit is of the new generation, and $k = 1$ if the counterfeit is of the old generation. The thresholds on θ are: $\theta_1 = \frac{p^R_{s,n} - 2p^R_{s,u}}{\alpha - \delta}$, $\theta_2 = \frac{p^R_{s,u} - p^R_c}{\delta - \delta_c k}$ and $\theta_3 = \frac{p^R_{s,c}}{\delta_c k}$.

Solving the inverse demand equations, we get these prices as follows: $p^R_{s,n}(q^R_{s,n}, q^R_{s,c}) = -2\delta_c k q^R_{s,c} - q^R_{s,n}(\alpha + 3\delta) + \alpha + \delta$, $p^R_{s,u}(q^R_{s,n}, q^R_{s,c}) = -\delta_c k q^R_{s,c} - 2\delta q^R_{s,n} + \delta$, and $p^R_{s,c}(q^R_{s,n}, q^R_{s,c}) = \delta_c k(1 - 2q^R_{s,n} - q^R_{s,c})$.

The competitor solves the problem $\max_{q^R_{s,c}} \Pi^R_{s,c} = p^R_{s,c} q^R_{s,c}$ subject to the constraints: $1 \geq \theta^R_{s1} \geq \theta^R_{s2} \geq \theta^R_{s3} \geq 0$ and $p^R_{s,u} \geq 0$. Similarly, the producer solves the problem $\max_{q^R_{s,n}} \Pi^R_s = (p^R_{s,n} - (\kappa_0 + \kappa_i \alpha^2)))q^R_{s,n}$ subject to $1 \geq \theta_1 \geq \theta_2 \geq \theta_3 \geq 0$ and $p^R_{s,n} \geq 0$. We assume that $\kappa_0 + \kappa_i \alpha^2 < \alpha + \delta - \delta_c k$ such that production is profitable. This problem gives the following Nash Equilibrium: $0 < \kappa < \alpha + \delta - \delta_c k$, $q^{R*}_{s,c} = \frac{\kappa + 2\delta}{2(\alpha + 3\delta - \delta_c k)}$, $q^{R*}_{s,n} = \frac{\kappa + \delta_c k - \alpha - \delta}{2(\delta_c k - \alpha - 3\delta)}$, $q^{R*}_{s,i} = 1 - 2q^{R*}_{s,n} - q^{R*}_{s,c}$. In this case, the producer profits as a function of α is: $\Pi^{R^*}_s(\alpha) = \frac{(\alpha + 3\delta)\left(\alpha - \left(\kappa + \alpha^2 \kappa_i\right) + \delta - \alpha\delta_c\right)^2}{4(\alpha + 3\delta + \alpha(-\delta_c))^2}$ if counterfeit is of the new generation. Then, the producer chooses the optimal innovation level to maximize profits as $\max_\alpha \Pi^{R^*}_s(\alpha)$ subject to the constraints $\kappa + \alpha^2 \kappa_i \leq \alpha + \delta - 2\delta_c$, $\alpha \leq \delta / \delta_c$, and $\alpha \geq 1$. If the counterfeit is of the old generation, the optimal profits as a function of the innovation level is: $\Pi^{R^*}_s(\alpha) = \frac{(\alpha + 3\delta)\left(\alpha - \left(\kappa + \alpha^2 \kappa_i\right) + \delta - \delta_c\right)^2}{4(\alpha + 3\delta - \delta_c)^2}$. Then, the producer chooses the optimal innovation level to maximize profits as $\max_\alpha \Pi^{R^*}_s(\alpha)$ subject to the constraints $\kappa + \alpha^2 \kappa_i \leq \alpha + \delta - 2\delta_c$, and $\alpha \geq 1$.

Non-ownership. With an innovation level of $\alpha \geq 1$, consumers with taste parameter θ get gross utility of $\alpha\theta$ from the new product, and the net utility of consumers who lease new products in every period become: $V_{no,n}(\theta) = \alpha\theta - p_{no,n}$. Then, the thresholds θ_1 and θ_2 are derived as: $\theta_1 = \frac{p_{no,n} - p_{no,u}}{\alpha - \delta}$ and $\theta_2 = \frac{p_{no,u}}{\delta}$. The inverse demand functions are $p_{no,n} = \alpha - \alpha q_{no,n} - \delta q_{no,u}$ and $p_{no,u} = \delta(1 - q_{no,n} - q_{no,u})$. Then, the producer's profit maximization problem becomes: $\max_{q_{no,n}, q_{no,u}} \Pi_{no} = q_{no,n}(p_{no,n} - (\kappa_0 + \kappa_i \alpha^2 + \gamma)) + q_{no,u} p_{no,u}$ s.t. $q_{no,u} \geq 0$, $q_{no,n} - q_{no,u} \geq 0$ and $1 - q_{no,n} - q_{no,u} \geq 0$. We further assume that $\kappa_0 + \kappa_i \alpha^2 + \gamma < \alpha + \delta$ such that production is profitable. The optimal production quantities depend on the production costs as follows.

If $\kappa_0 + \kappa_i \alpha^2 + \gamma < \frac{\alpha - \delta}{2}$, then partial remarketing is optimal and $q^*_{no,n} = \frac{1}{2}(1 + \frac{\kappa_0 + \kappa_i \alpha^2 + \gamma}{-\alpha + \delta})$, $q^*_{l,u} = \frac{\kappa_0 + \kappa_i \alpha^2 + \gamma}{2(\alpha - \delta)}$. Plugging these quantities in the profit function, we get the optimal profits as a function of the innovation level as $\Pi^*_{no}(\alpha) = \frac{(\kappa + \kappa_i \alpha^2 + \gamma)^2 - 2(\kappa + \kappa_i \alpha^2 + \gamma)\alpha + \alpha^2 + 2 * (\kappa + \kappa_i \alpha^2 + \gamma)\delta - \alpha\delta)}{4(\alpha - \delta)}$. Then we solve for $\max_\alpha \Pi^*_{no}(\alpha)$ s.t. $\alpha \geq 1$ and $\kappa_0 + \kappa_i \alpha^2 + \gamma < \frac{\alpha - \delta}{2}$. If $(\alpha + \delta) > \kappa_0 + \kappa_i \alpha^2 + \gamma \geq \frac{\alpha - \delta}{2}$, then full remarketing is optimal and $q^*_{no,n} = q^*_{no,u} = \frac{-(\kappa_0 + \kappa_i \alpha^2 + \gamma) + \alpha + \delta}{2(\alpha + 3\delta)}$. Plugging these quantities in, we get the profit function as $\Pi^*_{no}(\alpha) = \frac{(-(\kappa + \kappa_i \alpha^2) - \gamma + \alpha + \delta)^2}{(4(\alpha + 3\delta)}$. Then we solve for $\max_\alpha \Pi^*_{no}(\alpha)$ s.t. $\alpha \geq 1$ and $\alpha + \delta > \kappa_0 + \kappa_i \alpha^2 + \gamma > \frac{\alpha - \delta}{2}$.



(a) The counterfeit is of the old generation, $k = 1$.

(b) The counterfeit is of the new generation, $k = \alpha$.

Figure EC.2.2 Change in the optimal innovation level due to RTR with $\kappa_0 = 0.39, \kappa_i = 0.01, \gamma = 0.05, \delta = 0.5$. The dashed lines indicate the underlying business model change. In both panels, without RTR it is always optimal to sell. Under RTR, it is optimal to sell if $\delta_c < 0.05$ and keep ownership otherwise.

Numerical Analysis. With the addition of the innovation decision, our model becomes analytically intractable. We therefore analyzed the problem numerically. We conducted $5^3 = 125$ numerical analyses by holding $\kappa_0 = 0.2, \delta = 0.5, \kappa_i = 0.1$ fixed and varying $\gamma \in \{0.2, 0.4, 0.6, 0.8, 1\}, f \in \{0.2, 0.4, 0.6, 0.8, 1\}$, $\delta_c \in \{0.1, 0.2, 0.3, 0.4, 0.5\}$. We visualize the results from these analyses in Figure EC.2.2 for $\kappa_0 = 0.39, \kappa_i = 0.01, \gamma = 0.05, \delta = 0.5$. We observe in Figure EC.2.2 that RTR can result in higher incentives to innovate for a producer that sticks with selling (left-hand side of Figure EC.2.2, both panels). This is because, innovation can help differentiate the original product from the secondhand and counterfeit products. On the other hand, if RTR results in a switch from selling to non-ownership, then its impact on the producer's innovation decision depends on how long the product will be in use. That is, if the product already achieves a long lifetime without RTR (i.e., f is high), then the premature disposal under RTR can lead to lower innovation. This is because, the producer does not expend her budget innovating on a product if she knows she will discard it after a short period of time (right-hand side of both panels in Figure EC.2.2).

EC.2.2.2. Durability. The producer sequentially chooses the business model and the durability level of the product, δ. A product with durability level δ costs $\kappa = \kappa_0 + \kappa_d\delta^2$, where κ_0 is the baseline production cost (of an item with $\delta = 0$) and κ_d is the cost per unit of durability.

Selling without RTR. The producer's profit maximization problem is: $\max_{\delta\in(0,1)} \max_{q_{s,n}^{NR}} q_{s,n}^{NR}(p_{s,n}^{NR} - (\kappa_0 + \kappa_d\delta^2))$ s.t. $q_{s,n}^{NR} \geq 0$. The inner problem was analyzed in A.1. Plugging in the optimal quantity decision $q_{s,n}^{NR*}$ from A.1, the outer problem becomes: $\max_{\delta\in(\delta_c,1)} \frac{(-2+2\kappa_0-2f\delta+2\kappa_d\delta^2+\delta_{c0}+f\delta_{c0})^2}{8(2+f(4\delta-2\delta_{c0})+f^2(2\delta-\delta_{c0})-\delta_{c0})}$.

Selling under RTR. The producer's profit maximization problem is: $\max_{\delta\in(0,1)} \max_{q^R_{s,n}} q^R_{s,n}(p^R_{s,n} - (\kappa_0 + \kappa_d\delta^2))$ s.t. $q^R_{s,n} \geq 0$ Plugging in the optimal quantity $q^{R*}_{s,n}$ from A.2, the outer problem becomes: $\max_{\delta\in(\delta_c,1)} \frac{(-1+\kappa_0-\delta+\kappa_d\delta^2+\delta_c)^2}{4+12\delta-8\delta_c}$.

Non-ownership. The producer's profit maximization problem is: $\max_{\delta\in(0,1)} \max_{q_{no,n},q_{no,u}} q_{no,n}(p_{no,n} - (\kappa_0 + \kappa_d\delta^2) - \gamma) + q_{no,u}p_{no,u}$ s.t. $q_{no,n} \geq q_{no,u} \geq 0$. From A.3, depending on the production costs, and partial or full remarketing can be optimal. Plugging in the optimal quantity decisions $q^*_{no,n}, q^*_{no,u}$, when partial remarketing is optimal, the outer problem becomes $\max_{\delta\in(0,1)} \frac{2+2\kappa_0^2-2\delta+4\kappa_0(-1+\gamma+\delta+\kappa_d\delta^2)+2(\gamma+\kappa_d\delta^2)(-2+\gamma+\delta(2+\kappa_d\delta))+(-1+\delta)\delta_{c0}}{8(1-\delta)}$ Similarly, when full remarketing is optimal, the outer problem becomes $\max_{\delta\in(0,1)} \frac{(-1+\kappa_0+\gamma+\delta(-1+\kappa_d\delta)+\delta_{c0})((-1+9\delta)(-1+\kappa_0+\gamma+\delta(-1+\kappa_d\delta))+X)}{-4(-1+3\delta+2\delta_{c0})^2}$ where $X = (-3 + 2\kappa_0 + 2\gamma + \delta(-5 + 2\kappa_d\delta))\delta_{c0} + 2\delta_{c0}^2$.

Numerical Analysis. We conducted extensive numerical analyses by holding $\delta_{c0} = 0.00000001, \kappa_d = 0.0001, \gamma = 0.001$ fixed and varying $\kappa_b \in \{0.001, 0.05, 0.2\}, f \in \{0.01, 0.11, ..., 0.91\}, \delta_c \in \{0.01, 0.11, ..., 0.91\}$. For the environmental impact analyses, we choose two levels of $\Omega \in \{0.025, 0.2\}$ that respectively represent products with high and low use-phase impact. The findings from these numerical analyses are provided in the main text. The data are available from the corresponding author.