Evaluating Right-to-Repair when Repairability Rests with the Manufacturer

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Problem definition: The Right-to-Repair (RTR) movement has resulted in two governmental initiatives: a repair bonus policy and a policy mandating that manufacturers provide repair resources to consumers. This study assesses the effectiveness and impact of these policies on sales, repair demand, manufacturer profitability, consumer surplus, the environment, and social welfare. Academic/practical relevance: This study contributes to the RTR literature by explicitly modeling the manufacturer’s control over product repairability, and provides insights for policymakers and practitioners. Methodology: A two-period game-theoretic model is used to optimize government policy and the manufacturer’s response, with consumers, manufacturers, and the government as players. Results: We find that making repair resources available can decrease sales and increase repair demand, particularly when consumers’ repair cost is low, the consumers’ valuation of the availability of repair resources is low, and the manufacturer’s repair cost is high, but a repair bonus is most effective in other cases. Surprisingly, making repair resources available may improve manufacturer profitability, despite its hurting the repair business; Moreover, a low repair cost increases the appeal of a repair bonus policy for the manufacturer. Making repair resources available, unfortunately, can never generate a triple-win outcome, while a repair bonus policy can achieve it in certain conditions. Managerial implications: The findings of this study provide policymakers with concrete support and useful insights for designing policies based on product and market characteristics. We demonstrate that rather than imposing blanket regulations for all products, policies should differ based on the repairability of each product. Policymakers should require the manufacturer to make repair resources available if both the manufacturer’s repair cost and consumers’ repair valuation are high. Otherwise, the government should opt for a subsidy policy.

Key words: sustainable operations, right-to-repair, repairability, triple bottomline, social welfare

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1. Introduction

The Right-to-Repair (RTR) movement, which seeks to promote repairability and extend product lifespan, has garnered attention from policymakers. In accordance with prevailing regulations, consumers may lose their right to repair after the expiration of the guarantee, leaving them to bear the brunt of exorbitant repair expenses, inadequate access to essential software, components, and repair manuals, as well as a paucity or absence of repair shops in their vicinity, or products deliberately engineered to be unfixable. In light of these issues, the RTR movement advocates for
regulations that hold manufacturers responsible for enabling repair beyond the statutory guarantee period (European Parliament 2022).

The RTR principle is widely perceived as benefiting both consumers and the environment. In the electronics industry, as an example, RTR could foster competition in the repair market, potentially leading to greater options and lower prices for repair services (Keck 2019). Additionally, RTR could curb waste by enabling individuals to extend the lifespan of devices (Reimer 2020).

RTR initiatives call for government legislation that mandates manufacturers to provide repair resources, such as repair information, tools, and spare parts, to enable consumers to independently repair their products. We refer to this as Policy R in this paper. For instance, in the US, the Fair Repair Act bill compels OEMs of digital electronics to make certain documentation, diagnostic, and repair information available to independent repair providers and consumers (Fair Repair Act 2021). Similarly, the EU and the UK have launched comparable initiatives (European Parliament 2022, Conway 2021). France has implemented a “Reparability Scoring System” that assesses the availability of repair resources and assigns a score to each electronic product, allowing consumers to make informed purchase decisions (repair.eu 2021). Another initiative to make the repair less expensive and more attractive, thus inducing more consumer repairs, involves offering monetary incentives. In Austria and part of Germany, people can be partially reimbursed when repairing the product either through the manufacturer or independently (Meyer 2021). This policy covers a repair bonus scheme, and we call it Policy B throughout this paper.

An effective RTR policy hinges on manufacturers’ commitment to producing repairable products and providing public access to repair resources. Without such commitment, consumers are deprived of the benefits of repair, as evidenced by the use of adhesives in electronics (Schwartz 2019) and the use of software locks in agricultural machinery (VICE 2020). In addition, manufacturers often charge exorbitant fees for access to repair manuals and refuse to sell replacement parts, further hindering consumer repair efforts (Business Insider US 2020, Vox 2019). Our study focuses on the crucial role played by manufacturers in enabling independent repairs by consumers. The manufacturer’s decision to grant access to repair resources determines whether consumers can exercise their right to repair or not. In the absence of such access, manufacturers maintain a repair monopoly, depriving consumers of their right to repair.

The implementation of RTR policies has been widely regarded as beneficial to the environment, but potentially harmful to manufacturers. Seeing this as a threat to profitability, companies such as Apple and Microsoft have been lobbying against RTR (Surur 2019), while stating repair complexity and intellectual property issues as major challenges (Hilfinger et al. 2021). However, the argument on the impact of RTR on the profitability and environment overlooks a crucial factor: how consumers respond to the availability of repairable products. It is possible that offering repairable
products would increase consumers’ satisfaction and result in higher sales, potentially offsetting any losses in the manufacturer’s repair market and increasing environmental damage. Thus, the profitability of manufacturers under RTR policies and their environmental impacts are uncertain and requires further investigation. To address this issue, it is important to examine how, under RTR, manufacturers set repair fees and levels of repairability, and how these decisions affect sales of new products and demand for repair services. Therefore, we investigate the following research questions:

(1) **Given the characteristics of the market, product, and consumers, how does the response of the manufacturer to these policies impact sales of new products and the demand for repair?**

(2) **How do the impacts of these policies on the manufacturer’s repair fee and profitability, consumers’ surplus, environment, and social welfare compare?**

To address these inquiries, we develop a two-period analytical model featuring a government that aims to maximize social welfare, a manufacturer seeking to maximize profits, and a group of heterogeneous consumers. At the onset of the first period, the government selects between three options: Policy N, which involves no policy implementation; Policy B, which offers a repair bonus; or Policy R, which mandates the manufacturer to provide repair resources. We assume that consumers can only repair their products independently of the manufacturer if the latter authorizes them by providing the necessary repair resources. In the first period, consumers purchase new products. In the second period when a product fails, consumers can opt to either buy a new one or repair the faulty product after observing the manufacturer’s repair fee. Depending on the policy in effect, consumers may have access to the manufacturer’s repair service only, or both the manufacturer’s and independent repair services (including self-repair). By optimizing the government’s decision and the manufacturer’s response, we assess the profitability of the manufacturer, consumer surplus, and environmental impact of each policy, and compare the outcomes. A brief preview of our primary findings is as follows:

Concerning the **efficacy of these policies in decreasing sales and boosting repair demand**, our findings demonstrate that a high cost of manufacturer repairs renders Policy B as ineffective as Policy N. Furthermore, if the cost of independent repair is also high, then Policy R will lack effectiveness. Otherwise, a high independent repair cost makes Policy B superior. In other circumstances, Policy R will be the most effective provided that consumers do not highly value the availability of repair resources, which arises when, e.g., consumers face limited access to independent repair centers.

A notable result concerns the **profitability of the manufacturer**. It shows that Policy R, despite hurting the manufacturer’s repair business, can improve her profitability. It is realized if consumers’ appreciation of repairability boosts the sales of new; offsetting the loss of repair profit. Otherwise,
the manufacturers’ profitability will be the highest under Policy B. Furthermore, we show that a manufacturer with a low repair cost finds Policy B more profitable than one with a high repair cost.

In evaluating the impact of these policies on the manufacturer’s triple bottom line (which encompasses profit, environment, and consumer surplus), we find that only Policy B can potentially achieve a win-win-win outcome. This outcome is contingent upon the manufacturer having low repair costs and consumers placing a low value on the availability of repair resources. In contrast, Policy R fails to achieve this outcome but maximizes profitability and consumer surplus when the manufacturer’s repair costs and consumer valuation of the availability of repair resources are high.

Our study suggests that if the manufacturer has low repair costs and consumers do not highly value the access to the repair resources, the government should adopt Policy B. Conversely, if both the manufacturer’s repair costs and consumers’ valuation of repair resource availability are high, the government should choose Policy R. However, in these cases, Policy R maximizes social welfare through additional sales of new items, which is concerning as it goes against the spirit of RTR.

The rest of this paper is structured as follows. In Section §2, we review the relevant literature. We formalize our model in Section §3. Section §4 presents the equilibrium analysis under three policies and examines their impacts on pricing, sales and repair demand, the manufacturer’s profit, consumer surplus, the environment, and social welfare. Section §5 explores several extensions. Section §6 provides concluding remarks and discusses future research directions.

2. Literature Review

Our work contributes to two main streams of literature in sustainable operations: (1) the role of environmental regulations and (2) pricing and circular product design. In what follows, we review these two streams and highlight how this paper contributes to them.

2.1. The Role of Environmental Regulations

Scholars have shown interest in studying the impact of environmental regulations, such as subsidies and extended producer responsibility (EPR)-based take-back legislation, on the adoption of green practices and associated arrangements. Ata et al. (2012) has focused on a waste-to-energy firm and evaluated the effectiveness of a lump-sum investment subsidy. Cohen et al. (2016) has analyzed government subsidies for green technology adoption, offered directly to consumers while considering the manufacturing industry’s response. Ma et al. (2019) has studied two types of government subsidies for clean-technology products, namely service infrastructure subsidy and product subsidy. Their findings suggest that both types of subsidies can be detrimental to clean technology adoption under certain conditions. Babich et al. (2020) examine the effects of two subsidy policies, including feed-in-tariff and tax-rebate, on promoting investment in renewable energy sources and seek to find the conditions that favor one policy over the other from the perspective of
the government. Toffel (2003) has provided an overview of take-back legislation developments and their impacts on organizational decision-making. Atasu et al. (2009) have discussed the economic and environmental effects of EPR-type legislation, emphasizing the importance of making producers responsible for their own waste and favoring eco-design producers to generate stronger environmental benefits. Atasu and Van Wassenhove (2012) synthesize the experiences with e-waste laws passed in various countries to cast light on the operational perspectives of e-waste legislation. Esenduran and Kemahlıoğlu-Ziya (2015) have compared two compliance schemes, namely collective with cost allocation by market share and individual compliance scheme, in terms of their costs on firms and environmental benefits. Analyzing the inherent trade-off when producers respond to EPR, i.e., making the product more recyclable or more durable, Huang et al. (2019) have analyzed the product design implications of EPR-based take-back legislation on durable goods.

The RTR policy has recently gained attention from scholars in the field of operations and supply chain management. However, there are only two papers on this topic in the literature, namely, Jin et al. (2023) and Gulserliler et al. (2022). Jin et al. (2023) analyze the role of RTR by assuming that its implementation decreases independent repair costs. They investigate the manufacturer’s response to the price of new products under RTR and find that as the independent repair cost decreases, the manufacturer may initially reduce the new product price and then raise it. Their main findings indicate that the introduction of RTR always impairs the profitability of the manufacturer. They also study the impact of RTR on consumer surplus and the environment, highlighting that RTR may negatively affect both. Gulserliler et al. (2022) assume that the difference between RTR and non-RTR is whether consumers’ products can be completely repaired. They focus on intellectual property issues and analyze the business model selection between selling and leasing. Their results suggest that RTR may improve or worsen a company’s performance with respect to all aspects of the triple bottom line.

This paper explores the impact of policy design aspects of RTR. Specifically, we evaluate the effectiveness of repair bonuses and the availability of repair resources in promoting the use of repair services. Additionally, we consider the possibility that consumers may value products’ repairability at the time of purchase, which allows us to better assess the impact of these policies. Moreover, we include the manufacturer’s ability to influence consumers’ repair costs by controlling the availability of repair resources and treat it as a decision variable in one of our extensions.

Our results confirm some of the existing findings in the literature while also generating several new ones. For instance, we find that Policy R cannot generate an outcome where both the economic and environmental consequences improve, which is consistent with Jin et al. (2023) and Gulserliler et al. (2022). However, our results suggest that the manufacturer has the potential to earn more profits under Policy R, which differs from Jin et al. (2023) but aligns with Gulserliler et al. (2022).
Moreover, our analysis of Policy B generates several new results, indicating that Policy R may perform better than Policy B, but only the latter can generate a win-win-win outcome.

2.2. Pricing and Circular Product Design

Driven by the notion of “greening the supply chain”, the circular design of the durable good (see Agrawal and Toktay (2009) for an overview) and its associate pricing have received significant attention. Earlier studies have focused on the product design encompassing issues such as environmentally friendly quality attributes (Chen 2001, Plambeck and Wang 2009), product reuse (Debo et al. 2005, Galbreth et al. 2013), remanufacturability (Subramanian et al. 2009), and product modularity (Krishnan and Ramachandran 2011). Different from these papers, we aim at understanding the impacts of RTR policies, on the pricing of manufacturer’s repair services, the price of the new products, and the level of availability of repair resources. We also investigate how these decisions are influenced by different policies and evaluate the impact on the triple bottom line of companies.

3. Modeling framework

In this section, we present our model of a stylized market for a single product involving three key decision-makers: consumers, manufacturers (referred to as “she”), and the government (referred to as “he”). The sequence of events and decisions proceeds as follows:

At the beginning of the first period, the government sets a policy: either Policy R, Policy B, or Policy N. Policy N serves as a benchmark against which we can measure the impact and effectiveness of the other policies. Under Policy R, the manufacturer enables independent repair and allocates repair resources at level $k$. Under Policy B, the government announces a repair bonus $s$ that consumers will receive upon repairing a failed product. During the first period, consumers decide whether to purchase a new product, based on the product’s price ($p$) and the government’s policy. We now outline and rationalize our key assumption:

A two-period model: The product use phase can be divided into two periods, denoted by $t \in \{1, 2\}$. In the first period, the product is considered new, while in the second one, it becomes used and may eventually break down. This two-period framework allows us to model the entire use phase, as well as to examine the effects of government policy on both the sales of new products in the first period and the demand for repair services and associated fees in the second period. By using a two-period model, we can maintain tractability and ensure that our results are interpretable.

Independent repair: We adopt the same assumption as Jin et al. (2023) that independent repair comprises repairs performed by consumers themselves or by third-party repair shops, excluding authorized channels of the manufacturer.
**Repairability**: Our focus is on a type of product failure that requires the involvement of the manufacturer for repair, as the necessary tools, spare parts, information, software, and other resources are not accessible to consumers. Manufacturers achieve this by restricting public access to such resources, making it difficult or impossible for consumers to conduct effective and efficient repairs on their own. For example, Apple employs “pentalobe” screws that cannot be removed with standard screwdrivers. Similarly, as explained in Section §1, John Deere uses copyright-protected software to prevent consumers and independent repair shops from unlocking software and repairing high-tech tractors and other heavy machinery, leaving OEM or OEM-approved technicians as the only solution for consumers.

One of the primary drivers behind the demand for the RTR is to overcome the restrictions imposed by manufacturers. Therefore, we exclude cases where consumers already have the ability to repair their products independently. If the public can repair a product without the involvement of the manufacturer, we expect the introduction of the RTR to reduce the manufacturer’s profitability, as demonstrated in Jin et al. (2023). By making these exclusions, we not only streamline the analysis but can accurately evaluate the impact of empowering consumers to repair their products, which would be unachievable without the right-to-repair policy.

### 3.1. Consumers’ Problem

We assume a consumer population of 1, where each consumer can use at most one product at a time. Consumers vary in their valuation $v$ for a new product, which is assumed to be uniformly distributed in $[0, 1]$. For used or repaired products, the consumer’s valuation is reduced by a factor of $\alpha \in (0, 1)$, which captures the utility discount resulting from product performance deterioration. A similar assumption is made in previous studies, e.g., Agrawal et al. (2012) and Jin et al. (2023).

In addition to the standard utility, consumers can obtain an extra benefit, $mk$, when provided with the repair resources at a level of $k$ to fix the product under Policy R. The value $m > 0$ represents the consumer’s valuation of the availability of repair resources. This includes access to and availability of repair services as well as cultural openness to repair that may vary by region. For instance, Italy accounted for nearly 17% of the EU’s repair enterprises in 2019 in the computer, personal, and household goods sector (Eurostat 2023). Similarly, the availability of repair workers varies by state in the US (U.S. Bureau of Labor Statistics 2021). In essence, the term $mk$ in our model captures the consumers’ satisfaction from repairing the product, articulated by Gay Gordon-Byrne, a prominent figure in the RTR movement, as the “Yes!-I-Fixed-it feeling” (Gordon-Byrne 2022).

At the onset of Period 1, the consumer decides whether to purchase a new product, which they will use throughout this period. Subsequently, in Period 2, the product may fail with a probability of $1 - \theta$. Upon product failure, the consumer faces a decision to either purchase a new product or
repair the failed one. Under Policy N or B, the manufacturer is the sole resource for repairing the failed product. In contrast, under Policy R, the consumer has the option to undertake independent repair or leverage the manufacturer’s repair service. In the latter scenario, the manufacturer provides repair resources to the consumer at a level of \( k \), thereby augmenting the cost efficiency of the independent repair by a factor of \( 1 - k \). Specifically, the per-unit independent repair cost is represented by \( (1 - k)c \), where \( c \) denotes the base independent repair cost.

**Demand characteristics**

**Policy N and B.** At the onset of Period 1, consumers with a valuation of \( v \) decide whether to purchase a new product by observing the retail price \( p \). In Period 2, the product fails with a probability of \( 1 - \theta \). A consumer whose product does not fail will continue to use it. However, in the event of a product failure, the consumer faces two choices: (i) buy a new product or (ii) repair the failed product. Comparing the consumers’ utility of different choices, Lemma 1 characterizes the demand for new products and repairs.

**Lemma 1.** In case of Policy \( i \), \( i \in \{ N, B \} \), the demand for new product in the second period is

\[
D^i_2 = \begin{cases} 
(1 - \theta)(1 - p) & \text{if } f^i - s \cdot 1_{\{i = B\}} \geq \alpha p \\
(1 - \theta)(1 - \frac{p - f^i + s}{1 - \alpha}) & \text{Otherwise} 
\end{cases}
\]

Furthermore, the repair demand is calculated as

\[
D^i_r = \begin{cases} 
0 & \text{if } f^i - s \cdot 1_{\{i = B\}} \geq \alpha p \\
(1 - \theta)(\frac{p - f^i + s}{1 - \alpha} - p) & \text{Otherwise}. 
\end{cases}
\]

where \( 1_{\{i = B\}} \) is an indicator function that equals 1 if \( i = B \) and 0, otherwise.

As per the findings of Lemma 1, when the repair fee is high enough such that \( f^i - s \cdot 1_{\{i = B\}} \geq \alpha p \), consumers opt to purchase a new product instead of repairing the failed one. On the other hand, if the repair fee is below this threshold, consumers prefer to repair the failed product through the manufacturer. Furthermore, the demand for new products rises while the demand for repair decreases as the repair fee, \( f^i \), increases.

**Policy R.** At the beginning of Period 1, a consumer can gain a utility of \( v + mk \) by purchasing a new product while taking into account the availability of repair resources, \( k \). In Period 2, if a product fails, the consumer observes the repair fee, \( f^R \), and can choose from three options: (i) independent repair of the product, yielding a utility of \( \alpha v - (1 - k)c \), (ii) manufacturer repair of the product, resulting in a utility of \( \alpha v - f^R \), and (iii) purchasing a new product. The subsequent lemma summarizes the proportion of consumers selecting each of these three options.
Lema 2. In the case of Policy R, the demand for a new product in the second period is

\[
D_r^R = \begin{cases} 
(1 - \theta)(1 - p + mk) & \text{if } \alpha(p - mk) \leq \min\{f^R, (1 - k)c\} \\
(1 - \theta)(1 - \frac{p - mk - f^R}{1 - \alpha}) & \text{if } f^R \leq \min\{\alpha(p - mk), (1 - k)c\} \\
(1 - \theta)[1 - \frac{p - mk - (1 - k)c}{1 - \alpha}] & \text{if } (1 - k)c \leq \min\{f^R, \alpha(p - mk)\}
\end{cases}
\]

Furthermore, the repair demand is

\[
D^R = \begin{cases} 
0 & \text{if } \alpha(p - mk) \leq \min\{f^R, (1 - k)c\} \\
(1 - \theta)(\frac{p - mk - f^R}{1 - \alpha} - p + mk) & \text{if } f^R \leq \min\{\alpha(p - mk), (1 - k)c\} \\
(1 - \theta)[\frac{p - mk - (1 - k)c}{1 - \alpha} - p + mk] & \text{if } (1 - k)c \leq \min\{f^R, \alpha(p - mk)\}
\end{cases}
\]

It is noteworthy that \(D^R\) denotes the repair demand fulfilled by the manufacturer when \(f^R < \min\{\alpha(p - mk), (1 - k)c\}\). However, when \((1 - k)c \leq \min\{f^R, (1 - k)c\}\), it represents the demand for independent repair. Lema 2 reiterates that when the repair fee, \(f^R\), is sufficiently high, i.e., \(\alpha(p - mk) \leq f^R\), and the cost of independent repair is also high, i.e., \(\alpha(p - mk) \leq (1 - k)c\), then the consumer purchases a new product if the existing one fails. Only if \(f^R\) is adequately low, the consumer opts for the manufacturer’s repair service. For moderate values of \(f^R\), consumers prefer independent repair of the product.

3.2. Manufacturer’s Problem

At the start of Period 2, the manufacturer sets the repair fee, \(f^i\), based on government Policy \(i\). In our base model, the price, \(p_i\), is exogenous. It is reasonable as firms may have established brand reputation and customer loyalty that changing prices could potentially damage. For instance, Apple rarely changes the prices of older iPhone models unless new models are introduced (GSMArena 2021). This setting allows for an analytical comparison of different policies and an investigation of a manufacturer’s potential benefit from the RTR policy, even with a fixed retail price. We relax this assumption and treat the retail price as a decision variable in Section §5.1.

The costs of acquiring a single unit of the product and repairing it are denoted by \(c_p\) and \(c_r\), respectively. Under Policy R, the manufacturer provides repair resources at a level \(k\), which is pre-determined in our baseline model. However, companies may offer different approaches to facilitate product repairability. For instance, HP offers extensive repair information on its website and instructional videos on YouTube to assist customers in repairing their products (Lloyd 2019). Similarly, Microsoft recently redesigned its Surface 3 tablet to enable easy repairs, and Apple introduced Self Service Repair for its iPhone and Mac products (iFixit 2021). To capture these differences, we analyze a scenario in which \(k\) is a decision variable in Section §5.2. To maximize profits, the manufacturer solves the following problem:

\[
\max_{f^i} \Pi^i = (p - c_p)(D_1^i + D_2^i) + (f^i - c_r)D_r^i
\]

The first term represents the total profit from product sales in the first and second periods. The second term calculates the profit gained by repairing failed products in the second period.
3.3. Government’s Problem

The objective of the government is to devise a policy that maximizes social welfare as follows:

$$\max_{i \in \{N, B, R\}} w^i = \Pi^i - sD^i \cdot 1\{i = B\} + CS^i$$ (6)

The first, second, and third terms represent the profit earned by the manufacturer, the expenditure incurred by the government in providing the repair bonus, and the consumer surplus, respectively.

4. Equilibrium analysis

In this section, we conduct an analysis of the policies and present the corresponding equilibrium outcomes. For each policy, we use backward induction to solve our model, that is, we begin by solving the manufacturer’s problem followed by that of the government. The policies are then compared in terms of profitability, environmental impact, consumer surplus, and social welfare.

4.1. Policies N, B, and R

The optimal repair fee and consumers’ repair decision under Policy N are presented in Lemma 3.

**Lemma 3.** Under Policy N, there exists a threshold on the manufacturer’s repair cost, $c_r^N = c_p - (1 - \alpha)p$, such that when

i. $c_r \leq c_r^N$, consumers repair the failed product through the manufacturer, and the optimal repair fee is $f_r^N = \frac{1}{2}[(1 + \alpha)p + c_r - c_p]$.

ii. $c_r > c_r^N$, no consumer repairs the failed product.

Lemma 3 suggests that consumers may opt to repair their malfunctioning products only if the manufacturer’s repair cost is low. Otherwise, replacing the defective item with a new one becomes a more desirable option. Essentially, as her repair cost rises, the manufacturer will impose a higher repair fee to ensure profitability, thereby reducing consumers’ willingness to repair. As highlighted in Section §3.1, the demand for repairs declines, while sales increase as repair fees rise in the second period. Once the repair cost surpasses a threshold, consumers are unlikely to consider repairing defective products. This observation is consistent with a 2018 European Commission study, which identified the high cost of repair as the top reason for not repairing products (Sajin 2019).

A high repair cost also discourages the manufacturer from offering repair services, as the profit margin from repairs diminishes. Thus, the manufacturer may set high repair fees, prompting consumers to purchase new products instead of repairing them when they fail. The AirPods is a relevant example where repair is costly due to its design, resulting in a higher profit margin for the manufacturer by encouraging consumers to purchase a new product instead of repairing the defective one (Perzanowski 2022). Lemma 4 presents the results for Policy B.

Electronic copy available at: https://ssrn.com/abstract=4463563
Lemma 4. Under Policy B, when
i. If \( c_r \leq c_r^N \), consumers repair the failed product through the manufacturer; the optimal repair fee and repair bonus are \( f_{B*} = \alpha p \) and \( s^* = c_p - c_r - (1 - \alpha)p \), respectively.
ii. If \( c_r > c_r^N \), no consumer repairs the failed product and the government does not provide the repair bonus.

Lemma 4 highlights that when the manufacturer’s repair cost is low, consumers opt to repair their defective products. Comparing the repair fees in Policies N and B, we observe that the effective repair fee paid by the consumer decreases in Policy B. However, Policy B enables the manufacturer to charge a higher repair fee while capturing a portion of the repair bonus, as evidenced by \( f_{B*} = f_{N*}^* + s^*/2 \). This increase in repair demand is balanced by a decrease in sales of new products. Nevertheless, by capturing part of the repair bonus, the manufacturer can offset the loss incurred from the sales cannibalization.

Our findings also indicate that the repair bonus decreases as the repair cost increases. As mentioned in Section §3.3, the government aims to maximize social welfare, and an increase in repair costs leads to a decrease in the manufacturer’s marginal repair profit. Consequently, the government reduces the repair bonus to incentivize consumers to buy new products. Furthermore, Lemma 4 reveals that subsidizing the repair fee does not effectively address the situation where the manufacturer imposes a high repair fee, discouraging consumers from repairing and instead forcing them to purchase new products (i.e., \( c_r > c_r^N \)). Hence, when the repair cost is high, Policy B is as ineffective as Policy N in promoting repair demand. We now shift our focus to Policy R, and Lemma 5 presents the results.

Lemma 5. Under Policy R, there exist thresholds for consumers’ repair cost \( \check{c} \), and the manufacturer’s repair costs \( c_r^R \) and \( \bar{c}_r \), which are defined as follows: \( \check{c} = \frac{\alpha(p - mk)}{1 - k}, \quad c_r^R = c_p - (1 - \alpha)p - \alpha mk \), and \( \bar{c}_r = c_p - (1 + \alpha)p + \alpha mk + 2(1 - k)c \). Then:

i. If \( c \geq \check{c} \) and \( c_r \leq c_r^R \), then consumers repair their failed product through the manufacturer, and the optimal repair fee is \( f_{R*}^* = \frac{1}{2}[(1 + \alpha)p + c_r - c_p - \alpha mk] \). However, if \( c_r > c_r^R \), no consumer repairs their failed product.

ii. If \( c \leq \check{c} \) and \( c_r \leq \bar{c}_r \), then consumers repair their failed product through the manufacturer, and the optimal repair fee is \( f_{R*}^* = \frac{1}{2}[(1 + \alpha)p + c_r - c_p - \alpha mk] \). Conversely, if \( c_r > \bar{c}_r \), consumers repair the failed product independently at the cost of \( (1 - k)c \).

Lemma 5 elucidates the dual function of Policy R, which impacts both the demand for new products and repair. The provision of repair resources enhances the additional utility offered, thereby prompting more consumers to purchase the new product, which is consistent with previous studies, such as Huang et al. (2016) and Reischl (2021). This, in turn, leads to additional sales and allows the manufacturer to reduce the repair fee, thereby encouraging repairs. However, if the
consumers’ repair cost is sufficiently high \((c \geq \hat{c})\), the manufacturer remains the sole repair channel, and consumers’ decisions are akin to those under Policies N and B.

Moreover, compared to Policies N and B, the manufacturer’s repair service is appealing to consumers when her repair cost is sufficiently low (i.e., \(c^r < c^N\)). Intriguingly, consumers may still refrain from repairing the failed product, even if their repair cost is low (i.e., \(c \leq \hat{c}\)). This scenario arises when the manufacturer bears a low repair cost \((c_r \leq \bar{c}_r)\). In such cases, the manufacturer can charge a sufficiently low repair fee. As \(c_r\) increases, the manufacturer loses the advantage of a low repair fee, and consumers choose to repair independently. The following Proposition 1 evaluates the effectiveness of Policies N, B, and R in reducing sales and increasing repair demand. A more detailed summary is presented in Table ?? in Appendix A.

**Proposition 1.** Policy R is more effective in reducing sales and increasing repair demand compared to Policies N and B, but only if the following conditions are met simultaneously: i) consumers’ repair cost \(c\) is low, ii) the manufacturer’s repair cost \(c_r\) is high, and iii) consumers’ valuation of product repairability \(m\) is low. Otherwise, Policy B increases sales or decreases repair demand. Additionally, the effectiveness of Policy R improves with an increase in retail price \(p\), or an increase in \(k\) (provided \(m\) is sufficiently low).

Environmental policymakers have proposed RTR as a way to reduce new product sales, promote repair, and prolong product life. However, achieving these objectives is conditional, as outlined in Proposition 1. Failure to meet these conditions can lead to unintended consequences, such as the manufacturer raising repair fees and abandoning the repair market at a lower threshold compared to Policies N and B, i.e., \(c_r^R \leq c_r^N\), as seen in Lemma 5. Consequently, sales under Policy R may be higher than Policies N and B, while the repair demand is not. In other words, high repair costs for consumers create a situation where the manufacturer can ensure that consumers either buy a new product or turn to them for repairs. This explains why Apple’s self-service repair has been criticized by RTR activists, who accuse Apple of not wanting consumers to repair its products. The service comes at a high price which is more expensive than using Apple’s repair service. It also requires consumers to read lengthy instruction manuals and use heavy suitcases that are shipped with Apple’s repair toolkit, all contributing to a high consumer repair cost (Hollister 2022).

If the manufacturer’s repair cost \(c_r\) is low, Policy B is more effective in increasing repair demand than Policy R. This is because a low \(c_r\) enables the manufacturer to offer a more attractive repair fee under Policy B, due to the government subsidy \((f^{B*} - s^* < f^{R*})\). Consequently, the repair demand under Policy R is not the lowest, and the sales of new products are higher compared to Policy B.

As stated in Lemma 2, augmenting \(m\) leads to an increase in both the sales of new products and the demand for repair. Nonetheless, the effect on sales surpasses that on repair demand, given the manufacturer’s ability to set the repair fee. To attain the desired outcome of reducing sales and
boosting repair demand, Policy R necessitates a low value of \( m \). By setting \( m \) at a low level, the growth in sales is constrained. Nevertheless, when combined with a low consumer repair cost, it encourages self-repairs during the second period. As a result, the total sales in both periods under Policy R are lower compared to those under the other two policies.

Proposition 1 suggests that Policy R is more effective than other ones in decreasing sales and increasing repair demand for high-priced products. This is because the high price of new products reduces their purchase utility, making consumers more likely to pursue independent repairs. Furthermore, as product repairability increases, Policy R becomes even more effective in reducing sales and increasing repair demand, provided that \( m \) is sufficiently low. A low \( m \) restricts the increase in sales of new products, which, coupled with an increase in \( k \), leads to greater attractiveness of independent repair. This, in turn, boosts repair demand and reduces total sales.

4.2. Comparison of profit

In this section, we will initially investigate the effects of policies on the repair fee. Subsequently, we will discuss the manufacturer’s preference for the three policies.

**Proposition 2.** \( f^{B*} > f^{N*} > f^{R*} \).

Proposition 2 demonstrates that the repair fee for Policy B is the highest, while under Policy R, the manufacturer offers the lowest repair fee. It is because as indicated by Lemma 4, gaining a portion of the repair bonus, the manufacturer charges a higher repair fee in Policy B compared to Policy N. This mechanism is similar to the subsidy effects on consumer pricing documented in previous studies (e.g., Fan and Zhang 2022). However, Policy R involves two forces reducing the manufacturer’s repair fee below that of Policy N. Firstly, competition from independent repairers encourages the manufacturer to lower her repair fee to maintain repair profit, as, otherwise, she only profits from new product sales. Secondly, by providing repair resources, the manufacturer can boost consumer demand, which, in turn, allows for a reduction in the repair fee, thus further increasing the demand for repair. Next, Proposition 3 characterizes the conditions that determine whether Policy B or R maximizes the manufacturer’s profitability.

**Proposition 3.** Policy R maximizes the manufacturer’s profitability under the following conditions:

i. \( c \geq \hat{c} \) and either (a) \( m \geq m_0 \) and \( c_r \geq c_{r2} \) or (b) \( m \leq m_0 \) and \( c_r \geq c_{r1} \)

ii. \( c < \hat{c} \) and either (a) \( c_{r1} \leq c_r \leq \hat{c} \) and \( m \geq m_1 \) or (b) \( c_r \geq \hat{c} \), \( m \geq m_3 \), or (c) \( m_2 \leq m \leq m_3 \) and \( c_r \geq c_{r3} \geq \hat{c} \),

where \( m_0 = \frac{(1-\alpha)(2-\theta)(p-c_p)}{(1-\theta)k \alpha^2} \), \( c_{r2} \in (c_r^R, c_r^N) \), \( c_{r1} \in (0, c_r^R) \), and \( c_{r3} \in (\hat{c}, c_r^N) \). Otherwise, Policy B is superior.
Proposition 3 suggests that the manufacturer’s preference for a particular policy depends on three factors: consumers’ independent repair cost, \( c \), their valuation of availability of repair resources, \( m \), and the manufacturer’s repair cost, \( c_r \). Figure 1 illustrates these results. As a reminder, Lemmas 3 and 4 demonstrate that Policy B dominates Policy N, rendering the latter irrelevant.

To explain the results, we first define two effects: the sale-boost effect, which occurs under Policy R when providing repair resources leads to an increase in the sales of new products, and the repair-margin effect, which is observed under Policy B when the manufacturer benefits from the repair bonus. According to Lemma 3, when the consumers’ independent repair cost is high (i.e., \( c \geq \hat{c} \)), they are unlikely to repair the failed product themselves. In such cases, the repair-margin effect will prevail if \( c_r \) is sufficiently low (\( c_r \leq c_{r1} \)) and the consumers’ valuation of repair resources availability is low \( (m \leq m_0) \), as shown in Figures 1(a) and 1(b). This is because low \( c_r \) reinforces the repair-margin effect, while low \( m \) curbs the sale-boost effect. As a result, the manufacturer can earn a higher repair profit under Policy B. Furthermore, the lower effective repair fee of Policy B leads to an increased demand for repair beyond that of Policy R.

In contrast, the manufacturer decidedly benefits from Policy R when \( m \) and \( c_r \) are high, i.e., \( m \geq m_0 \) and \( c_r \geq c_{r2} \). In such cases, the sale-boost takes precedence over repair-margin as repair costs are prohibitively high. Accordingly, the increase in sales profits, resulting from consumers’ appreciation of the availability of repair resources, compensates for the loss of repair profits, leading to higher overall profits for the manufacturer. The situation becomes intriguing in conditions \( i.(a) \) and \( i.(b) \). We find that for high values of \( m \), Policy B is more likely to outperform Policy R when \( c_r \leq c_{r2} \). A low \( c_r \) enables the manufacturer to dominate the repair market. It may be expected that implementing Policy R when \( m \geq m_0 \) would lead to a significant sale-boost effect, reducing the demand for repair and the manufacturer’s control over the repair market \( (\frac{dcR}{dm} < 0) \). However, when the manufacturer’s repair cost is so low that the repair profit under Policy B outweighs the additional new sales profit of Policy R, then Policy B can outperform Policy R. Similarly, in \( i.(b) \), due to the low value of \( m \), the sale-boost effect is insignificant. However, sufficiently high values of \( c \) and \( c_r \) ensure the manufacturer’s control over the limited repair market. As a result, the sale-boost effect is strong enough for Policy R to dominate Policy B.

Likewise, we interpret the results for a situation where \( c \leq \hat{c} \). Our analysis reveals that under Policy R, the manufacturer earns a higher profit than under Policy B when \( c_r \leq \hat{c}_r \), and both \( m \) and \( c_r \) are high (see Figures 1(c) and 1(d)), which is similar to the sale-boost effect observed when \( c \geq \hat{c} \) (i.e., condition \( i.(b) \)). Lemma 5 further demonstrates that under Policy R, consumers repair the product independently, thereby completely cannibalizing the manufacturer’s repair stream when \( c_r \geq \hat{c}_r \). On the other hand, when \( m \) is sufficiently low \( (m \leq m_2) \), Policy B is more profitable for the manufacturer, while Policy R is preferred when \( m \geq m_3 \) (as shown in Figures 1(e) and 1(f)).
is evident that with a low enough $m$, Policy B prevails because the sale-boost effect is minimal. However, a relatively high $m$ (i.e., $m \geq m_3$ with $m_3 < m_0$) may make the sale-boost effect higher than the repair-margin effect weakened by the high repair cost ($c_r \geq \bar{c}_r$ with $\bar{c}_r < c_R$), and in this case, Policy R prevails. For moderate values of $m$, the dominance between the sale-boost effect and the repair-margin effect hinges on the value of $c_r$. Policy R outperforms B when a sufficiently high $c_r$ diminishes the repair profit.

**Observation 1** When $c$ is high or both $c$ and $c_r$ are low, the manufacturer’s preference for Policy R grows as $k$ increases; The opposite is observed when $c$ is low and $c_r$ is high.

Observation 1, as illustrated in Figure 1, indicates that the manufacturer can accrue more benefits under Policy R as $k$ increases, provided that either her repair cost is low or consumers bear a high repair cost. Figures 1(a)-1(d) illustrate the conditions under which Policy R dominates Policy B, and the region where Policy R is more advantageous expands with an increase in $k$. If the base independent repair cost for consumers is sufficiently high, they do not have the incentive to repair the failed product themselves, as explained in Lemma 5. Consequently, upon product breakdown, they will have to turn to the manufacturer to purchase a new product or repair the existing one. This allows the manufacturer to control the repair market and set the repair fee in such a way that
it can benefit from the repair margin effect when the repair cost is low or from the sale-boost effect when the repair cost is high.

On the other hand, if the base independent repair cost for consumers is low, the manufacturer will lose the repair profit. Hence, the manufacturer will only be inclined to increase repair resources if she can control the repair market. This happens when the manufacturer’s repair cost is sufficiently low. If the manufacturer’s repair cost is high, increasing the value of $k$ will alter the manufacturer’s preference from Policy R to B, as observed in Figures 1(e) and 1(f).

This observation sheds light on the reason why companies like Apple, Google, and Samsung have started providing repair information, tools, and spare parts to consumers, facilitating self-repairs (Ognenova 2022). Given the complexity of high-tech consumer electronic products, the cost of repairs can be very high for consumers, which can discourage them from attempting self-repairs (Clover 2022). Moreover, having access to proper technologies, tools, and information provides these companies with the means to lower repair costs so that they can gain control of the repair market if it is profitable.

4.3. Comparison of environmental impact

To investigate the environmental impact of a product, it is essential to adopt a life-cycle perspective. As per the existing framework proposed in the literature (Agrawal et al. 2012), we divide the life cycle into three phases, namely production, use, and disposal. The total environmental impact of a product depends on the volume of products in each phase, multiplied by the per-unit impact of the corresponding phase. To represent the per-unit impact due to the production of a new product and due to the disposal of an end-of-life product, we use $i_p$ and $i_d$, respectively. For the per-unit use impacts of new and old products (used and repaired), we use $i_{un}$ and $i_{ur}$, respectively. It is important to note that the energy efficiency of products tends to degrade with use, as observed in refrigerators and automobiles (Cooper and Gutowski 2017). Therefore, we assume that the use impact of an old product is higher than that of a new one, i.e., $i_{ur} \geq i_{un}$. Finally, the total environmental impact of the product can be determined by combining the impacts of the three phases.

$$E^i = (D_1^i + D_2^i)(i_p + i_{un} + i_d) + (D_r^i + \theta D_1^i)i_{ur}. \quad (7)$$

The first term calculates the total environmental impact of new products sold in Periods 1 and 2. The second term evaluates the use-phase impact of used and repaired products in Period 2. We present our findings on the environmental impact of three policies in Proposition 4. Figure 2 illustrates these results.

**Proposition 4.** Policy R is the superior environmental option only when conditions including $c \leq \bar{c}$, sufficiently low $i_{ur}$, $m \leq m_2$, and $c_r \geq c_{r4} \in (\bar{c}_r, c_{rN})$ are met. Otherwise, Policy B exhibits a superior impact.
Proposition 4 shows that Policy B and Policy R are more environmentally friendly than Policy N. Policy B results in higher repair demand and lower sales in Period 2 compared to Policy N, making it a better choice for the environment since new products have a higher environmental impact than used products. Policy R could perform better than Policy B if it leads to lower sales and higher repair demand, which happens when $c_r$, $c_r^r$, and $m$ are low, as shown in Proposition 1. However, Policy R may not outperform Policy B if the per-unit use impact of a used product is not sufficiently low. This is because Policy R increases demand, leading to a higher environmental impact in Period 2. Thus, for Policy R to remain environmentally superior, the per-unit use-phase impact of a used product must be sufficiently low.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure2.png}
\caption{\(c \leq \hat{c}\) and \(i_{ur} = 0\) (\(\alpha = 0.5, \theta = 0.5, p = 0.3, c_p = 0.26, k = 0.5, c = 0.2, i_p = 0.1, i_{id} = 0.1, i_{un} = 0\))}
\end{figure}

4.4. Comparison of consumer surplus

Policy B appears to be more attractive to consumers than Policy N, given its lower effective repair fee. In this section, we analyze the results comparing Policy B with Policy R and identify the conditions under which either policy yields the highest consumer surplus. For the sake of conciseness, we provide the formulation of consumer surplus under different policies in the proof of Proposition 5 in Appendix A. Proposition 5 presents the results and Figure 3 illustrates them.

**Proposition 5.** Policy R maximizes consumer surplus when

\begin{enumerate}
  \item \(c \geq \hat{c}\) and either of the following four conditions is met: (1) \(\alpha \leq \bar{\alpha}\) and \(c_r \geq c_r^5\), (2) \(\alpha > \bar{\alpha}\), \(\theta \geq \bar{\theta}\), and \(c_r \geq c_r^5\), (3) \(\alpha > \bar{\alpha}\), \(\theta < \bar{\theta}\), \(m \geq m_4\), and \(c_r \geq c_r^6\), (4) \(\alpha > \bar{\alpha}\), \(\theta < \bar{\theta}\), \(m \leq m_4\), and \(c_r > c_r^5\).
  \item \(c \leq \hat{c}\) and either of the following two conditions is met: (5) \(m \geq m_5\) and \(c_r \geq c_r^5\), (6) \(m \leq m_5\) and \(c_r \geq c_r^7\),
\end{enumerate}

where \(c_r^5 \in (0, c_r^R]\), \(c_r^6 \in (c_r^R, c_r^N]\), \(c_r^7 \in (\bar{c}_r, c_r^N]\), \(\bar{\alpha} = \sqrt{3} - 1\), and \(\bar{\theta} = \frac{\alpha^2 + 2\alpha + 1}{4\alpha^2 - 1}\). Otherwise, Policy B outperforms R in consumer surplus.

According to the findings of Lemmas 4 and 5, when \(c_r \geq c_r^N\), consumers are limited to only purchasing a new product under Policy B. However, under Policy R, consumers have the option of either buying a new product or repairing the failed one. Hence, the consumer surplus derived from
Policy R surpasses that of Policy B when $c_r \geq c_r^N$. If $c_r \leq c_r^N$, the following results are obtained: When consumers’ independent repair costs are high, i.e., $c \geq \hat{c}$, they have to rely on the manufacturer for repairs, regardless of the policy. We demonstrate that Policy R’s superiority over Policy B is contingent on a sufficiently high $c_r$, specifically $c_r \geq c_{r5}$ or $c_r \geq c_{r6}$. This is because Policy B’s effective repair fee increases more significantly than Policy R’s with an increase in $c_r$ (i.e., $\frac{df^B_s - s^*_s}{dc_r} > \frac{df^R_s}{dc_r}$), reducing the former policy’s price advantage. Additionally, Policy R’s inherent added purchase utility could lead to a higher consumer surplus than Policy B. A low value of $\alpha$ implies a low reuse value for used products, leading to an increased likelihood of consumers purchasing new products when $\alpha$ is sufficiently low ($\alpha < \bar{\alpha}$). Policy R provides additional purchase utility, making it superior to Policy B in terms of consumer surplus, provided that the manufacturer retains control of the repair market. This requires the manufacturer’s repair cost to be high enough ($c_r > c_{r5}$) yet low enough to ensure consumers keep using the manufacturer’s repair service ($c_{r5} < c_r^B$) as depicted in Figure 3(a) (condition (1)). Similarly, when both $\theta$ and $\alpha$ are sufficiently high, Policy R remains dominant (condition (2)), as illustrated in Figure 3(b). When $\theta > \bar{\theta}$ and the likelihood of product breakdown is low, the consumer surplus generated through purchasing a new product exceeds that of repair, even though the value of the repaired product is high ($\alpha > \bar{\alpha}$). Therefore, Policy R, which benefits from additional purchasing utility, is still dominant over Policy B when $c_r > c_{r5}$. In the scenario where $\alpha$ is high and $\theta$ is low, a low value of $\theta$ indicates a high likelihood of breakdowns. Under Policy R, a sufficiently high value of $m$ ($m \geq m_4$) enhances purchasing utility, thereby increasing consumer surplus. However, a high value of $m$ reduces the manufacturer’s control over the repair market as $\frac{dc_r^R}{dm} < 0$. Thus, Policy R generates the highest consumer surplus only in the following cases, as illustrated in Figure 3(c): i) when $m$ is sufficiently high such that the manufacturer is better off not providing repair service at all due to high repair costs ($c_r > c_{r6} > c_r^B$) (condition (3)), or ii) when $m$ is sufficiently low, yet the manufacturer has full control over the repair market due to low repair costs (condition (4)).

If $c < \hat{c}$, the manufacturer competes with consumers who independently repair their products, and to retain their repair service, the manufacturer needs to ensure the repair cost is sufficiently low ($c_r \leq \bar{c} < c_r^B$) compared to when $c \geq \hat{c}$. In this case, $m$ plays a critical role, and Policy R benefits consumers more when both $m$ and $c_r$ are high. As repair costs increase ($\bar{c} \leq c_r \leq c_r^N$), the advantage of Policy B’s low effective repair fee diminishes, and Policy R becomes more attractive for consumer surplus when $m$ is high (condition (5)). However, Policy R remains preferable to Policy B for consumer surplus, even with a low $m$, when $c_r$ and $f^R$ are high enough to significantly reduce the repair fee advantage of Policy B (condition (6)). Figure 3(d) illustrates these two conditions where Policy R outperforms Policy B.
We now characterize the policy that is the most beneficial for the manufacturer, the environment, and the consumers simultaneously, identifying a win-win-win outcome. Proposition 6 presents the results and Figures 4(a)-4(c) illustrate them.

**Proposition 6.**

i Policy B can generate a win-win-win outcome in either of the following cases:

1. $c \geq \hat{c}$ and $c_r \leq \min\{c_{r1}, c_{r2}, c_{r5}, c_{r6}\}$.
2. $c \leq \hat{c}$ and $c_r \leq \min\{\bar{c}_r, c_{r1}, c_{r5}\}$.
3. $c \leq \hat{c}$, $m \leq \min\{m_3, m_5\}$ and $\bar{c}_r \leq c_r \leq \min\{c_{r3}, c_{r4}, c_{r7}\}$.

ii Policy R cannot generate a win-win-win outcome, but it results in a win-loss-win outcome, when either of the following sets of conditions is satisfied:

1. $c \geq \hat{c}$ and $c_r \geq \max\{c_{r1}, c_{r2}, c_{r5}, c_{r6}\}$.
2. $c \leq \hat{c}$ and $c_r \leq \bar{c}_r$, $m \geq \max\{m_1, m_5\}$ and $c_r \geq \max\{c_{r1}, c_{r5}\}$.
3. $c \leq \hat{c}$ and $c_r \geq \bar{c}_r$, $m \geq m_2$ and $c_r \geq \max\{c_{r3}, c_{r7}\}$.
4. Loss-win-win outcome when $c \leq \hat{c}$, $i_{sr}$ is sufficiently low, $m \leq m_2$, and $c_r \geq \max\{c_{r4}, c_{r7}\} > \bar{c}_r$.

Figure 3 Consumers’ preference for Policy i

4.5. Win-win-win outcomes

We now characterize the policy that is the most beneficial for the manufacturer, the environment, and the consumers simultaneously, identifying a win-win-win outcome. Proposition 6 presents the results and Figures 4(a)-4(c) illustrate them.
Proposition 6 follows from Propositions 3-5. According to Proposition 4, providing the repair bonus results in the lowest environmental impact if \( c \geq \hat{c} \) or \( c \leq \hat{c} \) and \( c_r \leq \hat{c}_r \). In the case of Policy B, both consumers and the manufacturer earn the maximum benefit only if \( c_r \) is sufficiently low (Propositions 3 and 5). These requirements are captured in conditions (1) and (2).

For \( c \leq \hat{c} \) and \( c_r \geq \hat{c}_r \), a win-win-win outcome of Policy B also depends on a low \( m \) next to a low \( c_r \) (Propositions 3 and 5). These requirements are captured in conditions (1) and (2).

Proposition 4 suggests that for Policy R to result in the lowest environmental impact, certain conditions need to be met: \( m \leq m_2, c_r \geq \hat{c}_r \), and \( c \leq \hat{c} \). However, in such situations, the manufacturer prefers Policy B. Therefore, Policy R cannot benefit both the manufacturer and the environment. Propositions 3 and 4 reveal that a high repair cost \( (c_r \geq \max(c_{r3}, c_{r4}, c_{r7})) \) makes Policy R favorable to both consumers and the environment, thus generating a win-win outcome. We also identify the conditions under which Policy R is optimal for consumers and the manufacturer.

Propositions 3 and 5 state that when \( c \geq \hat{c} \), if the manufacturer’s repair cost is high, either the manufacturer or consumers benefit from Policy R, leading to conditions in \( \text{ii.}(4). (a) \), as shown in Figure 4(a). When \( c \leq \hat{c} \), high \( c_r \) and \( m \) are necessary to ensure that the manufacturer’s profitability, which declines due to the loss of repair profits, improves under Policy R (conditions \( \text{ii.}(4). (b) \) and \( \text{ii.}(4). (c) \)). In this case, as observed in Figure 4(b) and 4(c), Policy R is most beneficial to the consumers but not to the environment.

![Figure 4 Win-win-win outcome](image)

4.6. Social welfare comparison

Proposition 7 presents the government’s policy preference. Figure 5 illustrates these results.

**Proposition 7.** The government prefers Policy R when

- \( i \) \( c \geq \hat{c} \) and either (a) \( \alpha > \bar{\alpha}, \theta < \bar{\theta}, m \geq m_6 \), and \( c_r \geq c_{r9} \), or (b) \( \alpha \leq \bar{\alpha} \) and \( c_r \geq c_{r8} \), or (c) \( \alpha > \bar{\alpha}, \theta \geq \bar{\theta}, \) and \( c_r \geq c_{r8} \), or (d) \( \alpha > \bar{\alpha}, \theta < \bar{\theta}, m \leq m_0 \), and \( c_r > c_{r8} \)
$ii \ c \leq \hat{c} \ and \ either \ (a) \ c_r \leq \bar{c}_r, \ m \geq m_r \ and \ c_r \geq c_{r8}, \ or \ (b) \ c_r \geq c_{r10} \geq \bar{c}_r \ and \ c_p \leq \frac{2-\alpha}{2} p, \ m_8 \leq m \leq m_9, \ or \ (c) \ c_r \geq \bar{c}_r, \ c_p \leq \frac{2-\alpha}{2} p \ and \ m \geq m_9,$

where $c_{r9} \in (c_r^L, c_r^N), c_{r8} \in (0, c_r^L),$ and $c_{r10} \in (\bar{c}_r, c_r^N)$.

Otherwise, Policy B is preferred.

Here, we make the assumption that $c_p \leq \frac{2-\alpha}{2} p$ to simplify our analysis. In the later part of this section, we will conduct a numerical analysis to explore the scenario where $c_p \geq \frac{2-\alpha}{2} p$, as illustrated in Figure 6. Policy N will not be covered in our discussion since it is outperformed by Policy B.

We first analyze the case where $c \geq \hat{c}$. As both $\alpha$ and $\theta$ impact social welfare in a manner akin to consumer surplus, we exclude their discussion and refer readers to Proposition 5 for relevant discourse. In addition to these two factors, we observe that for Policy R to generate higher consumer surplus and profit than Policy B, it needs to rely on a high $c_r$. This is because Policy B’s repair bonus decreases as $c_r$ increases, leading to a higher effective repair fee and a decrease in repair demand. This allows Policy R to offer higher consumer surplus and profit, especially when repairability valuation is low (i.e., $m \leq m_6$). In such a scenario, the competition between repairing and purchasing is not significant, and both consumers and the manufacturer benefit. Consequently, Policy R outperforms Policy B when $c_r$ is relatively low (i.e., $c_{r8} \leq c_r \leq c_{r9}$).

Figure 5 Government’s preference for Policy i in the case of $c_p < \frac{2-\alpha}{2} p$
An interesting observation is made when $m_6 > m_4$. It indicates that if $m$ is moderate (i.e., $m_4 < m < m_6$), Policy B cannot generate more social welfare than Policy R at a high $c_r$, despite consumers earning more surplus under Policy B. Two potential reasons could explain this outcome. Firstly, the government incurs a high additional expenditure under Policy B due to the highest repair demand (see Proposition 1). Secondly, the manufacturer has the potential to generate more profit with moderate $m$ under Policy R, supported by the fact that $m_6 < m_6$ (see Proposition 3).

Under Policy R, when $c \leq \hat{c}$ and $c_r \leq \bar{c}_r$, both consumer surplus and manufacturer’s profit are higher than that under Policy B provided that $m$ and $c_r$ are high. These result in higher social welfare in these situations compared to Policy B. Now, when $c \leq \hat{c}$ and $c_r \geq \bar{c}_r$, Policy R outperforms B if $m$ is sufficiently high. A high $m$ ensures sales profits that suffices to offset the corresponding welfare losses from a high repair cost; Hence, it results in a higher social welfare under Policy R. In case of a sufficiently low $m$ (i.e., $m \leq m_4$), Policy B maximizes the social welfare, although its consumer surplus is not higher than that of Policy R when $c_r$ is high. This is because, according to Lemma 3, the manufacturer only gains the sales profit, under Policy R as consumers use the independent repair services. As $m$ decreases, the manufacturer’s profit decreases as well, and Policy B becomes more profitable. The increase in profits of Policy B offsets the loss in its consumer surplus, resulting in more social welfare. However, Policy B can only remain optimal if $c_r$ is sufficiently low as $m$ increases, the gap in profit between the two policies narrows. For a situation where $c_p \geq \frac{2-\alpha}{2} p$, from Figure 6, we can draw Observation 2.

**Observation 2** If $c \leq \hat{c}$, $c_r \geq \bar{c}_r$, and $c_p \geq \frac{2-\alpha}{2} p$, the government prefers Policy R when either i) $m$ is high or ii) $c$ is relatively high, $m$ is moderate and $c_r$ is high or iii) $c$ is relatively low, $m$ is not high, and $c_r$ is high. Otherwise, Policy B is preferred.

![Figure 6 Government’s preference for Policy i when $c_p \geq \frac{2-\alpha}{2} p$](https://ssrn.com/abstract=4463563)

Figure 6 provides evidence of the robustness of our main findings. The difference is that for low values of $m$, Policy R may be more effective in maximizing social welfare than Policy B if consumers’
base independent repair costs are sufficiently low and product acquisition costs are high. The possible reasons are: As mentioned in Proposition 7, in the case of low \(m\), Policy R cannot generate the highest social welfare due to the low manufacturer’s profit. However, suppose \(c_r\) is sufficiently high. In that case, the social welfare under Policy B may be lower than that under Policy R. First, when \(\bar{c}_r \leq c_r \leq c_r^N\), Policy B is the government’s preferred option and thus offers a repair bonus. However, a high acquisition cost can lead to a significant increase in government expenditure \((\frac{dc_p}{dc_r} > 0)\), which can seriously harm social welfare. Additionally, the effective repair fee under Policy B increases \((\frac{d(f^B-*s^B)}{dc_r} > 0)\) as \(c_r\) increases, which can hurt manufacturer profitability and consumer surplus. As a result, Policy R may dominate Policy B in terms of social welfare. Secondly, when \(c_r \geq c_r^N\), the manufacturer only earns profits from sales under either Policy R or Policy B. Using Propositions 3 and 5, we find that Policy B maximizes profit while Policy R generates the highest consumer surplus. With low consumer repair costs and high product acquisition costs, the impact of Policy R on improving consumer surplus is more significant than that of Policy B on profit. Therefore, Policy R generates the highest social welfare in this scenario.

5. Extensions

In this section, we explore four extensions to our base model. Given the complexity of the base model, further extensions are analytically intractable leading us to rely on numerical analysis.

5.1. Endogenous Retail Price

We assume that the manufacturer determines both the repair fee and the retail price with the latter remaining constant over time (consistent with Gulserliler et al. (2022) and Jin et al. (2023)). The results are presented in Lemmas ?? in Appendix B. We use \(PN\), \(PB\), and \(PR\) for the notation corresponding to Policy N, B, and R, respectively. Overall, our analysis indicates that consumers’ responses to these policies are expected to remain similar to the baseline model.

One notable difference from the baseline model is the order of repair fees, specifically \(f^{PB*} > f^{PR*} > f^{PN*}\). As in the base model, Policy B entails the highest repair fee. However, surprisingly, the manufacturer sets a higher repair fee under Policy R than under Policy N. This is because as consumers become more willing to purchase due to the availability of repair resources, the manufacturer has the incentive to increase the retail price, which we show as \(p^{PR*} > p^{PN*}\). As a result, the manufacturer raises the repair fee to generate more repair profits. Regarding the retail price, we find two key results. First, with the manufacturer’s repair monopoly, we observe \(p^{PR*} > p^{PN*} > p^{PB*}\). This implies that the manufacturer charges a higher retail price under Policy R than under Policy N. Interestingly, Policy B features the lowest retail price. This is because a low effective repair fee, i.e., \((f^{PB*} - s^{PB*} < f^{PN*})\), incentivizes the manufacturer to lower the retail price to keep sales competitive. Second, if \(c\) is sufficiently low to encourage independent repair and
break the repair monopoly, we observe $p^{PR*} < p^{PN*} = p^{PB*}$. This means that if the manufacturer loses the repair business and earns profits only from sales, he must reduce the retail price to stimulate new product purchases.

We confirm that the effectiveness of Policy R in decreasing sales and increasing repair demand remains similar to the base model. Additionally, our numerical analysis in Appendix B, Figures ??-?? reveals that Policy R fails to achieve a win-win-win outcome even when the manufacturer sets the retail price. In contrast, Policy B still generates the win-win-win outcome, provided that $c_r$ and $i_{ur}$ are sufficiently low. In cases where $i_{ur}$ is not sufficiently low, Policy N minimizes the environmental impact instead of Policy B.

Under Policy B, consumers benefit from the lowest effective repair fee ($f^{PB*} - s^{PB*} < f^{PN*}$), leading to a higher willingness to repair than under Policy N. Therefore, the repair demand generated by Policy B is sufficiently high making Policy N superior to Policy B in environmental aspects if $i_{ur}$ is not sufficiently low. However, different from the base model, Policy B cannot generate the win-win-win outcome if $c_r \geq c_{r2}^{PR}$, which occurs when consumers earn the highest surplus from Policy R due to the manufacturer’s strategic price response. In this scenario, the retail price decision is limited by consumers’ independent repair cost under Policy R. Conversely, under Policy B, the manufacturer controls both the sales and repair markets, limiting the consumer surplus.

5.2. Endogenous Repairability Score

Policy R can incentivize manufacturers to improve the repairability of their products by enhancing the accessibility and availability of repair tools, spare parts, and repair information, and eliminating part pairing, among other measures. For example, Apple has redesigned the internal components of the iPhone 14 to comply with Right to Repair (RTR) regulations, resulting in a significant improvement in repairability. iFixit, an expert in device repair and RTR advocacy, awarded the iPhone 14 a repairability score of 7 out of 10, the highest ever given to an iPhone (Wiens 2022). To further encourage manufacturers to improve repairability, we introduce the repairability level, $k$, as a decision variable, along with the repair fee. The cost of setting the repairability level is captured by a quadratic function $\lambda k^2/2$, where $\lambda$ represents the cost coefficient. The manufacturer’s profit function is thus formulated as follows:

$$\max_{f_i,k} \Pi_i = (p - c_p)(D_i^1 + D_i^2) + (f_i - c_r)D_r^i - \lambda k^2/2. (8)$$

The optimal outcomes for Policies N and B remain unchanged from Lemma 3 and 4. We denote the corresponding notation for Policy R as $ER$, and Appendix C’s Lemma ?? presents the optimal $k$, repair fee, and consumers’ repair decisions. As in the base model, the manufacturer charges the
highest repair fee under Policy B. However, the repair fee is higher under Policy R than under N when \( c_r \) is low, as evidenced in Lemmas 3, 4, and ?? (see Appendix C for the latter). This is because a lower \( c_r \) allows the manufacturer to increase repair profits by charging a high repair fee and setting a low \( k \) to limit sales cannibalization. This result is verified by \( \frac{dk_{R^*}}{dc_r} > 0 \).

Our numerical analysis in Appendix C, Figures ??-??, shows that the results of the base model regarding the effectiveness of Policy R in decreasing sales and increasing repair demand together with the win-win-win outcome of the base model remain valid. It is important to note that Policy R, with manufacturer setting \( k \), cannot guarantee the most environmentally-friendly outcome unless the conditions outlined in Proposition 4 are satisfied. However, even under these conditions, Policy B may prove to be more profitable than Policy R. Therefore, achieving a triple-win outcome is not feasible under Policy R in this particular scenario. There are two key differences between the base model and our analysis. First, the combination of low \( c_r \) and low \( m \) makes Policy B a win-win-win policy. This result is driven by the manufacturer’s decision on \( k \), where \( \frac{dk_{R^*}}{dc_r} > 0 \). When repair costs are low, a manufacturer may choose to set a low \( k \), thereby amplifying the repair margin effect. Additionally, if \( m \) is high, the sales-boost effect kicks in, allowing consumers to obtain more surplus from purchasing under Policy R. Second, Policy B may fail to generate a win-win-win outcome if \( c_r \geq c_{ER} \) (i.e., the manufacturer loses the repair business under Policy R). In this scenario, the manufacturer’s sole interest lies in increasing sales. To maintain profits, they may set a high \( k \) to improve consumers’ willingness to buy, which also reduces their repair cost. As a result, consumers may obtain the highest surplus under Policy B.

5.3. Repair Café

In this extension, we aim to incorporate the role of Repair café into our modeling framework. The Repair café movement originated in the Netherlands in 2007, and it has since expanded globally to over 2500 Repair cafés (Repair Cafe 2022). At these cafés, consumers can learn how to repair a wide range of broken products, such as audio and video devices, laptops, and phones, and acquire the necessary skills to do so. One potential government strategy to encourage self-repair among consumers could be to allocate funding to these organizations, thereby improving the accessibility of repair services. For instance, the Scottish Government and Zero Waste Scotland recently announced a £310,000 project to support the expansion of Repair cafés (Case 2021), while the Repair café Foundation has raised approximately $525,000 through grants from the Dutch government, foundations, and donations, as reported by The New York Times (McGrane 2012).

The role of Repair café can be incorporated into our modeling framework in two scenarios: First, a government investment, \( \delta \), in Repair cafés can reduce the independent repair costs by a factor of \((1 - \delta)\). Secondly, investment in Repair cafés increases the accessibility of repair resources, leading to an increase in consumers’ valuation of repairability from \( m \) to \((1 + \delta)m\).
Lemma ?? in Appendix D highlights that first, in comparison with the base model, the thresholds related to $c$ increase when Repair café is introduced, indicating that consumers with high independent repair costs are more likely to switch from the manufacturer’s to independent repair services. Second, we demonstrate that the manufacturer needs to lower its repair cost to retain control of the repair market when consumers have access to Repair cafés to hone their repair skills.

Lemma ?? in Appendix D states that the investment in Repair café to improve $m$ may not necessarily increase the repair demand, despite the decrease in repair fee. This is because, firstly, the threshold related to $c$ at which the customer decides to perform self-repair under Policy R is lower than that in the base model. Therefore, only those consumers with sufficiently low repair costs have the potential to repair the broken product by themselves. Secondly, we observe that if consumers’ repair cost is high, the manufacturer will set a repair fee that makes purchasing a new product more attractive, resulting in no consumer using the repair service. Furthermore, in addition to decreasing the repair fee, the Repair café also encourages consumers to buy new products due to their appreciation of the increase in repair accessibility.

Lemmas ?? and ?? highlight the potential double-edged nature of Repair café, indicating that decisions regarding investment in these organizations should consider the potential impact on new product sales and repair volumes. Despite the potential benefits of Repair café, our findings suggest that it cannot help Policy R achieve a win-win-win outcome.

5.4. Secondary Market

Consider that in practice, consumers may opt to purchase a secondhand product instead of a new one. According to a survey, 62% of Gen Z and millennial consumers reported looking for secondhand items before considering purchasing new ones (Walk-Morris 2022). Furthermore, there are various peer-to-peer platforms, such as Craigslist, Kijiji, and Face Bay (Jiang et al. 2017), that provide consumers with a marketplace to trade unwanted products. Therefore, in our analysis, we incorporate the possibility that consumers may buy or sell used products in Period 2. Below, $SN$, $SB$, and $SR$ are used to represent the notation corresponding to Policies N, B, and R, respectively.

**Policies N and B.** In Period 2, a consumer can choose to either continue using their product and gain a utility of $\alpha v$, or sell it and buy a new one with a utility of $v + p_u - p$, where $p_u$ is the price of a used product. If the product breaks down, the consumer can choose to repair it with a utility of $\alpha v - f^i + s \cdot \mathbb{1}_{i=B}$, buy a used product with a utility of $\alpha v - p_u$, or purchase a new one with a utility of $v - p$. Additionally, a consumer who did not buy a product in Period 1 may choose to buy a used product in Period 2, earning a utility of $\alpha v - p_u$.

**Policy R.** In Period 2, assuming the product does not fail, the consumer faces two choices: either to continue using it, receiving a utility of $\alpha v$, or to sell it and purchase a new product, with a utility
of $v + p_u - p + mk$. If the product does fail, the consumer has four options: to have it repaired by the manufacturer, yielding a utility of $\alpha v - f$; to have it repaired independently, with a utility of $\alpha v - (1 - k)c$; to purchase a used product, with a utility of $\alpha v - p_u$; or to buy a new product, with a utility of $v - p + mk$. Finally, a consumer who does not purchase a product in Period 1 may opt to purchase a used product in Period 2, with a utility of $\alpha v - p_u$.

In Appendix E, Lemmas ?? demonstrate the optimal repair fee, repair bonus, price of the used product, and consumers’ repair decision under Policies N, B, and R. By conducting a comparative analysis, we confirm the validity of the base model’s results regarding the manufacturer’s repair fee decisions and the effectiveness of Policy R in decreasing sales and increasing repair demand. Our numerical study (Figures ??) confirms that the base model’s main insights about the triple-win scenario still hold. However, Policy R fails to produce a triple-win scenario, even in the presence of a secondary market. Conversely, Policy B can generate a triple-win scenario if both $c_r$ and $m$ are low. If $c_r$ is low and $m$ is high, Policy R maximizes consumer surplus, making it the preferable option. If the manufacturer does not control the repair market, Policy B can only produce a triple-win scenario if $c$ is high. When $c$ is low, consumers repair their products independently, and Policy R generates more surplus for consumers who sell their used products. When $c$ is high, Policy B can produce a triple-win scenario only if $m$ is high or both $m$ and $i_{ur}$ are low. If $i_{ur}$ is high, Policies N and B are more detrimental to the environment than Policy R.

6. Conclusion

The RTR movement has prompted the introduction of government legislation to incentivize repairs. This study examines two workable policies: (1) a subsidy for consumers who choose to repair and (2) a policy mandating manufacturers to provide repair resources to customers facilitating independent repair. We investigate which of these policies would be more advantageous for the manufacturer, consumers, the environment, and society, and provide our findings below.

*The effectiveness of RTR policies in decreasing sales and increasing repair volume:* Our analysis indicates that Policy B is more effective than Policy N, but not always superior to Policy R. Policy B is the best option when consumers can repair their products cost-effectively or both the consumer and manufacturer repair costs are low. When consumers incur low repair costs but the manufacturer’s repair cost is moderate and repair services are accessible, Policy B is still the most effective. However, if the manufacturer’s repair costs are not low, Policy R can achieve its objective if consumers can repair their products cost-effectively and their valuation of repair resources availability is low. Policy B is ineffective when high repair costs force manufacturers to increase the price of the repair to a level resulting in consumers only buying new products.

*Manufacturer’s repair fee response:* Compared to other policies, Policy B offers the highest repair fee due to the repair bonus. The repair fee under Policy R is determined by the manufacturer’s
pricing strategy. For established products with fixed prices, such as refrigerators and washing machines, the repair fee is lowest under Policy R. However, if the manufacturer needs to set the price for a new product, the repair fee and retail price will both be higher under Policy R compared to Policy N. Notably, the manufacturer charges the lowest retail price under Policy B.

The manufacturer’s profitability: To increase profits, the manufacturer can charge a high repair fee with a repair bonus, under Policy B. Our findings show that Policy R may increase the manufacturer’s profitability, despite the conventional belief that it hurts her profitability by reducing repair profit. This is realized when their repair costs are not low, and consumers place a high value on the availability of repair resources. This is because easier repairs make products more appealing to consumers. However, consumers with high independent repair costs still rely on the manufacturer’s repair service. To clarify, Policy R is deemed effective solely in facilitating consumers’ independent repair when the cost of repair is not prohibitively high. To alleviate the situation by decreasing repair costs, we demonstrate that Repair cafés can play a pivotal role. This highlights the government’s commitment to promoting and expanding the scope of Repair cafés.

Government preference and effects of policies on the triple bottom line outcomes: Our analysis demonstrates that Policy B consistently outperforms N in terms of either consumer surplus or environmental impact. Additionally, Policy R is effective at maximizing consumer surplus only if the manufacturer’s repair cost is high, leading to either increased product repairability or reduced repair costs as the manufacturer’s repair monopoly dissipates. In terms of environmental impact, Policy R is most effective if consumers’ independent repair costs and their valuation of the availability of repair resources are low, the manufacturer’s repair cost is high, and the per-unit environmental use impact of a product is low. In conclusion, only Policy B can yield a win-win-win outcome.

Policy R can benefit the manufacturer and consumers or consumers and the environment, but it presents a contradiction between increasing manufacturer profits and protecting the environment. Protecting the environment requires reducing sales and increasing demand for repairs, which only occurs if consumers repair the product themselves, causing the manufacturer to lose out on repair profits. Moreover, for Policy R to be environmentally friendly, each product’s use impact must be low enough; otherwise, Policy R’s promotion of consumer repairs may result in increased sales and corresponding increases in use impact, which is harmful to the environment.

From the standpoint of social welfare, it is generally advisable to apply Policy B to products with low manufacturers’ repair costs, while reserving Policy R for those with high manufacturers’ repair costs. This is because a low manufacturer’s repair cost makes repairs economically attractive for the manufacturer, thanks to the subsidy provided under Policy B, thereby enhancing consumer surplus. However, when the manufacturers’ repair cost is high, implementing Policy R under certain conditions can help break the monopoly of the manufacturer, leading to an increase in
consumer surplus, such that its positive impact on social welfare offsets any potential negative impact on the manufacturer’s profitability. Nevertheless, it is worth noting that in some cases, consumers may still be unable to repair the product themselves under Policy R due to the high independent repair cost, yet the policy can still maximize social welfare. Moreover, while a high valuation of repairability can make Policy R optimal, it may be due to increased sales, which goes against the main purpose of the RTR. Therefore, markets, where consumers’ valuation of repairability is moderate, may be better suited for Policy R, whereas those with a low valuation of repairability would be more suitable for Policy B.

The findings of this research offer valuable insights for policymakers. Specifically, rather than imposing blanket regulations for all products, policies should differ based on the repairability of each product. Subsidy policies can be applied to products that are easy to repair, while policies ensuring the availability of repair resources can be implemented for products that are harder to repair. To enhance environmental protection measures, the government should regulate manufacturers to reduce the use-phase impact of their products, rather than simply mandating the availability of repair resources. In addition, in accordance with the RTR principles, the government should invest in training consumers’ repair skills to reduce the cost of independent repairs and reduce dependence on manufacturers for repairs. Such measures can effectively promote independent repair and reduce waste.

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