Can Consumer Complaints Reduce Product Reliability? Should We Worry?

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Abstract

We analyze a monopolist's pricing and product reliability decision in a model where consumers are entitled to product replacement if the product fails, but have heterogeneous costs of exercising this right. Our main result shows that, under some conditions, a decrease in consumers expected claiming cost leads to a decrease in products reliability but an increase in profits and welfare. This result is robust to a number of extensions. Our results are in line with anecdotal evidence suggesting that changes in consumers' claiming cost can be induced by both third parties (governments, consumers' organizations, private enterprises, etc.) and firms. More precisely, since, under some conditions, profit and welfare align, public initiatives oriented to lower consumers' claiming cost will be ultimately joined by firms which benefit from further increases in complaints.

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1 Introduction

In the past five decades consumers have increasingly resorted to customers' claims in response to the purchase of faulty units. Several factors may contribute to explain this observation. First, legislation has

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granted an increasing number of rights to consumers. In 1962, Kennedy's Administration introduced the Consumer Bill of Rights introducing, for the first time, the rights to Safety, Choose, Be Informed, and Be Heard. Later, in 1985, additional consumer rights were added: Satisfaction of Basic Needs, Redress, Consumer Education, and Healthy Environment. Since then, similar legislations have been passed in most countries. Second, markets have experienced a proliferation of institutions aimed at easing the process of complaining by consumers. Examples of these abound: small courts, class action lawsuits, public agencies (e.g., NHTSA in the US) and consumer associations (e.g., Consumer Union provides information or claims on consumer's behalf). At the same time, developments in information and communication technologies (ICT) have made simpler for consumers to voice their complaints. For example, car-related complaints directed to the National Highway Traffic Safety Administration (NHTSA) rose from dozens to thousands when e-mail and online complaints were first introduced in 1995. In the same way, customer engagement platforms like "getsatisfaction.com" (US) or "miqueja.com" (Spain) provide online services to handle complaints, to mediate between consumers and firms, and to rank firms according to the number of complaints received and the responses given to them. Finally, firms have recently taken upon themselves to handle consumer complaints effectively; more than 40,000 firms use "getsatisfaction.com" in the US.[1] In view of these trends, it is natural to ask to what extend changes in consumers' claiming cost —and thus in consumers' complaining behavior— affect product reliability, firm's profit, and welfare.

This paper studies the effects that an exogenous reduction in consumers claiming cost has on product reliability, private profits, and social welfare. In our model, a monopolist chooses the price and the reliability rate of the product it manufactures. Product's reliability is defined by the probability that the product is not defective. Providing a more reliable product or replacing a faulty unit are costly actions for the firm. At the same time, increasing product's reliability lowers the firm's expected cost associated with replacements. This effect, that we termed *replacement effect*, increases with the number of replacements requested.

In our benchmark model consumers with heterogeneous valuations for the product are either claimants at no claiming cost or non-claimants (or, alternatively, they have an extremely high claiming cost). Their utilities depend on whether the product turns out to be defective or not. After buying a faulty product, a claimant files a costless complaint to pursue a replacement and a non-claimant scraps the product.[2]

[1] Among these firms: Procter and Gamble, Microsoft, Panasonic, and Amazon. It is also worth noting that most sales incorporate explicit and implicit warranties to which firms usually comply.

[2] We indifferently refer to consumer complaint and replacement request because both are in the same nature of incurring

We assume that consumers only know if they are claimants or non-claimants after purchasing a faulty product. Consumers anticipate the expected future cost associated with defective units when calculating their willingness to pay for the product. In our benchmark case, this cost comprises a cost associated to the disposal of defective units —in case the consumer is non-claimant. We call *demand effect* to the effect of an increase in product's reliability on consumers' willingness to pay. The higher the probability that the consumer is non-claimant, the lower his willingness to pay but the larger the demand effect. In other words, as it becomes less likely for a consumer to request a replacement, his willingness to pay becomes more sensitive to the product's reliability. For this benchmark case, a reduction in consumers' claiming cost is represented by an increase in the likelihood of being claimant and thus, an increase in the number of claimants among buyers.

We first show that product's reliability decreases when the number of claimants increases (consumers' claiming cost decreases). This result is driven by the impact that a reduction in the demand effect has on the incentives to provide reliability. In particular, an increase in the likelihood of requesting replacement of defective units decreases the demand effect by reducing the probability of scrapping faulty units. Notice, however, that any increase in the number of claimants also increases the replacement effect as more consumers will now request a replacement. We prove that any increase in the number of claimants, induces a reduction in product's reliability.

Secondly, we show that an increase in the number of claimants increases firm's profit. When the number of claimants, consumers' willingness to pay increases but firm's expected cost of replacements increases as consumers are more likely to request replacements. In the benchmark case, we show that any increase in the number of complaints, induces an increase in profits. Additionally, firm's profit and social welfare are aligned; the increase in claimants increases firm's profit and social welfare albeit reduces product's reliability.

In this benchmark case, reducing consumers' claiming cost and increasing the number of socially desirable claimants are linked together by the simplifying strong assumption that claimants have always zero claiming cost. This scenario is extended to the more complex (and realistic) case where consumers have heterogeneous claiming costs and they choose whether to pursue a replacement of a faulty product even when it is costly to do so (or even socially undesirable). In particular, a reduction in consumers' claiming cost may increase the number of claimants but it may decrease firm's profits; similarly, when

a claiming cost in order to get some reward when the product does not perform as expected. The model concentrates on replacements but any other form of repairing or compensation would have same qualitative analysis.

complaints are socially undesirable, social welfare may also decrease. Moreover, if a reduction in consumers claiming cost that increases the number of claimants has an small impact in increasing consumers' willingness to pay, product reliability may also increase. This may happen when the demand effect does not decrease and there is an increase in the replacement effect due to more replacement requests.

Consequently, it is not obvious the extent of our results presented in the benchmark case. We show that the main results still hold under mild assumptions over claiming cost distributions in the following way. We prove that when the number of claimants is large enough any reduction in consumers' claiming cost induces an increase in the number of complaints and profits and a reduction in product's reliability. Additionally, when the number of claimants is large enough firm's profit and social welfare are aligned; then, a decrease in consumers' claiming cost increases firm's profit and social welfare albeit reduces product's reliability.[3]

The key assumption over distributions is to assume that when a reduction in consumers' claiming cost motivates an increase in the number of claimants, it also reduces the expected cost of claimants; in the limit, expected claiming cost are zero. That is, the expected claiming cost to be decreasing in the number of claimants. Under this assumption, replacement requests may not be socially desirable when the number of claimants is small; the firm may not benefit from those replacements. However, when the number of claimants is above certain threshold, any additional replacement request is socially desirable, increases firm's profits (aligning private and social incentives), and motivates a reduction in product reliability. We show that there are many common families of distributions, like Exponential and Pareto, that satisfy this property.

We also extend both models to prove that our main results are robust to a number of extensions where: (i) product reliability depends on product design expenditures, (ii) replacement requests may not be honored, i.e., *no strict liability*, (iii) replaced units can also fail, and (iv) defective units may generate additional costs to consumers.

A remarkable implication of our results is that if a firm was allowed to make an exogenous and local change in consumers' claiming cost, it would prefer to discourage consumers from complaining only if consumers' claiming cost is high enough. Conversely, when consumers' claiming cost are low enough and the number of claimants is large, the firm is better off by encouraging consumers' complaints. Moreover, welfare also increases with the number of claimants. Consequently, a policy implication of our

[3]From the benchmark case there are also some trivial implications: product's reliability may decrease and firm's profit may increase when consumers' claiming cost decreases; moreover, there is always a reduction in consumers' claiming cost that reduces product reliability and increases profits and welfare.

results is that policy makers should allocate efforts in promoting and simplifying complaints; eventually, firms will find rewarding to join or complement these initiatives. Consistent with this policy implication are policy interventions and legislation designed to reduce consumers' claiming cost –the US experience from the 1960s onwards– and supported by consumer movements. Also consistent with our results is the recent trend among important firms toward facilitating consumers' complaints through private on-line initiatives. Our results suggest that these policies may increase firms' profits and social welfare even when they may be reducing products' reliability.

Many papers study the effect of product liability on product reliability. When consumers perfectly observe product reliability, a change in product's liability from consumer to producer can negatively affect quality (Oi, 1973). When consumers have misperceptions about product reliability, producer liability (to consumers and to the state) can be used to restore the incentives to provide reliability (Spence, 1977).[4] Under firm's liability, there may exists a non-monotonic relationship between (the degree of) product liability and the ex-ante investment to improve reliability when the firm can take preventive ex-post solutions, e.g., recalls, (Chen and Hua, 2012). However, unlike our model, these approaches assume it is costless for consumers to complain when the product fails. More in the direction of our work, Simon (1981) introduces costly litigation to resolve consumers' disputes. A reduction in consumers' litigation cost induces an increase in product reliability. Yet, in her model consumers are restricted to buy one unit of the product, eliminating the demand effect driving our non-monotonic effect of consumers' claiming cost on reliability.[5] Along the same line Hua (2011) analyzes firm's incentives to recall a defective product under alternative liability assumptions when this action imposes a cost to consumers. Unlike this paper, his model assumes that quality is exogenous and consumers have already purchased the product.

Another strand of literature related to our work analyzes the use of warranties in the market.[6] In a symmetric information environment, Matthews and Moore (1987), Murthy and Djamaludin (2002), Huang, Liu, and Murthy (2007) analyze the role of warranties as an exploitation device, affecting firm's choice of product reliability and demand. In an asymmetric information environment, Mann and Wissink (1990) and Shieh (1996) model the use of (money-back and replacement) warranties as signals of quality; also Padmanabhan (1995) and Lutz and Padmanabhan (1998) use extended warranties to discriminate consumers (screening). Again, these articles assume it is costless to exercise a warranty or a consumer

[4]Swan (1970) and Spence (1975) focus on the optimal level of reliability. Goering and Read (1995) show that product reliability of durables may depend on industry structure and on whether the product is rented or sold. We are not interested directly in the optimal level of reliability but in its changes when considering reductions in consumers' claiming cost.

[5]Shavell (2007) incorporates other important aspects of product liability for accidents.

[6]See Emons (1989) for an extensive survey and Priest (1981) for an investment approach.

right.[7] An exception is Palfrey and Romer (1983) which studies the relationship between optimal warranty and buyer-seller disputes. However, they assume homogeneous consumers and exogenous product reliability.[8,9]

To the best of our knowledge, our paper is the first to model the relationship between demand effect (recognized in the literature of warranties) and consumers' claiming cost (recognized in the literature on product liability) to analyze the incentives to provide reliability; and to show the existence of a non-monotonic relation between consumers' claiming cost and product reliability (and profits).

The rest of the paper is organized as follows. Section 2 introduces the benchmark model. Section 2.2 performs the comparative statics and derives our main results and section 2.3 introduces the welfare analysis. Section 3 extends the benchmark model to incorporate heterogeneity in consumer valuations. Section 4 extends the welfare analysis showing that profits and welfare are aligned. Section 5 shows some numerical examples and section 6 provides some evidence of the demand and replacement effects. Section 7 discusses the robustness of our results to the extensions mentioned above. Finally, 8 concludes. The Appendix contains all proofs.

2 Benchmark model

A monopolist chooses its product's price p and reliability rate $x \in [0,1]$ to maximize its profit anticipating that buyers may request a replacement if the product sold is faulty. We take the product reliability rate x to be the probability of functioning. We assume as Chen and Hua (2012) and Matthews and Moore (1987) that reliability is observed by consumers.[10,11] The firm grants all replacement requests (there is binding legislation) by exchanging faulty products for new units with the same reliability rate.[12] Consumers

[7] Most results linking warranty conditions and product reliability (including the results on the signaling approach to warranties) rely on the assumption that consumers exercise their warranties and that consumers' claiming cost is negligible.

[8] Other mechanisms –repeated purchases, reputation, cooperation, and brand name– can be used to explain the provision of reliability (Klein and Leffler, 1981; Greif, Milgrom, and Weingast, 1994). In our static environment, however, these mechanisms have no bite.

[9] Our work also relates to the literature on consumers' complaint behavior (CCB), which focuses on the consumers' reaction to dissatisfaction (Chebat, Davidow, and Codjovi, 2005; Owens and Hausknecht, 1999).

[10] Our results, as in Chen and Hua (2012) and Matthews and Moore (1987), still hold if reliability x is private information. When the choice of x is privately observed and disclosure costs are small enough the firm prefers to disclose its reliability rate to avoid being perceived as the lowest quality type. This happens, for example, when consumers' visual inspection reveals x.

[11] We additionally provide (in section B.4) a dynamic version with asymmetric information about product reliability, showing that our results hold when the incentives to provide reliability arise from future sales (representing the demand effect in this static model with observable reliability).

[12] Our results are robust to situations where i) replacements are not granted (see appendix B.5); and ii) replaced units are non-defective.

differ in their claiming cost which may lead to some consumers requesting a replacement and some scrapping faulty products.[13]

2.1 Consumers and monopoly

In the benchmark case we assume that there is a unit mass of heterogeneous consumers whose claiming cost is simplified to be either 0 or $+\infty$ with probability μ and $1-\mu$, respectively.[14] That is, on average a proportion μ of buyers always request a replacement at no cost and a proportion $1-\mu$ of buyers never request a replacement of a defected unit. Consumers realize their claiming cost after purchasing the product and replacement requests are always granted. This dichotomy in consumers' claiming cost represents a particular case of our model where consumers claiming cost can take any value in $\mathbb{R}_+$; this simplification helps us to present the main driving force of our results and we extend to a general case in section 3.

Each consumer derives utility $v \in [0,\overline{v}]$ from consuming one unit of a non-faulty good and utility zero if the product is faulty or if the consumer chooses not to buy it. Valuations v are heterogeneous according to some cumulative distribution G, i.e., $v \sim G : [0,\overline{v}] \to [0,1]$ with density g. In what follows we assume that $1-G$ is twice-differentiable and log-concave.[15] For a non-trivial case, the value of $\overline{v}$ is assumed to be high enough. We also assume that independently of his valuation, any consumer has the same probability μ of being a claimant. Each consumer decides sequentially whether to purchase one unit of the product at price p and reliability rate x, and whether to pursue a replacement if the product breaks down. Then, the expected utility of buying a unit of a product with reliability rate x (observable) at a price p is

$$EU(p,x;\mu,v) = (x+(1-x)\mu)v-p. \tag{1}$$

The consumer pays a price p in exchange of a unit of the product that works well with probability x, enjoying a utility of v. With probability $(1-x)\mu$ the product breaks down and the consumer requests a replacement, getting the expected benefit of v (he request a replacement each time the product breaks down until receiving a non-defected unit). With probability $(1-x)(1-\mu)$ it breaks down and

[13] We use Nash Subgame Perfection as an equilibrium concept.

[14] Our results do not change qualitatively if the claiming cost is positive, instead of zero, with probability μ, as long as it is low enough.

[15] We may also assume that g is log-concave, which is a stronger assumption.

the consumer scraps the product. A consumer purchases the product if $EU(p,x;\mu,v) \geq 0$. Note that if $\hat{v}$ buys, any $v > \hat{v}$ also buys, then given μ the marginal consumer for a product (p,x) is characterized by $EU(p,x;\mu,\hat{v}) = 0$, $\hat{v}(p,x;\mu)$.

A monopoly produces a good with reliability x at a unit cost $c(x)$, that is increasing, twice-differentiable and convex function of x; i.e., $c' > 0$ and $c'' > 0$. A replacement unit also cost $c(x)$ and, thus, the expected cost of selling a unit of the product is $c(x) + \frac{(1-x)}{x}\mu\, c(x)$; the manufacturing cost $c(x)$ plus the expected cost associated with replacements $\frac{c(x)}{x}$ when the product fails (either the sold unit or the replaced units) and the consumer requests replacements (i.e., $(1-x)\mu$). To ensure that some level of reliability is always desirable we further assume $c(0) > 0$ and $\lim_{x\to 0} c'(x) = 0$. These assumptions say that some cost must be borne in order to manufacture a unit of a product of the lowest reliability level, and that the marginal cost of providing a low level of reliability is small.[16] Furthermore, we assume that manufacturing a defect-free product is too expensive, i.e., $c(x=1) > \overline{v}$ (or $\lim_{x\to 1} c(x) = +\infty$). We assume that $c(x)\frac{(2-x)}{x}$ is convex to guarantee second order conditions. The monopoly profit of selling a unit at price p and reliability x is

$$\Pi(p,x;\mu) = \left(p - c(x) - \frac{(1-x)}{x}\mu\, c(x)\right)\Big[1 - G(\hat{v}(p,x;\mu))\Big], \tag{2}$$

where $\hat{v}(p,x;\mu)$ is defined by $EU(p,x;\mu,\hat{v}) = 0$. To complete the characterization of the equilibrium we need to provide optimality conditions for the choice of price p and reliability rate x. Since there is a unique marginal consumer $\hat{v}$ for any pair (p,x), choosing (p,x) is equivalent to choosing $(\hat{v},x)$ and we can write expected profits for a pair $(\hat{v},x)$ as

$$\begin{aligned}
\Pi(\hat{v},x;\mu) &= \Big(x\hat{v} + (1-x)\mu\,\hat{v} - c(x) - \frac{(1-x)}{x}\mu\, c(x)\Big)\Big(1 - G(\hat{v})\Big), \\
\Pi(\hat{v},x;\mu) &= (x + (1-x)\mu)\Big(\hat{v} - \frac{c(x)}{x}\Big)\Big(1 - G(\hat{v})\Big). \qquad (3)
\end{aligned}$$

Notice that the firm faces a downward sloping demand; then, the unit mark-up depends on the marginal

[16] Alternatively we can assume that $c(0) = 0$, and incorporate an additional cost per replacement request $c_r > 0$ as in Mann and Wissink (1990). In this case the cost associated with replacements would be $(1-x)\mu(c(x)+c_r)$. With $c(0) > 0$ or with $c_r > 0$ when $c(0) = 0$ we avoid the uninteresting and unrealistic case in which $x = 0$ minimizes the unit cost of selling a unit of the product.

consumer $\hat{v}$. Differentiating with respect to $\hat{v}$ we get

$$\hat{v} - \frac{1-G(\hat{v})}{g(\hat{v})} = \frac{c(x)}{x}. \tag{4}$$

This equation represents the usual "marginal revenue equal to marginal cost" condition. The firm excludes some consumers in order to increase the unit mark-up. Differentiating Π with respect to product reliability x gives

$$c'(x) = [1-\mu]\,\hat{v} + \mu\left[\frac{c(x)}{x^2} - \frac{(1-x)}{x}c'(x)\right]. \tag{5}$$

Equation (5) implicitly defines x which, together with the expression for $\hat{v}$, for the price above and the consumers buying decision, completely characterize the equilibrium. The left hand side of Equation (5) is the marginal cost of providing reliability. The right hand side represents the marginal benefit of providing reliability: the increase in the marginal buyer's willingness to pay for the product plus the reduction in the expected cost of replacement. In words, the firm provides costly reliability in order to reduce the cost associated with replacements and to increase the willingness to pay for the product of the marginal buyer, which is ultimately appropriated with a higher price.

We make two remarks on the right hand side of Equation (5). First, notice that the firm's problem is to generate and appropriate the consumer's willingness to pay (WTP) for the product, given by $WTP := v\,[x + (1-x)\mu]$, that increases with product reliability x and with the possibility of requesting replacements. Consequently, consumer's willingness to pay increases in the number/proportion of claimants (μ). The impact of product reliability in consumer's willingness to pay, defined as *demand effect*, is $\frac{\partial \mathrm{WTP}}{\partial x} := v\,[1-\mu]$. Calculated at the marginal consumer $\hat{v}$, it represents the marginal effect of reliability on the marginal consumer, first formulated by Spence (1975). Our framework explicitly models product reliability as a dimension of quality, but the importance of this dimension is affected by the possibility of requesting replacements, as the *demand effect* decreases in μ. This implies that replacement requests and product reliability are substitutes. In other words, when consumers anticipate they can benefit from a product's replacement in case of failure, their willingness to pay for the product increases, but their willingness to pay to increase reliability decreases.

Second, attending replacements costs $\frac{(1-x)}{x}\,\mu\,c(x)$ to the firm and we define a *replacement effect* to $\frac{\partial}{\partial x}\frac{(1-x)}{x}\,\mu\,c(x) = \mu\,[-\frac{c(x)}{x^2} + \frac{(1-x)}{x}c'(x)]$ in equation (5); that is, the effect of increasing reliability on the expected cost associated with replacements. Notice that increasing reliability affects firm's replacement cost with two opposite effects: first directly by reducing the probability of consumer requests –first term in brackets decreases the replacement cost– and indirectly by increasing the unit cost of replacement units –second term in brackets increases the replacement cost. The magnitude of the replacement effect is positively related to μ. The sign of the replacement effect can be either positive or negative; however, the direct impact is most likely to be dominant. Our assumptions $c(0) > 0$ and $\lim_{x\to 0} c'(x) = 0$ imply that the replacement effect is negative at least for small values of x since $\lim_{x\to 0} -\frac{c(x)}{x^2} + \frac{(1-x)}{x} c'(x) = -\infty < 0$.[17]. In an extension, product reliability depends on expenditures in product design (appendix B.2); if this is the case, there is only a direct effect and the replacement effect is always negative.[18]

2.2 Reductions in consumers' claiming cost

We now introduce our main results on how changes in consumers' claiming cost affects product reliability and profits. In this benchmark case a reduction in consumers' claiming cost is represented by an increase in the number of consumers with zero claiming cost that coincides with the increase in the number of claimants μ.

Proposition 1. *Firm's profits increase in the number of claimants and product reliability decreases in the number of claimants; i.e.,* $\frac{\partial \Pi}{\partial \mu} > 0$ *and* $\frac{\partial x}{\partial \mu} < 0$.

Proposition 1 states that, in this simple model, an increase in the number of claimants (μ) has a monotonic impact on profits and product reliability. For the first result, notice that an increase in μ increases consumers' willingness to pay for the product, as it is more likely that they request a replacement when the product fails. This increase in consumers' willingness to pay is appropriated (at least partially) with an increase in price and in markups. Additionally, an increase in the number of claimants increases firm's replacement cost as more replacements are requested, reducing the unitary markup. For the benchmark case a replacement request, if generated, implies no cost for the consumer, guaranteeing that the positive effect on consumer willingness to pay is high and it always dominates the negative effect on replacement cost, and thus there is an increase in unitary markups and, consequently, in profits. In other words, the firm can profit from replacements through a higher markup (net of replacement cost). Consequently the firm will always increase profits when more consumers are claimants.

[17]For example, it is always negative for the cost function $c(x) = \beta + x^2$ as long as $\beta > 1/27$.

[18]As it will be clear later, our results are straightforward when the replacement effect is positive; consequently, we focus on the case where the replacement effect is negative.

For the second result, we should recall that an increase in the number of claimants also increases the *replacement effect* (i.e., $\frac{\partial\mu\frac{(1-x)}{x}c(x)}{\partial x}\uparrow$) and reduces the *demand effect* (i.e., $\frac{\partial\text{WTP}}{\partial x}\downarrow$). Again, as the replacement request implies no cost for the buyer, the reduction in the *demand effect* is greater than the increase in the *replacement effect*, and product reliability decreases.

The intuition of this results is simple. Recall that product reliability and replacement requests are substitutes as both increase the willingness to pay and the firm's markup. When replacement requests have no cost for the consumer, it is always desirable for the firm that consumers voice a complaint when receiving a defected unit. In other words, when consumer's claiming cost is zero increasing reliability as a mechanism to increase markups is more expensive for the firm than just replacing defected units by new ones. This replacement choice, however, depends on consumers claiming cost (that sometimes is too high) and the firm's response to the few number of request is to substitute this cheap and efficient request mechanism by a costly increase in product reliability. Consequently, when consumer's claiming cost decreases and the number of replacement requests increase, then firm's incentives to provide reliability decreases.

We can summarize this model as a particular case where requests are always desirable because they are Pareto efficient. Then,

2.3 Welfare

We now turn to the welfare analysis and the implications of our results. The surplus created when a consumer with valuation v buys one unit of the product is $vx - c(x)$. If additionally this buyer requests a replacement at no claiming cost when the product results to be defective, the expected surplus generated is instead $vx - c(x) + (1-x)(v - \frac{c(x)}{x}) = v - \frac{c(x)}{x}$.

Since consumers with $v \geq \hat{v}$ buy a unit of the product with reliability x, the total number of units traded is $1 - G(\hat{v})$. Among these buyers, a proportion μ request a replacement at zero claiming cost when the product received fails. Consequently, the welfare generated when trading products with reliability x, the marginal buyer is $\hat{v}$, the proportion of claimants is μ, and $v \sim G$ is

$$\begin{aligned} W(x,\hat{v};\mu) &= \int_{\hat{v}}^{\overline{v}} (1-\mu)[vx - c(x)] + \mu\left(v - \frac{c(x)}{x}\right) dG, \\ &= [\mu + (1-\mu)x]\left(\frac{\int_{\hat{v}}^{\overline{v}} v\, dG}{1-G(\hat{v})} - \frac{c(x)}{x}\right)[1-G(\hat{v})], \\ &= [x + (1-x)\mu]\left(E[v|v \geq \hat{v}] - \frac{c(x)}{x}\right)[1-G(\hat{v})]. \end{aligned} \tag{6}$$

As formulated by Spence (1975), for a given $\hat{v}$ the welfare accounts for the surplus generated by all buyers, that is represented by the average buyer $E[v|v \geq \hat{v}]$, while the firm considers only the marginal consumer valuation $\hat{v}$ (the valuation of the consumer that motivates the firm not to increase the price).

There are two sources of inefficiency: an inefficient exclusion of consumers by firms —due to asymmetric information– and an inefficient level of product reliability. The first inefficiency is due to the typical exclusion of consumers resulting from the monopoly's profit maximizing behavior. On the one hand, it is efficient to supply goods to all consumers with $v \geq \tilde{v} := \frac{c(x)}{x}$. However, the firm's pricing strategy restricts demand to those consumers with $v \geq \hat{v} := \frac{c(x)}{x} + \frac{1-G}{g}$, which is strictly higher than $\tilde{v}$.

The second inefficiency on product reliability rate is a consequence of the observation made by Spence (1975). He claims that the firm may overprovide or underprovide quality depending on how an increase on quality affects the marginal and the average consumer. Given a marginal buyer $\hat{v}$ the optimal level of product reliability is characterized by the first order condition of W with respect to x, that we can expressed as

$$c'(x) = [1-\mu]\, E[v|v \geq \hat{v}] + \mu\left[\frac{c(x)}{x^2} - \frac{(1-x)}{x}c'(x)\right]. \tag{7}$$

Notice that this condition depends on the valuation of the average consumer $E[v|v \geq \hat{v}]$. The firm provides reliability considering the impact on the marginal consumer $\hat{v}$ instead of the average consumer $E[v|v \geq \hat{v}]$. As $E[v|v \geq \hat{v}] \geq \hat{v}$ for any $\hat{v}$, our case is particular application where the firm chooses a reliability rate that is lower than the optimal one. The magnitude of this inefficiency depends on the consumers' claiming cost distribution, defined by μ in this benchmark case. Lemma 1 extends the results in Spence (1975) for this model.

Lemma 1. *For a given number of buyers the firm under-provides product reliability.*

In spite of this underprovision, product reliability converges to the optimal one as $\mu \to 1$. Additionally, as $\mu \to 1$ the cost $\frac{c(x)}{x}$ is minimized and the marginal consumer $\hat{v}$ chosen by the firm is reduced, increasing the number of buyers and, thus, welfare. Consequently, welfare increases as the number of claimants μ increases. These claims are summarized in the following proposition.

Proposition 2. *Welfare and Firm's profits are aligned and both increase with the number of claimants; i.e.,* $\frac{\partial W}{\partial \mu} > 0$ *and* $\frac{\partial \Pi}{\partial \mu} > 0$.

Proposition 2 states that, in this simple model, a reduction in consumers claiming cost has a direct impact in the consumer complaining behavior that is partially appropriated by the firm with a higher price. However, consumer surplus also increases, guaranteeing an increase in total welfare.

2.4 Discussion

In this benchmark model we have presented the main forces that drive the impact of a reduction in consumer's claiming cost, and an increase in the number of claimants, in product reliability, profits, and welfare. In this simple environment consumers surplus, profits, and welfare are all better off when all consumers request a replacement of a defected unit. In sum, the society is perfectly aligned in the desirability of promoting replacements request, disputes, and complaints.

This implications is not supported by the anecdotal evidence suggesting that the initiatives in the last decades have first been born in consumer movements, public agencies, and small courts. These initiatives have been supported by firms after some time.

This model, however, has one strong simplifying assumption: any replacement request implies either no consumer's claiming cost or an infinite claiming cost. This assumption has two implications. First, any replacement requested is socially desirable: replacement requests are made when they imply no consumer's claiming cost; so they generate always more expected value on consumers than the replacement cost incurred by the firm in replacing a defected unit.

The second implication, which follows directly from the first one, is that there is no need to worry about inefficient replacement requests. If the consumer's claiming cost is high, it may be the case that it is socially desirable that the consumer scraps the product. In the benchmark case, an inefficient replacement coincides with the case where the consumer does not have incentives to make a request.

This observation open the question of how results are affected when incorporating the real situation that some consumer may bear some positive consumer's claiming cost to request a replacement (or to make a complaint) that may lead to inefficiencies. To tackle this question, next section extends the model for the case where consumer requests depend on their claiming cost which follows some cumulative distribution in $\mathbb{R}_+$. The consumer replacement requests is the consequence of consumer's private incentives and he has no way to commit to certain future complaining behavior (like to make only socially desirable requests).

3 Extended Model: heterogeneous claiming costs

In this section we extend for the case where consumers' claiming cost is distributed in $\mathbb{R}_+$. In particular we assume that consumers' claiming cost is a proportion k of consumer valuation v, i.e., the cost of requesting a replacement of the product that a consumer values v is kv. This k has cumulative $F : [0,+\infty) \to [0,1]$ with finite mean; if $k > 1$, the cost of requesting a replacement is higher than consumer' valuation v.

Each consumer learns the value of his claiming cost only if the product fails. Each consumer decides sequentially whether to purchase one unit of the product at price p and reliability rate x, and whether to pursue a replacement if the product breaks down. We assume that the claiming cost is incurred only in the first replacement request, representing the time to learn how to request a replacement. Consequently, upon receiving a faulty product, since the claiming cost is sunk in the first replacement request, a consumer with claiming cost kv pursues a replacement if $v - kv \geq 0$.[19] Ex ante, the consumer anticipates that the probability of making a replacement of a defected unit is $\Pr(kv \leq v) := \Pr(k \leq 1) = F(1)$.

We assume that $k \sim F$ and $v \sim G$ are independent; thus, consumers' valuations v and claiming cost kv are positively correlated. This positive correlation may reflect the case in which consumers must spent time to request a replacement and a consumer with higher valuation has higher opportunity cost for his time. We leave for future work the adoption of alternative distributional specifications for k and v.[20]

The (ex-ante) expected utility of buying a unit of a product with price p and reliability rate x for a

[19] For the first replacement request the consumer incurs kv and receives a product that works well with probability x, enjoying utility v, and it breaks down with probability $1-x$. After this first request, a consumer has zero claiming cost and he will request replacements until receiving a non-defected unit. Then, $v = \sum_{i=0}^{+\infty}(1-x)^i x v$ represents the gross benefit of requesting a replacement after receiving a defected unit. This assumption simplifies the exposition of the results, allowing us to focus on the effect of repeated replacements on firm's costs. However, our results remain if the consumer incurs a claiming cost between $[0, kv]$ each time he requests a replacement.

[20] If we assume instead that consumers' claiming costs and valuations are independent, the expected number of requests of individual v is $F(v)$ (where F represents the cumulative of consumers' claiming cost K) and, aggregating across buyers with $v \geq \hat{v}$, gives the expected number of total requests $\int_{\hat{v}}^{\overline{v}} F(v)dG$.

consumer with valuation v is

$$EU(p,x;\mu,\alpha,v) = xv + (1-x)F(k=1)\big[v - vE[k|k \leq 1]\big] - p, \tag{8}$$

The consumer pays a price p in exchange of a unit of the product that works well with probability x, enjoying a utility of v. With probability $(1-x)F(1)$ the product breaks down and the consumer requests a replacement (each time the product breaks down until receiving a non-defected unit), getting the expected benefit of $v - vE[k|k \leq 1]$. With probability $(1-x)(1-F(1))$ it breaks down and the consumer scraps the product. The consumer purchases the product if $EU(p,x) \geq 0$. For simplicity we denote by $\mu \in [0,1]$ to the expected proportion of claimants, i.e., $\mu := F(1)$ (or the expected proportion of consumers that would request a replacement if the product fails). We additionally define

$$\alpha := 1 - E\big[k\,\big|k \leq 1\big] = \frac{\int_0^1 F(k)\mathrm{d}k}{F(1)}, \tag{9}$$

where $\alpha \in [0,1]$ represents the fraction of valuation v that claimants recovered when they choose to request a replacement of a defective unit (net of the claiming cost). With these definitions we can write $EU = v[x + (1-x)\mu\alpha] - p$. In out previous section $\alpha = 1$ and now $\alpha \leq 1$, implying that a consumer may incur some cost to request a replacement.

Given (p,x) we can identify the marginal buyer $\hat{v}$ from $EU(p,x;\mu,\alpha,\hat{v}) = 0$ and compute the demand $1 - G(\hat{v})$. The marginal buyer $\hat{v}$ decreases (and demand increases) in x, μ, and α; but increases in p.

The supply side is the same as in the benchmark case. A monopolist maximizes profits by selling a product at price p and reliability x. As in the benchmark case we can write expected profits for a pair $(\hat{v},x)$.[21]

$$\Pi(\hat{v},x;\mu,\alpha) = \left(\hat{v}(x + (1-x)\mu\,\alpha) - \frac{c(x)}{x}(x + (1-x)\mu)\right)\Big(1 - G(\hat{v})\Big). \tag{10}$$

Different to the benchmark case is that now the firm does not profit from replacement requests when α is low. That is, as consumers find too costly, on average, to request a replacement, the increase in their willingness to pay may not compensate the replacement cost incurred by the firm. This is true when $\hat{v}\alpha - \frac{c(x)}{x} < 0$.

[21] We consider the case where the firm makes a unique offer (p,x) to all consumers. The price discrimination case is left for future work.

We obtain firm's strategy $(\hat{v},x)$ from first order conditions. First, differentiating with respect to $\hat{v}$

$$\left[\hat{v}-\frac{1-G(\hat{v})}{g(\hat{v})}\right][x+(1-x)\mu\alpha]=\frac{c(x)}{x}[x+(1-x)\mu]. \tag{11}$$

Again, this equation represents the usual "marginal revenue equal to marginal cost" condition. However, this equation now shows that the marginal buyer faces some losses when requesting a replacement, represented by $\alpha < 1$, that cannot be appropriated by the firm. Differentiating Π with respect to product reliability x gives

$$c'(x)=\hat{v}\,[1-\mu\alpha]+\mu\left[\frac{c(x)}{x^2}-\frac{(1-x)}{x}c'(x)\right]. \tag{12}$$

With respect to the benchmark case (in Equation 5) Equation (12) includes a higher demand effect due to expected consumers' claiming cost α. As consumers must now bear some cost to request a replacement, they are willing to pay less for the product but they are willing to pay more for an extra level of product reliability. Formally, $WTP := v\,[x+(1-x)\mu\alpha]$ increases in α and $\frac{\partial \text{WTP}}{\partial x} := v\,[1-\alpha\mu]$ decreases in α. Accounting for consumers' claiming cost has two implications. First, the firm has more incentives to increase reliability with respect to our benchmark case; second, the firm may not always profit from consumers' requests. The latter implication affects our central results.

3.1 Reductions in consumers' claiming cost

We now extend our main results on how changes in consumers' claiming cost affects product reliability and profits. Recall that for any F we can calculate the number of claimants μ and the benefits consumers get when they request a replacement α. A reduction in consumers' claiming cost (a downward shift of F) affects both the number of complaints (μ) and the benefits from requesting a replacement (α) simultaneously. We begin our comparison with a comparative static analysis of marginal changes in α and μ separately and then we comment on joint changes.

Lemma 2. *Product reliability decreases in consumer's benefit from requesting a replacement , i.e.,* $\frac{\partial x}{\partial \alpha} < 0$*; firm's profit increases in consumer's benefit from requesting a replacement, i.e.,* $\frac{\partial \Pi}{\partial \alpha} > 0$.

An increase in the benefit from requesting a replacement increases the willingness to pay of consumers, allowing the firm to increase the price and, consequently, profits; it also reduces the *demand effect*, reducing the demand for reliability and, thus, product reliability. The intuition of these results is simple. When replacements are expensive consumers' willingness to pay for the product is low because with some probability the product will not work properly recovering small proportion of their valuation v, consequently their willingness to pay to increase reliability is high (high *demand effect*), i.e., the lower the α, the lower the WTP and the higher the $\frac{\partial \text{WTP}}{\partial x}$. Then, whenever requesting a replacement becomes more accessible (for example, given due to cost saving on-line initiatives) consumers' willingness to pay for the product increases, but their willingness to pay for reliability decreases. As the number of claimants μ does not change, the expected cost associated with replacements does not change neither.

Lemma 3. *Product reliability decreases in consumer complaints if consumer's benefit from requesting a replacement is high enough, i.e.,* $\frac{\partial x}{\partial \mu} < 0$ *if* $\alpha \hat{v} > \frac{c(x)}{x^2} - \frac{(1-x)}{x} c'(x)$. *Firm's profit increases in consumer complaints if consumer's benefit from requesting a replacement is high enough, i.e.,* $\frac{\partial \Pi}{\partial \mu} > 0$ *if* $\alpha \hat{v} > \frac{c(x)}{x} > 0$.

An increase in the number of claimants (μ) has a non-monotonic impact on profits and product reliability. An increase in μ increases consumers' willingness to pay for the product, as it is more likely that they request a replacement when the product fails; but the magnitude of this increment in willingness to pay depends on the expected benefit of requesting a replacement α, i.e., $\frac{\partial \text{WTP}}{\partial \mu} = (1-x)\,\hat{v}\,\alpha$. Additionally, an increase in the number of claimants increases firm's replacement cost as more replacements are requested, $\frac{\partial \mu \frac{(1-x)}{x} c(x)}{\partial \mu} = \frac{(1-x)}{x} c(x)$. If the benefit from requesting a replacement is high enough, the former effect dominates the latter and there is an increase in unitary markups and, consequently, in profits.

An increase in the number of claimants also increases the *replacement effect* (i.e., $\frac{\partial \mu \frac{(1-x)}{x} c(x)}{\partial x} \uparrow$) and reduces the *demand effect* (i.e., $\frac{\partial \text{WTP}}{\partial x} \downarrow$). Again, the reduction in the *demand effect* depends on consumers' benefit from replacement requests α. If the benefit from requesting a replacement is high enough, the firm can benefit from consumer requests and the change in the *demand effect* is larger than the change in the *replacement effect*, and product reliability decreases.

These non-monotonic results are driven by two forces; the existence of consumers' claiming cost and incomplete contracting in consumers' complaining behavior. On one hand, the existence of consumers' claiming cost is the only reason in the model that stop a consumer from complaining and we can interpret this claiming cost as a transaction cost. This transaction cost reduces profits and motivates an increase in product reliability to increase consumers willingness to pay (*demand effect*). Then, when the firm can benefit from consumer requests, a reduction in consumers' claiming cost generates an increase in the number of complaints that ultimately reduces product reliability x and increases profit Π.

On the other hand, since consumers cannot commit to pursue *only* efficient (albeit costly) complaints, reliability may increase and profit may decrease in the number of claimants. A replacement is efficient if and only if its benefit is larger than its total cost, i.e., if $v \geq k + \frac{c(x)}{x}$. When *only* efficient replacements are pursued the condition $\alpha\hat{v} - \frac{c(x)}{x} > 0$ is guaranteed and our results are stronger: *any* increase the number of claimants μ generates a reduction in product reliability and an increase in firm's profit. However, consumers can neither contract (by law) nor commit to efficient complaining: they request a replacement as long as $1 \geq k$ and thus inefficient replacements are possible. Consequently, the firm may not benefit from consumers' requests, in which case an increase in the number of claimants generates an increase in product reliability and a decrease in profits. Section 4.1 discusses a mechanism to deter inefficient complaints. If α is trivially high, then replacement requests are (on average) efficient and it is sufficient for our main result.[22]

As we anticipated at the beginning of this section, however, both the number of claimants and the benefit from requesting a replacement are closely related through the distribution of consumers' claiming cost F. For any F we can calculate the value of μ and α; then, a reduction in consumers' claiming cost affects both μ and α simultaneously. That is, a downward shift on F increases the number of claimants ($\Delta\mu \geq 0$) and also increases or decreases the expected benefit from requesting a replacement ($\Delta\alpha \lesseqgtr 0$). Consequently, the relation of μ and α with F will define our results.

We next introduce some reasonable strong assumptions that are discussed in detail in the Appendix C.2 . We restrict the set of distributions of consumers claiming cost $\mathbb{F}$ to those that allow us to write a function $\alpha(\mu) : [0,1] \rightarrow [0,1]$ that links μ and α with a continuous and differentiable function that satisfies the following properties,

ASSUMPTION 1: $\alpha'(\mu) > 0$, and

ASSUMPTION 2: $\lim_{\mu \to 1} \alpha(\mu) = 1$.

Assumption 1 says that consumers' average cost of requesting replacements is decreasing in the total number of requests/complaints. If μ increases, α increases and $E[k|k \leq 1]$ decreases.[23] Consequently, a reduction in consumers' claiming cost not only encourages consumers to be claimants but also reduces all claimants expected cost of doing so. This effect may be generated by an effective intervention or

[22] Notice that $\alpha v - \frac{c(x)}{x} > 0$ implies that $v - \frac{c(x)}{x} > E[k|k \leq v]$ where some replacements may still be inefficient.

[23] Certainly, there are more than one distribution (continuous, discrete, and mixed distributions) with same μ and α, and many sets $\mathbb{F}$ satisfying assumptions 1 and 2. We provide some examples but we do not need to distinguish among them.

may be generated by the spillovers of a particular intervention. That is, if there is an intervention helping consumers to handle their requests/complaints, then additional initiatives or mechanisms may arise that facilitate requests/complaints even further, guaranteeing a reduction in claimants' expected cost of requesting a replacement. For instance, suppose that a simplified claiming procedure is introduced increasing the number of consumers that now find worthy to claim. Then, the direct increment in the number of claimants may generate other effects like: 1) new private initiatives (like on-line websites) may arise; 2) the likelihood of using alternative devices or tools, like class action lawsuits, increases; 3) consumer associations may use and promote the use of this device, simplifying their followers' claiming procedure; and 4) new claimants may notify their relatives and friends about this simplified claiming procedure.[24]

Assumption 2 requires that the expected consumers' claiming cost is set to zero when *all* consumers are claimants.[25] Assumptions 1 and 2 clearly restrict the set of distributions for comparative analysis, but many commonly used distributions (e.g., Exponential and Pareto distributions) satisfy these assumptions.[26] We elaborate formally on this issue in Appendix C.[27]

We define a reduction in consumers' claiming cost as *all-claimants-beneficial* if: (a) μ increases, and (b) assumptions 1 and 2 are satisfied. Proposition 3 states our main results linking those in Lemmas 2 and 3.

Proposition 3. *Given a function $\alpha(\mu)$, if the consumer benefit from replacements is high, any all-claimants-beneficial reduction in consumers' claiming cost generates a reduction in product's reliability and an increase in profits; i.e., given assumptions 1 and 2, there exists μ_0 such that if $\mu \geq \mu_0$ then $\frac{\partial x}{\partial \mu} < 0$ and $\frac{\partial \Pi}{\partial \mu} > 0$.*

The comparative static analysis combines the results in Lemmas 2 and 3. The positive relation be-

[24]A similar reasoning applies to litigation benefits of increasing the number of claimants: if a law adding consumer rights is passed, consumers will be more inclined to claim for their rights; additionally consumer movements or consumer associations may promote these rights, exacerbating the impact on reducing consumers' litigation cost and thus on their complaining behavior.

[25]Assumption 2 can be replaced by a weaker assumption, $v\alpha(\mu = 1) - c > 0$, requiring that the expected claiming cost for consumers is sufficiently low when all consumers are claimants. In this case, $\alpha(\mu = 1) < 1$ is allowed for. Replacing Assumption 2 by this weaker assumption does not affect our comparative statics results but unnecessarily complicates their exposition.

[26]Notice that we exemplify with specific families of uni-dimensional distributions, but this is not necessary as long as the set of distributions satisfies assumptions 1 and 2.

[27]Using the weaker version of Assumption 2 introduced in footnote 25 allows us to consider additional distributions. For example, consider $F(k) = \frac{2k}{\lambda} - \frac{k^2}{\lambda^2}$ for $k \in [0, \lambda]$, where $\lambda \gtreqless 1$. For this distribution, $\alpha(\mu = 1) = \frac{2}{3}$ when $\lambda = 1$, forcing us to replace Assumption 2 by $\frac{2}{3} - c > 0$. Actually, reductions in λ when $\lambda < 1$ would increase α but $\mu = 1$.

tween μ and α guarantees that α increases with μ (Lemma 2) increasing profits and decreasing reliability. It also guarantees that there exists μ_0 such that $\alpha(\mu_0)$ is high enough (and by Lemma 3) reinforcing these effects of increasing profits and reducing reliability.

In terms of our results, assumptions 1 and 2 guarantee that reductions in consumers' claiming cost will eventually generate efficient replacement requests that ultimately allow firms to make profit out of them. Consequently, any increase in complaints will increase profits. Additionally, the reduction in the demand effect is greater than the increase in the replacement effect, motivating firms to reduce reliability.

Appendix C.2 analyze alternative relations of μ and α with F and discusses the implications and boundaries of assumptions 1 and 2, emphasizing that they are sufficient but not necessary for our results to hold.

If α is small, the firm's mark-up decreases in the number of claimants μ. This motivates to reduce demand, increasing the marginal consumer $\hat{v}$. An increase in μ generate an increase in product reliability and a reduction in profits, generating the opposite effects of an increase in α; then the net effects are undetermined.

Consequently, with heterogeneous valuations, the choice of the marginal consumer $\hat{v}$ also depends on μ and α, but this relation can be non-monotonic. When the fraction of claimants μ is high enough guaranteeing a high α, an increase in μ, given x and $\hat{v}$, increases the unit mark-up. Consequently, profits will increase and the firm has incentives to increase demand by decreasing the marginal consumer $\hat{v}$.

4 Welfare

We now extend the analysis of the welfare implications of our results. The surplus created when a consumer with valuation v buys one unit of the product is $vx - c(x)$. If additionally this buyer incurs a claiming cost kv to request a replacement when the product results to be defective, the expected surplus generated is instead $vx - c(x) + (1-x)(v - kv - \frac{c(x)}{x})$.

With a marginal consumer $\hat{v}$, the total number of units traded is $1 - G(\hat{v})$. Among these buyers, those with $k \leq 1$ request a replacement when the product fails, and thus the proportion of claimants is $\mu = F(1)$. Consequently, when the firm provides a product with reliability x, the marginal buyer is $\hat{v}$,

$k \sim F$, and $v \sim G$, the welfare generated is

$$\begin{aligned} W(x,\hat{v};\mu,\alpha) &= \int_{\hat{v}}^{\overline{v}} v[x+(1-x)\alpha\mu] - c(x)\Big(1+\frac{(1-x)}{x}\mu\Big)dG, \\ &= \left(E[v|v \geq \hat{v}][x+(1-x)\mu\,\alpha] - \frac{c(x)}{x}[x+(1-x)\mu]\right)[1-G(\hat{v})]. \end{aligned} \tag{13}$$

Comparing equations 10 and 13, we observe again the remark of Spence (1975): the firm's profit considers the surplus (mark-up) generated by the marginal consumer $\hat{v}$ instead of the surplus generated by the average consumer $E[v|v \geq \hat{v}]$ that is considered in the welfare function. Moreover, the impact of reliability on the average consumer is higher than on the marginal consumer, leading to the underprovision of reliability as stated in Lemma 1.

In this extension there is a new source of inefficiency. On top of the inefficiencies generated by the monopolist when it reduces the quantity sold and underprovides product reliability, we identify a new source due to an inefficient complaining behavior by consumers. This inefficiency arises because consumers request replacements when $v \geq k\,v$ while it is efficient to provide these replacements only if $v \geq k\,v + c(x)$. That is, each consumer internalizes his private cost of requesting replacements but not the social cost of it.

Our next result shows that, even when the firm excludes consumers, demand increases with μ if α is high enough. Additionally, consumers' complaining behavior relaxes when α increases. Finally, even when we do not analyze the over or underprovision of product reliability, we show that its distortion decreases as μ increases. Since both sources of inefficiency decrease and the distortion on product's reliability decreases with μ when α is high enough, we can take advantage of the function $\alpha(\mu)$ and state the following proposition.

Proposition 4. *Conditional on market behavior (i.e., firm's choice of (p,x) and consumers' complaining behavior) welfare is highest at $\mu = 1$ and $\alpha = 1$. Additionally, if the consumer benefit from replacements is high, any all-claimants-beneficial reduction in consumers' claiming cost increases welfare.*

Therefore, firm's profit and social welfare are aligned when consumers' claiming cost is sufficiently low, or equivalently when the number of complaints is large enough. The following lemma (which requires no proof) states this observation.

Lemma 4. *If the consumer benefit from replacements is high, any all-claimants-beneficial reduction* *in consumers' claiming cost generates an increase in welfare and profits; i.e., given a function $\alpha(\mu)$ satisfying assumptions 1 and 2, there exists μ_1, such that $W(\mu)$ and $\Pi(\mu)$ are increasing in μ whenever $\mu \geq \mu_1$.*

Proposition 4 suggests that social and private incentives are aligned and thus firms find profitable to promote complaints when the number of complaints reaches certain threshold. Before this threshold, any initiative oriented toward reducing consumers' claiming cost (and thus increasing complaints) may have ambiguous effects on welfare, but moves the market in the direction of the threshold where private and social interest are aligned. Beyond this threshold, firm's profit (Proposition **??**) and welfare (Proposition 4) increase with the number of claimants. Additionally, it states that welfare is maximized when every consumer is a claimant. This result answers the second question in the title of this paper: we should not worry if reliability decreases with the number of consumer complaints as it is welfare enhancing.

In line with this result, note that consumers' associations goals are, among others, to help consumers voice their complaints and enforce the provision of reliable products. In this article, we show that these goals may not be aligned: the firm may decide to produce a less reliable product if more consumers request a replacement of a defective product. This effect, however, should not worry consumer associations and consumer agencies (public or private) as we showed that these effects are welfare improving.

4.1 Upfront fee for requesting a replacement

Our model suggests that the lack of commitment to efficient complaining by consumers has important effects on firm's reliability choice and profits. A policy implication of this observation is that a mechanism forcing consumers to submit only efficient complaints should improve welfare. In this section we discuss one of these mechanisms: an upfront fee for the right to request a replacement.

Suppose the firm chooses to charge an upfront fee ϕ to discourage inefficient complaints. Now, a consumer will choose to request a replacement only if $v-k-\phi \geq 0$. If the upfront fee is set equal to the cost of replacing a defective unit only efficient complaints will be submitted. This optimal upfront fee reduces product reliability by decreasing the incentives that inefficient requests (now eliminated) provide to increase reliability, and reinforces our result that reliability decreases with the number of claimants.[28]

The introduction of an upfront fee raises some concerns. First, consumers may feel discouraged by

[28]For an interesting discussion on price controls to stop fake complaints *see:* The Economist news "www.economist.com/node/21560304". The article suggests that the upfront fee should be returned to consumers only if the complain proves to be legitimate. In our model, the upfront fee should never be returned to the claimant.

the additional out-of-pocket expenses needed to complain and they may choose not to complain even when it is efficient to do so. Formally, this case can be represented with a claiming cost k that depends on ϕ. Second, the upfront fee may disproportionally exclude low income consumers from complaining (raising some additional inequality issues). Third, an upfront fee may be used strategically by the firm to manipulate consumers complaining behavior by, for instance, modifying product quality or manipulating the value of the upfront fee.[29] Finally, the optimal upfront fee scheme may be complex, if, for instance, faulty units are repaired instead of replaced. In this case, the upfront fee scheme must be designed to account for different repairing cost (depending on the particular part of the product to be replaced).

We are not aware of any case where a warranty incorporates a claiming fee. In spite of these caveats, it is an interesting extension to explore.

5 Numerical examples

We run simple numerical examples with alternative distributions of consumers claiming cost F to show that a number of claimants around half of the buyers is enough to get a result that product reliability decreases and profit increases with an increase in the number of claimants.

Example 1: $c(x) = 0.1 + x^3$, $G = v$ for $v \in [0,1]$ and the Exponential distribution in claiming cost $F(k) = 1 - e^{k\,log(1-\mu)}$ with $k \in [0,\infty)$ (directly expressed as a function of the number of claimants $F(1) = \mu$).

Example 2: $c(x) = 0.1 + x^3$, $G = v$ for $v \in [0,1]$ and the Pareto distribution in claiming cost $F(k) = 1 - \frac{1-\mu}{k}$ with $k \in [1-\mu,\infty)$ (directly expressed a function of the number of claimants $F(1) = \mu$).

In these examples, claiming cost distributions satisfy assumptions 1 and 2 where α increases with μ. One way to see empirically if the actual consumers' claiming cost distribution satisfies assumption 1 is through consumer satisfaction surveys, verifying whether consumers express a better satisfaction in those industries with higher proportion of claimants (e.g., something that may be in the interest of the Better Business Bureaus).

If instead we assume a uniform distribution $F(k) = \frac{k}{k_1}$ for $k \in [0,k_1]$. If $k_1 \geq 1$, $\mu = F(1) = \frac{1}{k_1}$ and $\alpha = \frac{1}{2}$; but if $k_1 < 1$ then $\mu = F(1) = 1$ and $\alpha = 1 - \frac{k_1}{2}$. The main results hold always if $\hat{v} > 2\frac{c(x)}{x}$.

[29] As we mentioned, the optimal upfront fee equals the replacement cost which is likely to be private information of the firm and difficult to estimate by outsiders.

6 Discussion

Even when it is not so simple to recognize these results in practice, there is evidence showing the relationship between consumers' complaints behavior and willingness to pay (demand effect), claiming cost and the number of claimants, and the number of claimants and replacement/complaints costs (replacement effects).

For instance, the evidence supports the fact the number of complaints for airline companies are rising even when "few travellers ever actually lodge complaints" (The Economist, "Complaints against America's airlines are rising" 2017). Moreover, "not only did receiving a response boost customer satisfaction, but faster replies made it more likely that passengers would fork out for more expensive tickets from that airline in the future." This is consistent with the *demand effect*.

Finally, it is not obvious to show how reliability changes within the firm. However, after the *sudden-acceleration* scandal in Toyota vehicles from 2002 to 2009, the company released information about how car's reliability were downward shifted by some strategic decisions that implied relaxing quality controls (The Economist 2010, "The machine that ran too hot").

7 Robustness

In this section we comment on the implications of a number of alternative specifications. Specifically, we argue that our results hold when: reliability depends on ex-ante expenditures in product design; replacements are not always granted (no strict liability); the level of product reliability is firm's private information (extending the model to a dynamic framework); and consumers may suffer some damages when the product fails and they can pursue monetary compensation in addition to product replacement. A formal treatment of these extensions is reported in the Appendix B.

Until now we assumed that the marginal cost of manufacturing a product is increasing in reliability, i.e., $c'(x) > 0$. Our results still hold if this marginal cost is constant and firms invests in product design (e.g., R&D) to develop a more reliable product. For example, R&D expenditures may lead to improvements in product assembling, affecting reliability without changing manufacturing costs. In the case of homogeneous valuations, replacement effect is always negative and the same results hold. In the heterogeneous valuation case results are more complex. A new effect arises: investments in product design are a sunk expenditure affecting total production cost (unit cost times quantity sold), thus there are additional incentives to increase reliability when demand is higher. Our results remain as long as demand is elastic enough around the marginal consumer or unit manufacturing cost is low enough.

So far, we maintained the assumption that replacements are always honored. If instead, replacements are honored with probability $z < 1$ our qualitative results remain unaffected. This extension relates to the problem of *partial liability*. In this case, consumers request a replacement if $k \leq zv$ instead of $k \leq v$. Moreover, when firms can affect consumers' claiming cost and probability of honoring a request, if profit increases when consumers' claiming cost falls, it will also increase when the probability of honoring replacing request increases. In the same way, if profit increases when consumers' claiming cost increases, it will also increase when the probability of replacing defective units decreases.

Our results remain if the firm holds private information about her choice of the level of product reliability. In a static model with asymmetric information there is no room for our demand effect. A meaningful way to incorporate asymmetric information in our framework of demand and replacement effects is to model interaction as a repeated game. In such dynamic model with asymmetric information about product reliability, firm's loss of future sales (or reputation) works as a demand effect if the product turns out defective and the consumer does not request a replacement because it is too costly. In the spirit of Hirschman (1970), after receiving a defected unit of the product the consumer may either (i) voice his replacement request when it is cheap to do so, or (ii) he may exit the dynamic relation (stop buying, at least for some time) as a source of punishment when he finds expensive to voice a request and scraps the defective product. This sales losses may be more expensive in terms of consumers willingness to pay (and profits) than exercising warranties when claiming cost is low, but it may be cheaper when claiming costs are high. So a reduction in consumers' claiming cost generates an increase in the number of claimants and a decrease in the number of dissatisfied consumers that exit the trade (at least for some periods of time).

Finally, we introduced consumer damages derived from a failing unit and we allow consumers to seek monetary compensation in addition to the replacement. Even when compensations are money transfers among agents, they affect product reliability. Demand and replacement effects operate as before and once again our qualitative results hold. These results are independent on whether replacements or monetary compensations are always granted or are granted with positive probability.

8 Conclusion

We have provided a simple model to introduce consumers' claiming cost to the analysis of complaints and product's reliability choice. Under reasonably weak assumptions, when the number of claimants is large enough a decrease in consumer's expected claiming cost leads to a decrease in product's reliability but increases profits and welfare. These results provide a positive answer to the first question in the title and a negative answer to the second one.

Anecdotal evidence suggests that changes in consumers' claiming cost can be induced both by third parties (consumer agencies, governments, or private enterprises) or by firms. In the past few decades, new initiatives to help consumers channeling complaints have resulted in an increase in the number of complaints. Most recently, firms started joining these initiatives by outsourcing consumer requests to on-line platforms. These observations are consistent with our model predictions. Since profit and welfare eventually align—when enough consumers are claimants—public initiatives oriented to lower consumer's claiming costs will be ultimately joined by firms who will profit from further increases in complaints.

Our static model assumes that product reliability is observed by consumers before they decide whether to purchase the product or not. As mentioned in the introduction, the literature has emphasized the role of warranties as signaling or incentive devices. We see warranties and consumers' claiming cost as the two sides of the same coin: warranties work as signals or incentives for quality as long as consumers execute them, but evidence suggests this is not always the case. One reason for this, is that executing a warranty is costly.

We have also omitted considerations of consumer's moral hazard. Extending our framework to accommodate asymmetric information will prove insightful. Work on these grounds is welcome.

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A Appendix: Proofs

A.1 Benchmark model

Proof of Proposition 1. To prove that $\frac{\partial \Pi}{\partial \mu} > 0$, we consider the expression in Equation 3. Using the envelope theorem we obtain

$$\frac{\partial \Pi}{\partial \mu} = (1-x)\left(\hat{v} - \frac{c(x)}{x}\right)\left(1 - G(\hat{v})\right) > 0.$$

For the second result, the comparative static is given by

$$\frac{\partial x}{\partial \mu} = -\frac{\hat{v} - \frac{c(x)}{x^2} + \frac{1-x}{x}c'(x) - (1-\mu)\frac{\partial \hat{v}}{\partial \mu}}{c''(x) - \mu\left(\frac{2c'(x)}{x^2} - \frac{2c(x)}{x^3} - \frac{1-x}{x}c''(x)\right)}, \tag{14}$$

that is always negative, because both denominator and numerator are always positive. To verify these claims, the convexity of $\frac{1-x}{x}c(x)$ guarantees that the denominator is positive. For the second claim you may notice that $\frac{c(x)}{x^2} - \frac{(1-x)}{x}c'(x) = \frac{c(x)}{x} - \frac{(1-x)}{x}\left(c'(x) - \frac{c(x)}{x}\right)$ which, in equilibrium, is always lower than $\frac{c(x)}{x}$ and, thus, lower than $\hat{v}$. Finally, notice (in Equation 4) that $\hat{v}$ depends on μ through x; consequently it can never be true the $\frac{\partial \hat{v}}{\partial \mu} > 0$. □

Proof of Lemma 1. Given that $E[v|v \geq \hat{v}] \geq \hat{v}$ for any $\hat{v}$, the result is direct from simple inspection of equations (7) and (5), □

Proof of Proposition 2. Π and W are both increasing in μ. □

A.2 Heterogeneous valuations

Proof of Lemma 2. Using envelope theorem $\frac{\partial \Pi}{\partial \alpha} = \hat{v}\mu(1-x)[1-G(\hat{v})] > 0$; and, by convexity of $c(x)$ and $c(x)\frac{(2-x)}{x}$, $\frac{\partial x}{\partial \alpha} = -\frac{\mu\hat{v} - \frac{\partial \hat{v}}{\partial \alpha}[1-\alpha\mu]}{c''(x)[1+\mu\frac{(1-x)}{x}] - 2\frac{c'(x)}{x^2}\mu + \mu\frac{2c(x)}{x^3}} < 0$. □

Proof of Lemma 3. We start with the second result. Using envelope theorem $\frac{\partial \Pi}{\partial \mu} = [v\alpha - \frac{c(x)}{x}](1-x)$ which is positive if $v\alpha > c(x)$. By convexity of $c(x)$ and $c(x)(2-x)$, and $\mu \leq 1$ we have $c''(x)[1 + \mu\frac{(1-x)}{x}] - 2\frac{c'(x)}{x^2}\mu + \mu\frac{2c(x)}{x^3} > 0$. As the denominator is positive, then $\frac{\partial x}{\partial \mu} = -\frac{\alpha v - \frac{c(x)}{x^2} + \frac{(1-x)}{x}c'(x)}{c''(x)[1+\mu\frac{(1-x)}{x}] - 2\frac{c'(x)}{x^2}\mu + \mu\frac{2c(x)}{x^3}} < 0$ if $\alpha v - \frac{c(x)}{x^2} + \frac{(1-x)}{x}c'(x) > 0$. Notice that $\alpha v - \frac{c(x)}{x^2} + \frac{(1-x)}{x}c'(x) > 0$ if α is high enough.
$\frac{\partial x}{\partial \mu} = -\frac{\alpha\hat{v} - \frac{c(x)}{x^2} + \frac{(1-x)}{x}c'(x) + \frac{\partial \hat{v}}{\partial \mu}(1-\mu\alpha)}{c''(x)[1+\mu\frac{(1-x)}{x}] - 2\frac{c'(x)}{x^2}\mu + \mu\frac{2c(x)}{x^3}} < 0$ □

Now we turn to the proof of Proposition 3.

Proof of Proposition 3. With heterogeneous valuations v and costs k (with $k := av$) the comparative static is

$$\frac{\partial x}{\partial \mu} = -\frac{\hat{v}[\alpha + \mu\alpha'] - [c(x) - (1-x)c'(x)] - \frac{\partial \hat{v}}{\partial \mu}[1-\alpha\mu]}{c''(x) + \mu[(1-x)c''(x) - 2c'(x)]}.$$

The denominator of this equation is positive because $c(x)(2-x)$ is convex. Moreover, $\frac{\partial \hat{v}}{\partial \mu}$ is negative if μ and $\alpha(\mu)$ are large enough. In particular, notice that $\hat{v}$ is lowest when $\mu = 1$ and hence eventually the marginal consumer $\hat{v}$ must decrease with μ. The rest of the proof follows the same logic than the proof of Proposition 3.

Regarding profits, note that: i) $1-G(\hat{v})$ is highest when $\mu = 1$ (because $\hat{v}_2$ is smallest); and ii) unit margin is also highest when $\mu = 1$ (given x, the expression $xv - c(x) + (1-x)[v - c(x)]$ is the highest, and $x_2 = \arg\max_x v - c(x)(2-x)$). Consequently, profits are highest when $\mu = 1$.

For the second part of the proof, the derivative (using the envelope theorem) is

$$\frac{\partial \Pi}{\partial \mu} = \big(1-G(\hat{v})\big)(1-x)\Big(\hat{v}[\alpha + \mu\,\alpha'] - c(x)\Big).$$

In equilibrium $\hat{v} > c(x)$, then the existence of F_0 such that $\Pi(\mu)$ is increasing in μ if $\mu \geq \mu_0$ is straightforward. □

A.3 Welfare

Proof of Proposition 4. Total welfare is calculated by adding the welfare generated by each buyer v (weighted by $g(v)$),

$$W(x,\hat{v};\mu,\alpha) = \int_{\hat{v}}^{\overline{v}} vx - c(x) + (1-x)\mu[\alpha v - \frac{c(x)}{x}]dG(v).$$

The first order condition of the firm that characterizes $\hat{v}$ guarantees that $vx - c(x) > 0$ for all $v \in [\hat{v}, \overline{v}]$. Then, we can claim that the argument of the integral is increasing in μ if α is high enough and increasing in α. A change in α and μ also motivates the firm to change x and p (that is, x and $\hat{v}$).

We analyze the impact of α and μ on welfare. On the one hand, an increase in α motivates the firm to reduce product reliability but also it reduces the optimal level of product reliability (for a given $\hat{v}$). The difference between these two reliability levels shrinks, and it eventually disappears, as both μ and α approaches 1. In the limite, the value of x is the one that maximizes the surplus generated by the marginal consumer $\hat{v}$.

Moreover, an increase in α also motivates the firm to reduce $\hat{v}$, increasing the number of unit traded and thus welfare. As both μ and α approaches 1, the surplus of any consumer converges to $v - \frac{c(x)}{x}$ and $x = \arg\max_y \left(v - \frac{c(y)}{y}\right)$.

On the other hand, any increase in μ motivates a reduction in product reliability when α is high enough. As already mentioned, the inefficiency also shrinks.

Finally, an increase in μ has two opposite effects on $\hat{v}$. First, it reduces the cost $c(x)/x$ (by reducing x), which ultimately reduces $\hat{v}$. But also, it increases $\hat{v}$ as $\frac{x+(1-x)\mu}{x+(1-x)\mu\alpha}$ increases. However, this second effect vanishes as α converges to 1. Then, there exists a value of α high enough such that $\hat{v}$ decreases with μ.

Consequently two things are proved: (1) welfare is maximized at $\alpha = 1$ and $\mu = 1$; (2) if α is high enough any increase in μ motivates an increase in welfare.

Assuming that there exists a function $\alpha(\mu)$, the second result guarantees that any all-claimants-beneficial reduction in consumers' claiming cost increases welfare.

□

B Robustness

In this section we show that our results are robust to a number of extensions.

B.1 When consumers known their claiming cost.

We have focused on the case where consumers does not know their claiming cost before purchasing the product. Our results hold if, instead, consumers know their claiming cost. This extension implies that a consumer anticipates his claiming behavior if the product results to be defective. The firm can anticipate this even when she does not observe consumers' claiming cost. We work in the case where the offer comprising a unique product comprising its price and reliability (we do not look for screening strategies based on heterogeneous claiming cost). We show this extension in the simple example of section 2.1.

Consumer's claiming cost is reduced to 0 or $+\infty$ with probability μ and $1-\mu$, respectively. Consumers knows whether they always request a replacement at no cost or they never request a replacement of a defected unit. As before replacement requests are granted. Consumers valuation of a defected unit is 0 and of a non-defected unit is $v > 0$. The reservation utility is zero. Then, expected utility of buying a unit of a product with reliability rate x at a price p for a consumer with claiming cost $k \in \{0, \infty\}$ is

$$EU(p,x) = \begin{cases} xv - p & \text{if } k = +\infty, \\ v - p & \text{if } k = 0. \end{cases}$$

Anticipating consumer's behavior, a monopolist chooses its product price p and reliability rate $x \in [0,1]$ to maximize profits. The expected unit cost is $c(x) + \mu \frac{(1-x)}{x} c(x)$. Notice that now demand is 1 if $p \leq xv$, μ if $p \in (xv, v]$, and 0 if $p > v$.

Firm's expected profit when choosing a price p and reliability x is

$$\Pi(p,x) = \begin{cases} 0 & \text{if } p \in (v, +\infty), \\ \mu \left(p - c(x) - \frac{(1-x)}{x} c(x) \right) & \text{if } p \in (xv, v], \\ p - c(x) - \mu \frac{(1-x)}{x} c(x) & \text{if } p \in [0, xv]. \end{cases}$$

Firm's problem simplifies to $\max_{(p,x)} \Pi$. Given a reliability x, the pricing strategy of the firm is one of these two $p \in \{xv, v\}$. There will be a threshold μ_0 below which $p = xv$ and above which $p = v$ (exactly at μ_0, both prices get the same profits). Consequently we can write the solution depending on μ with respect to some threshold μ_0.

(1) If $\mu < \mu_0$, then $p = xv$ and x_1 is defined by

$$c'(x_1) = v + \mu \left(\frac{c(x_1)}{x_1^2} - \frac{(1-x_1)}{x_1} c'(x_1) \right).$$

(2) If $\mu \geq \mu_0$, then $p = v$ and x_2 is defined by

$$c'(x_2) = \left(\frac{c(x_2)}{x_2^2} - \frac{(1-x_2)}{x_2} c'(x_2) \right).$$

If v is high enough, so that there is always positive profits (i.e., there is always trade), then $x_1 > x_2$ $\forall \mu$. Notice that $\frac{\partial x_1}{\partial \mu} > 0$; as long as $p = xv$ any increase in the number of claimants increase product reliability. However, there is an increase in the number of claimants such that $\mu > \mu_0$ where the price changes from $p = x_1 v$ to $p = v$ and product reliability decreases to x_2. As well, firm's profit decreases in μ when $p = x_1 v$ (i.e., $\mu \leq \mu_0$) and increases in μ when $p = v$ (i.e., $\mu > \mu_0$). This result provides some intuition in line with Johnson and Myatt (2006) of demand rotation when the firm chooses between niche and mass market posture.

B.2 Expenditures in product design

We have assumed that manufacturing cost depends on product reliability. However, it is possible to envision situations in which product reliability depends on expenditures on product design rather than on manufacturing costs. To represent this situation we assume that the firm must incur in a product design cost $I(x)$ with $I' > 0$ and $I'' > 0$, to produce a unit of good with reliability x. Additionally, we assume $c(x) = c\ \forall x$. To guarantee and interior solution we assume $I(0) = 0$, $\lim_{x\to 0} I'(x) = 0$, and $I(1) = +\infty$. For a non-trivial case we now assume that $\max_x x v - c - I(x) > 0$.

The firm's expected cost of selling a unit of the product is $c + (1-x)\mu c$ and the profit function is $\Pi(p,x) = p - c - (1-x)\mu c - I(x)$. Consumers and demand remain as in the benchmark case. The firm's problem is to maximize profits subject to $EU(p,x) \geq 0$.

Since the participation constraint binds, the price is $p = xv + (1-x)v\mu\,\alpha(\mu)$. Replacing this price in firm's profits and differentiating with respect to x gives the first order condition

$$I'(x) = v[1 - \mu\,\alpha(\mu)] + c\mu.$$

We claim that under this extension the results in our main propositions remain valid.

Proposition 5. *There always exists a claimants-encouraging reduction in consumers' claiming cost that reduces product reliability and increases profits, i.e., for any distribution F there always exists F' such that $\mu' > \mu$, $x(\mu') < x(\mu)$, and $\Pi(\mu') > \Pi(\mu)$. Moreover, if the number of claimants is high enough, any all-claimants-beneficial reduction in consumers' claiming cost generates a reduction in product's reliability and an increase in profits; i.e., there exists μ_0 such that for all F' with $\mu' > \mu_0$ and $\alpha(\mu') > \alpha(\mu_0)$, then $x(\mu') < x(\mu_0)$ and $\Pi(\mu') > \Pi(\mu)$.*

Proof of Proposition 5. Differentiating with respect to μ (the second derivative uses the envelope theorem),

$$\begin{aligned} \frac{\partial x}{\partial \mu} &= -\frac{v[\alpha + \mu\,\alpha'] - c}{I''(x)}, \\ \frac{\partial \Pi}{\partial \mu} &= (1-x)\Big(v[\alpha + \mu\,\alpha'] - c\Big). \end{aligned} \tag{15}$$

Since $I(x)$ is convex, the denominator in Equation (15) is positive. The rest of the proof follows a similar reasoning than in proving Proposition 3. □

We can extend this model to the case where replacement unit has the same product reliability as the first one. The firm's expected cost of selling a unit of the product is $c + (1-x)\mu\frac{c}{x}$ and the profit function is $\Pi(p,x) = p - c - (1-x)\mu \frac{c}{x} - I(x)$. Consumers and demand remain as in the benchmark case. The firm's problem is to maximize profits subject to $EU(p,x) \geq 0$.

Since the participation constraint binds, the price is $p = xv + (1-x)v\mu\,\alpha(\mu)$. Replacing this price in firm's profits and differentiating with respect to x gives the first order condition

$$I'(x) = v[1 - \mu\,\alpha(\mu)] + \frac{c}{x^2}\mu.$$

We claim that under this extension the results in our main propositions remain valid.

Proposition 6. *There always exists a claimants-encouraging reduction in consumers' claiming cost that reduces product reliability and increases profits, i.e., for any distribution F there always exists F' such that $\mu' > \mu$, $x(\mu') < x(\mu)$, and $\Pi(\mu') > \Pi(\mu)$. Moreover, if the number of claimants is high enough, any all-claimants-beneficial reduction in consumers' claiming cost generates a reduction in product's reliability and an increase in profits; i.e., there exists μ_0 such that for all F' with $\mu' > \mu_0$ and $\alpha(\mu') > \alpha(\mu_0)$, then $x(\mu') < x(\mu_0)$ and $\Pi(\mu') > \Pi(\mu)$.*

Proof of Proposition 6. Differentiating with respect to μ (the second derivative uses the envelope theorem),

$$\begin{aligned} \frac{\partial x}{\partial \mu} &= -\frac{v[\alpha + \mu\,\alpha'] - \frac{c}{x^2}}{I''(x) + 2\mu\frac{c}{x^3}}, \\ \frac{\partial \Pi}{\partial \mu} &= (1-x)\Big(v[\alpha + \mu\,\alpha'] - \frac{c}{x}\Big). \end{aligned} \tag{16}$$

Since $I(x)$ is convex, the denominator in Equation (16) is positive. The rest of the proof follows a similar reasoning than in proving Proposition 3. □

B.3 Expenditures in product design: heterogeneous consumers

The case of product design expenditures extends nicely to heterogeneous valuations. The differences with respect to the case in Section 3 are that $I(x)$ is now independent on the size of demand $1 - G(\hat{v})$ and $c(x)$ does not depend on x. Profits can be written as

$$\Pi(\hat{v},x) = \Big(x\hat{v} + (1-x)\hat{v}\mu\,\alpha(\mu) - c - (1-x)\,\mu\,c\Big)\Big(1 - G(\hat{v})\Big) - I(x).$$

From the first order condition with respect to the marginal consumer $\hat{v}$ we obtain

$$\hat{v} - \frac{1-G(\hat{v})}{g(\hat{v})} = c\,(2-x)\frac{\mu}{x+(1-x)\alpha\mu} + \frac{c}{x}\frac{x(1-\mu)}{x+(1-x)\alpha\mu}. \tag{17}$$

From the first order condition with respect to product reliability x we obtain

$$I'(x) = (1-G(\hat{v}))\Big[\hat{v}(1-\alpha\,\mu) + \mu c\Big]. \tag{18}$$

The only difference between Equation (18) and Equation (12) in the text is the factor $1-G$.

To derive our results, we can use the envelope theorem in the profit function to get

$$\frac{\partial \Pi}{\partial \mu} = (1-x)\Big(1-G(\hat{v})\Big)\Big(\hat{v}\,[\alpha + \mu\,\alpha'] - c\Big).$$

As in the previous case, $\hat{v} > c$ (in equilibrium) and hence the existence of F_0 such that $\Pi(\mu)$ is increasing in μ if $\mu \geq \mu_0$ is straightforward. The comparative static of product reliability with respect to μ is

$$\frac{\partial x}{\partial \mu} \quad = \quad -(1-G(\hat{v}))\frac{\hat{v}[\alpha + \mu\,\alpha'] - c}{I''(x)} + \frac{1}{I''(x)}\frac{\partial \hat{v}}{\partial \mu}\Big[-g\Big(\hat{v}[1-\mu\,\alpha] + \mu c\Big) + (1-G)[1-\mu\,\alpha]\Big],$$

A new effect defined by $\frac{\partial \hat{v}}{\partial \mu}$ appears, and is obtained by differentiating Equation (17). If c is relatively small, this effect $\frac{\partial \hat{v}}{\partial \mu}$ is small (for example if $c = 0$, then $\frac{\partial \hat{v}}{\partial \mu} = 0$). Alternatively if $\frac{\partial}{\partial v}\frac{1-G}{g}$ is large enough so that $\hat{v}$ is not sensitive to μ then $\frac{\partial \hat{v}}{\partial \mu}$ is small. The rest of the reasoning follows the same logic as in proving Proposition 3.

B.4 Reliability is seller's private information

In this section we show that our results are robust to a case where product reliability is not observable by consumers. In this section, consumers infer product reliability by the seller's incentives to provide it. We use a dynamic framework with discounting where the seller and consumers interact indefinitely.

In particular we assume that consumers behave as follows: observing the price p and having beliefs about reliability x, a consumer chooses whether to buy one unit of the product or not. If a consumer has bought one unit in period t, he will buy a new unit of the product at $t+1$ as long as one of two conditions hold: (a) the unit bought in t works well, or, (b) the unit bought was defective and he has requested a replacement of it to the firm (that it is granted). Otherwise, if at t the consumer received a defected unit but he has not requested a replacement, the consumer delays the new purchasing decision for some time as a source of punishment. For simplicity, we assume that a non-claimant buyer will wait for one period to make a new purchase.[30] This behavior of voice versus exit (temporary) the market is consistent with Hirschman (1970). The outside option is zero and the discount factor is $\delta \in (0,1)$.

We consider a unit mass of homogeneous consumers with valuation v; we assume (as in section 2.1) that consumers' claiming cost equals zero with probability μ and it is extremely high (e.g., $+\infty$) with probability $1-\mu$. However, this cost is learned after buying the product and may vary from one period to the other.[31]

There are two possible stages for each consumer in each period: a purchasing stage and a punishing stage. We define consumer valuation when buying $V(\text{buy}) := V_b$ and when punishing $V(\text{punish}) := V_p$. In steady state V_b and V_p are,

$$\begin{aligned} V_b(\text{buy}) &= x(v+\delta V_b)+(1-x)\mu(v+\delta V_b)+(1-x)(1-\mu)(0+\delta V_p)-p, \\ V_p(\text{punish}) &= 0+\delta V_b. \end{aligned}$$

In the buying stage, the consumer pays the price p getting a unit of the product; this unit works well with probability x, getting the valuation v and buying again in the following period (δV_b); this unit is defective with probability $1-x$. When receiving a defected unit, the consumer requests a replacement (as many times as necessary until getting a non-defective one) with probability μ; in this case the consumer enjoys a utility v and he chooses to buy another unit in the next period (getting δV_b). However, with probability $1-\mu$ the consumer does not request a replacement and scraps the product; if this is case, the consumer moves to a punishing stage in the following period. In the punishing stage the consumer gets 0 in the current period and moves to the buying stage in the following period.

Solving for the steady state values of V_b and V_p,

$$\begin{aligned} V_b(x,p;\delta,v,\mu) &= \frac{v[x+(1-x)\mu]-p}{(1-\delta)[1+\delta(1-x)(1-\mu)]}, \\ V_p(x,p;\delta,v,\mu) &= \delta V_b. \end{aligned}$$

Replaced units fail with the same probability as the original unit, but a claimant consumer in a period is

[30] Alternatively, we can consider a case where non-claimants never buy again and a cohort of new consumers born every period.

[31] We can also introduce heterogeneity in consumers' claiming cost $k \sim F : [0,+\infty) \to [0,1]$.

willing to request as many times as necessary until receiving a non-defected unit. Notice that a consumer buys the product if $V_b \geq 0$ or, equivalently, if $p \leq v[x+(1-x)\mu]$.

In the supply side, the seller chooses the price and reliability rate to maximize her profits. She announces a price p and reliability rate x. The reliability rate is seller's private information (non-observable) so each buyer has a belief ot it (which, of course, holds in equilibrium). As in the main model, a product with reliability rate x costs $c(x)$ and replacing a defected unit also costs $c(x)$ (with the same technology as in the main text); as said, replaced units also fail with probability x.

We look for a steady state where $(p_t, x_t) = (p, x)\ \forall t$. Given the behavior of the buyer, in each period t the expected demand is of size $\frac{1}{1+(1-x)(1-\mu)}$; the rest of consumers, i.e., $\frac{(1-x)(1-\mu)}{1+(1-x)(1-\mu)}$, are in the punishing stage. Consequently, in the steady state the seller gets the following expected profit

$$\Pi(p,x;\mu) \quad = \quad \frac{1}{1-\delta}\frac{p-c(x)-\frac{(1-x)}{x}\mu c(x)}{(1+(1-x)(1-\mu))}. \tag{19}$$

We assume that the steady state exists. We now explain the effects of changing reliability from its steady state level x in a given period t. First, a change in x_t affects both Today's markup $p-c(x_t)-\frac{1-x_t}{x_t}\mu\, c(x_t)$ and the future number of consumers that purchase or punish in the future $Q_{t+1}, Q_{t+2}, Q_{t+3}, \ldots$. However, the demand at t is given by $Q_t = \frac{1}{1+(1-\mu)(1-x)}$ and the amount of consumers that punish are $\frac{(1-\mu)(1-x)}{1+(1-\mu)(1-x)}$. Second, $x_j = x\ \forall j \neq t$, which is correctly anticipated by consumers. For any period $j \neq t$ the firm mark up is $p-c(x)-\frac{1-x}{x}c(x)$ (does not change).

So discounted profits at t $\Pi_t(x_t, x, p; \mu)$ are

$$\left(p-c(x_t)-\frac{1-x_t}{x_t}\mu\, c(x_t)\right)Q_t + \left(p-c(x)-\frac{1-x}{x}\mu\, c(x)\right)\left(\delta Q_{t+1}+\delta^2 Q_{t+2}+\delta^3 Q_{t+3}+\delta^4\ldots\right) =,$$

$$\frac{\left(p-c(x_t)-\frac{1-x_t}{x_t}\mu\, c(x_t)\right)}{1+(1-\mu)(1-x)} + \left(p-c(x)-\frac{1-x}{x}\mu\, c(x)\right)\left[\delta\left(\frac{1-(1-x_t)(1-\mu)}{1+(1-\mu)(1-x)}+\frac{(1-\mu)(1-x)}{1+(1-\mu)(1-x)}\right),\right.$$

$$+\delta^2\left(\frac{[1+(1-\mu)(x_t-x)](1-(1-\mu)(1-x))}{1+(1-\mu)(1-x)}+\frac{(1-x_t)(1-\mu)}{1+(1-\mu)(1-x)}\right),$$

$$+\delta^3\left(\frac{[1-(1-\mu)^2(1-x)(x_t-x)](1-(1-\mu)(1-x))}{1+(1-\mu)(1-x)}+\frac{[1+(1-\mu)(x_t-x)](1-x)(1-\mu)}{1+(1-\mu)(1-x)}\right),$$

$$\left. +\delta^4\ldots\right]$$

then profits from t onwards can be expressed as

$$\frac{\left(p-c(x_t)-\frac{1-x_t}{x_t}\mu\, c(x_t)\right)}{1+(1-\mu)(1-x)}+\left(p-c(x)-\frac{1-x}{x}\mu\, c(x)\right)\left(\delta\left(\frac{[1+(1-\mu)(x_t-x)]}{1+(1-\mu)(1-x)}\right),\right.$$
$$\left.+\delta^2\left(\frac{[1-(1-\mu)^2(1-x)(x_t-x)]}{1+(1-\mu)(1-x)}\right)+\delta^3\left(\frac{[1+(1-\mu)^3(1-x)^2(x_t-x)]}{1+(1-\mu)(1-x)}\right)+\delta^4\ldots\right).$$

using the properties of the sum of a sequence we have

$$\begin{aligned} = \quad & \frac{\left(p-c(x_t)-\frac{1-x_t}{x_t}\mu\, c(x_t)\right)}{1+(1-\mu)(1-x)}, \\ & +\delta\frac{\left(p-c(x)-\frac{1-x}{x}\mu\, c(x)\right)}{1+(1-\mu)(1-x)}\left(\frac{1}{1-\delta}+\frac{(1-\mu)(x_t-x)}{1-\delta^2(1-\mu)^2(1-x)^2}-\frac{\delta(1-\mu)^2(1-x)(x_t-x)}{1-\delta^2(1-\mu)^2(1-x)^2}\right), \end{aligned}$$

rearranging terms we get the final expression of profits when x_t deviates from steady state,

$$\Pi_t(x_t,x,p;\mu)=\frac{\left(p-c(x_t)-\frac{1-x_t}{x_t}\mu\, c(x_t)\right)}{1+(1-\mu)(1-x)}+\delta\frac{\left(p-c(x)-\frac{1-x}{x}\mu\, c(x)\right)}{1+(1-\mu)(1-x)}\left(\frac{1}{1-\delta}+\frac{(1-\mu)(x_t-x)}{1+\delta(1-\mu)(1-x)}\right),$$

The reader may see that it $x_t = x$, profits are equal to the steady state level shown in equation (19). Taking the first order condition with respect to x_t we have,

$$c'(x_t)=\mu\left(\frac{c(x_t)}{x_t^2}-\frac{1-x_t}{x_t}c'(x_t)\right)+\delta(1-\mu)\left(\frac{p-c(x)-\frac{1-x}{x}\mu\, c(x)}{1+\delta(1-\mu)(1-x)}\right), \tag{20}$$

where $p = v(x+(1-x)\mu)$ is calculated from the consumer's participation constraint with beliefs x about reliability. Notice that Equation 20 captures the main effects identified in the benchmark case: increasing reliability is costly (in the left hand side) but it reduces the replacement cost at t (replacement effect) and increases future purchases from those buyers that do not request a replacement of a defected unit and would punish the firm for a period of time (demand effect); these two effects are in the right hand side. In the steady state product reliability is $x_t = x$, where x satisfies Equation 20 and the price is $p = v(x+(1-x)\mu)$. The consumer beliefs about product reliability is at this level x is, of course, correct.

There are two differences in the demand effect with respect to our benchmark case: first the demand effect comes from future sales, so it is discounted; second, this demand effect is defined in terms of unitary markup instead of consumers' willingness to pay. In order to have a unitary markup high enough for our result, the assumption "$xv - c(x) > 0$ for some x" should be replaced by the assumption "$xv - 2c(x) > 0$ for some x."

The right hand side of Equation (20) is an average of the replacement and demand effects, weighted by the number of claimants μ among buyers. Increasing the number of claimants reduces the demand effect and increases the replacement effect. Consequently, increasing the number of claimants eventually motivates a reduction in product reliability.

Proposition 7. *If the number of claimants is high enough and the firm patience is high enough, an increase in the number of claimants increases firm's profits and reduces product reliability . If μ and δ are sufficiently high, $\frac{\partial \Pi}{\partial \mu} > 0$ and $\frac{\partial x}{\partial \mu} < 0$.*

Proof. We can write firm's profits as

$$\Pi = \frac{v(x + (1-x)\mu) - c(x) - \frac{1-x}{x}\mu\, c(x)}{(1-\delta)(1+(1-\mu)(1-x))}.$$

By the envelope theorem, the impact of μ on Π is,

$$\frac{\partial \Pi}{\partial \mu} = \frac{(1-x)\left(v - \frac{c(x)}{x}\right)}{(1-\delta)(1+(1-\mu)(1-x))} + (1-x)\frac{\left(v(x+(1-x)\mu) - c(x) - \frac{1-x}{x}\mu\, c(x)\right)}{(1-\delta)(1+(1-\mu)(1-x))^2} > 0.$$

For the comparative static analysis of x with respect to μ, we must first replace the constraint $p = v(x + (1-x)\mu)$ in the first order condition. We define DE:$= \frac{p - c(x) - \frac{1-x}{x}\mu\, c(x)}{1+\delta(1-\mu)(1-x)}$ and calculate the derivative.

$$\frac{\partial x_t}{\partial \mu} = -\frac{\delta\, \mathrm{DE} - \left(\frac{c(x_t)}{x_t^2} - \frac{1-x_t}{x_t}c'(x_t)\right) - (1-\mu)\delta\frac{\partial \mathrm{DE}}{\partial \mu}}{c''(x_t) + \mu\left(\frac{2c(x_t)}{x_t^3} - \frac{2c'(x_t)}{x_t^2} + \frac{1-x_t}{x_t}c''(x_t)\right)}. \tag{21}$$

As $\frac{c(x)}{x}$ is convex, the denominator is positive. Consequently, the derivative is negative if the numerator is positive. The third term in the numerator is negative because $\frac{\partial \mathrm{DE}}{\partial \mu} > 0$. This third term is bounded (above and below), and it is increasing in μ and it converges to zero as $\mu \to 1$.

The expression DE is positive and greater than the second term for μ high enough. Consequently, for μ and δ high enough, the numerator is positive and the derivative is negative.

Notice that the *replacement effect* is defined by $\frac{c(x_t)}{x_t^2} - \frac{1-x_t}{x_t}c'(x_t)$. As $\mu \to 1$, $x^* \in \arg\min_x \frac{c(x)}{x}$ and, thus, DE is maximized. Then, DE $- \frac{c(x_t)}{x_t^2} - \frac{1-x_t}{x_t}c'(x_t) \to v - 2\frac{c(x_t)}{x_t}$ which is positive by assumption

$xv - 2c(x) > 0$ for some x.

As a result, the comparative static is negative if μ and δ are high enough, say $\mu > \mu_0(\delta)$. As the numerator increases in μ, the derivative is still negative for any $\mu > \mu_0(\delta)$.

□

B.5 Replacements are not granted (no strict liability)

In this extension we relax the assumption that replacement requests are always honored. Instead we assume the firm honors warranties with probability $z \leq 1$. This extension may represent alternative scenarios: the case of partial liability (no strict liability), the case in which the complaining procedure or regulation is not clear enough (allowing the firm to reject some requests), and the case where the product is likely to fail due to consumer's misuse (but the consumer is not perfectly aware of it). To relate the paper with the literature on product liability, I focus on the case of no strict liability.

We assume as before that when consumers request a replacement they incur in a claiming cost kv. However, we assume now that they receive a replacement only with probability z; and thus they are forced to scrap the product with probability $1-z$ (i.e., they cannot complain again). As in our benchmark case, a replaced unit has the same reliability rate as the original unit. Consequently, with probability $F(z)$ the claiming cost kv is lower than zv and the consumer expects to recover $zv - E\left[kv \middle| kv \leq zv\right]$. The ex-ante expected utility of buying is $EU_B(p,x) = xv + (1-x)\int_0^z F dk - p$. We denote the number of claimants by $\mu = F(z)$ and $\int_0^z F dk = \mu\,\alpha$. Where $\alpha \in [0,z]$ now represents the expected surplus of v that the consumer recovered when request a replacement, net of claiming cost and internalizing that with probability z there is no replacement.

For the firm, the expected unit cost is $c(x) + (1-x)\mu z c(x)/x$: where $c(x)$ is the cost of producing the first unit and its replacement (if granted), and $(1-x)\,\mu z$ is the number of expected replacements. The function $c(x)$ has the same technology as in the main text. The firm's problem is to find (p,x) to maximize profits

$$\Pi(p,x;\mu,z,\alpha) = \left(x\hat{v} - c(x) + (1-x)\,\mu\left(\hat{v}\,\alpha(\mu) - z\frac{c(x)}{x}\right)\right)(1 - G(\hat{v}))\,.$$

Assumption 2 should be replaced by $\alpha(\mu = 1) = z$. If, instead, we simplify the claiming cost to be 0 with probability μ and $+\infty$ with probability $1-\mu$, as in the benchmark case, the profit function simplifies to

$$\Pi(p,x;\mu,z) = \Big(x+(1-x)\mu z\Big)\left(\hat{v}-\frac{c(x)}{x}\right)(1-G(\hat{v}))\,.$$

From the first order condition with respect to x is

$$c'(x) = \hat{v}(1-\alpha\mu)+z\mu\Big(\frac{c(x)}{x}-\frac{1-x}{x}c'(x)\Big).$$

If the following proposition states the main results of this extension. We omit the proof because it is analogous to the proof of Proposition 3.

Proposition 8. *Given a function $\alpha(\mu)$, if the consumer benefit from replacements is high, any all-claimants-beneficial reduction in consumers' claiming cost generates a reduction in product's reliability and an increase in profits; i.e., given assumptions 1 and 2, there exists μ_0 such that if $\mu \geq \mu_0$ then $\frac{\partial x}{\partial \mu} < 0$ and $\frac{\partial \Pi}{\partial \mu} > 0$.*

This Proposition shows that our main results when there is full or partial liability, when consumers may incorrectly request replacements (when they are not covered by the guarantee), or when consumer misuse may affect the product performance with firm's limited liability.

B.6 Consumer Damages when the product fails

In this extension we incorporate consumer damages when the product fails. For simplicity, we assume that the utility of the consumer is v always, but the consumer faces a damage $-D$ for some $D > 0$ if the product fails. The utility of not buying remains at 0. We also assume that replacements are granted but a compensation for damages D is granted only with probability $z > 0$. Like Chen and Hua (2012), partial liability is represented by $z < 1$ and strict liability by $z = 1$. A consumer incurs in a claiming cost of zero with probability μ and a claiming cost of $+\infty$ to request a compensation for the damage. Then, his expected utility of buying is

$$EU(x,p;\mu) = v-(1-x)D+(1-x)\mu zD-p.$$

The consumer pays a price p and receives a unit of the product enjoying a utility of v. With probability $1-x$ the product breaks down damaging the consumer in D. With probability μ the consumer pursues some compensation and he receives zD (due to limited liability).

The seller cost of production is $c(x)$ and the cost of attending a compensation request is $d < D$. Assumption $d < D$ may represent a situation where the firm is in a better position to attend consumer's damage. For instance, an airline is in a better position to find accommodation and food services for a passenger when a flight connection is missed and the passenger must spend a night in an airport. Our results also hold when $d = D$ but the consumer obtain utility v only when the products works well (like in the main text).

The firm's profit can be written as

$$\Pi(x,p;\mu,d,D) = (\hat{v} - (1-x)(1-\mu z)D - c(x) - (1-x)\mu z d)\,(1 - G(\hat{v}))\,.$$

For a non-trivial problem we assume that $max_x\, v - (1-x)D - c(x) > 0$. The following condition (from the first order condition with respect to x) implicitly defines the optimal reliability level

$$c'(x) = D(1-\mu z) + \mu z d.$$

We next state our results concerning product reliability and profits.

Proposition 9. *Firm's profits increase in the number of claimants and product reliability decreases in the number of claimants; i.e.,* $\frac{\partial \Pi}{\partial \mu} > 0$ *and* $\frac{\partial x}{\partial \mu} < 0$.

Proof of Proposition 9. Taking the derivative of product reliability (from the first order condition) and of profits (using envelope theorem) we get

$$\begin{aligned} \frac{\partial x}{\partial \mu} &= -\frac{z(D-d)}{c''(x)} < 0, \\ \frac{\partial \Pi}{\partial \mu} &= (1-x)z(D-d)[1-G(\hat{v})] > 0. \end{aligned}$$

□

C Distributions and assumptions 1 and 2

In this appendix we extend on the assumptions regarding distributions of consumers' claiming cost. First, we show that assumptions 1 and 2 are satisfied by two commonly used distributions: Exponential and

Pareto. Second, we extend on a more general set of distributions, re-defining assumptions 1 and 2 and explaining that these assumptions are sufficient but not necessary for the main results of the paper.

C.1 Exponential and pareto distributions

C.1.1 Exponential: $k \sim F(k) = 1 - e^{-k/\lambda}$

Suppose that $k \sim F(k) = 1 - e^{-k/\lambda}$ for $k \in [0, +\infty)$. We need to express α in terms of μ. Given this distribution, we write $\mu = F(1) = 1 - e^{-1/\lambda}$, $\lambda = -\frac{1}{\ln(1-\mu)}$, and,

$$\int_0^1 F(k)dk = \int_0^1 1 - e^{-k/\lambda} dk \;=\; 1 - \lambda\left(1 - e^{-1/\lambda}\right), \\ = 1 + \frac{\mu}{\ln(1-\mu)}.$$

Consequently, we can write α as,

$$\alpha(\mu) = \frac{\int_0^1 F(k)dk}{\mu} \;=\; \frac{1}{\mu} + \frac{1}{\ln(1-\mu)},$$

which is increasing in μ for all $\mu \in (0,1)$. Additionally, $\lim_{\mu \to 1} \alpha = 1$.

C.1.2 Pareto: $k \sim F(k) = 1 - \left(\frac{\underline{k}}{k}\right)^{\lambda}$

Suppose that $k \sim F(k) = 1 - \left(\frac{\underline{k}}{k}\right)^{\lambda}$ for $k \in [\underline{k}, +\infty)$, $\lambda > 0$, and $\underline{k} > 0$. We assume that $1 > \underline{k}$. Given this distribution, $\mu = 1 - (\underline{k})^{\lambda}$, $\lambda = \frac{\ln(1-\mu)}{\ln(\underline{k})}$, and, $\underline{k} = (1-\mu)^{1/\lambda}$. Additionally,

$$\int_{\underline{k}}^1 F(k)dk = \int_{\underline{k}}^1 1 - \left(\frac{\underline{k}}{k}\right)^{\lambda} dk = \begin{cases} 1 - \underline{k} - \frac{1}{\lambda - 1}\left[\underline{k} - \underline{k}^{\lambda}\right], & \text{if } \lambda \neq 1, \\ 1 - \underline{k} - \underline{k}\ln\left(\frac{1}{\underline{k}}\right), & \text{if } \lambda = 1. \end{cases}$$

Note that consumers' claiming cost varies in $[\underline{k}, +\infty)$, affecting the function α. For this case notice that $\int_{\underline{k}}^1 F dk \in [0, (1-\underline{k})F(1)]$, then α is defined by

$$\alpha(\mu) = \frac{\int_{\underline{k}}^1 F(k)dk}{(1-\underline{k})\mu} \;=\; \frac{1}{\mu} - \frac{1}{(1-\underline{k})\left(\frac{\ln(1-\mu)}{\ln(\underline{k})} - 1\right)} + \frac{1}{\mu\left(\frac{\ln(1-\mu)}{\ln(\underline{k})} - 1\right)}, \text{ if } \lambda \neq 1. \tag{22}$$

The Pareto distribution has two parameters $(\underline{k}, \lambda)$ affecting μ. We show that assumptions 1 and 2 are satisfied when modifying any of these parameters separately. First, we analyze changes in μ due to changes in λ keeping $\underline{k}$ constant. In this case, Equation 22 is increasing in μ for all $\mu \in (0,1)$ and all $\underline{k} \in (0,1)$.

Finally, we analyze changes in μ due to changes in $\underline{k}$ keeping λ constant. Writing α as in terms of λ and μ.

$$\alpha(\mu) \quad = \quad \frac{1}{\mu} - \frac{1}{(1-(1-\mu)^{1/\lambda})\,(\lambda-1)} + \frac{1}{\mu\,(\lambda-1)}, \text{ if } \lambda \neq 1. \tag{23}$$

which is increasing in μ for any $\lambda \neq 1$. It is also clear that $\lim_{\mu \to 1} \alpha(\mu) = 1$ in both Equation (22) and Equation (23).

C.2 Claiming costs, complaints, and consumers' benefit from replacement requests

Here we study in depth the relationship between the reduction in consumers' claiming cost (F), the number of claimants (μ), and the benefits to claimants (α), that plays a critical role on the impact of changes in F on product reliability and profits. This section focus on generalizing our previous results in a more general and, maybe, a little more technical environment; however it can be skipped with no loss of continuity. First we introduce a weak definition of increasing the number of claimants as *claimants-encouraging* change in F; secondly we analyze the implications of the commonly used partial order denoted as *first order stochastic dominance* and its limitations, then we define the *all-claimants-beneficial* change in F showing its implications and limitations and, finally, we comment on the boundaries of these assumptions.

Any intervention that increases the number of claimants μ will be defined as *claimants-encouraging* change in consumers' claiming cost. Formally, for any F and F', if $\mu' := F'(v) \geq \mu := F(v)$, then F' represents a *claimants-encouraging* change in consumers' claiming cost with respect to F. Notice that a downward shift in F satisfying the *first order stochastic dominance* (FOSD) criteria is a sufficient condition for having a *claimants-encouraging* change in consumers' claiming cost. Formally, we say that distribution F *first-order stochastically dominates* F', if $F'(k) \geq F(k)$ for all $k \in [0,+\infty)$ with strict inequality for some k, and we denote it $F \succ_1 F'$. The following lemma requires no proof.

Lemma 5. *If $F \succ_1 F'$, then $\mu' \geq \mu$.*

For instance, any intervention helping consumers to request a replacement, like intensifying the influence of consumer associations, may be represented by a downward shift in the distribution F satisfying the FOSD criteria. Restricting to *claimants-encouraging* changes in consumers' claiming cost distributions that satisfy the FOSD criteria is not strong but still allow us to write following result.

Lemma 6. *There always exists a reduction in consumers' claiming cost satisfying the FOSD criteria such that product reliability decreases and profits increase. Formally, for any F there exists F' with $F \succ_1 F'$, such that $x(F') \leq x(F)$ and $\Pi(F') \geq \Pi(F)$.*

A *claimants-encouraging* reduction in consumers' claiming cost satisfying the FOSD criteria generates two effects. First, it increases the expected number of consumers that request a replacement if the product fails, i.e., the number of claimants μ weakly increases. Second, it increases the expected utility consumers recover when the product fails (accounting for the probability of requesting a replacement), i.e., $v\alpha\mu := \int_0^v F dk$ weakly increases. These two effects affect the incentives to provide reliability expressed in equation (**??**) (and profits) in opposite direction.[32] Lemma 6 shows that there always exists one distribution that is dominated in terms of FOSD guaranteeing a reduction in reliability and an increase in profits.[33]

As it turns out, this *FOSD* criteria is not strong enough to provide general insights regarding which of these effects dominates (increase in μ or increase in $\mu\alpha$) and whether reliability increases or decreases when there is a reduction in F. Figure 1 clarifies this point: Figure 1.a shows a change from distribution F_A (continuous-blue line) to F_B (dashed-red line) that impacts mainly in the number of claimants μ (i.e., in the replacement effect), increasing firm's incentives to provide reliability. On the contrary, Figure 1.b shows a change from F_A to F_C (dashed-green line) that mainly increases $\int_0^v F dk = v\alpha\mu$ (affecting mainly the demand effect), reducing firm's incentives to provide reliability.

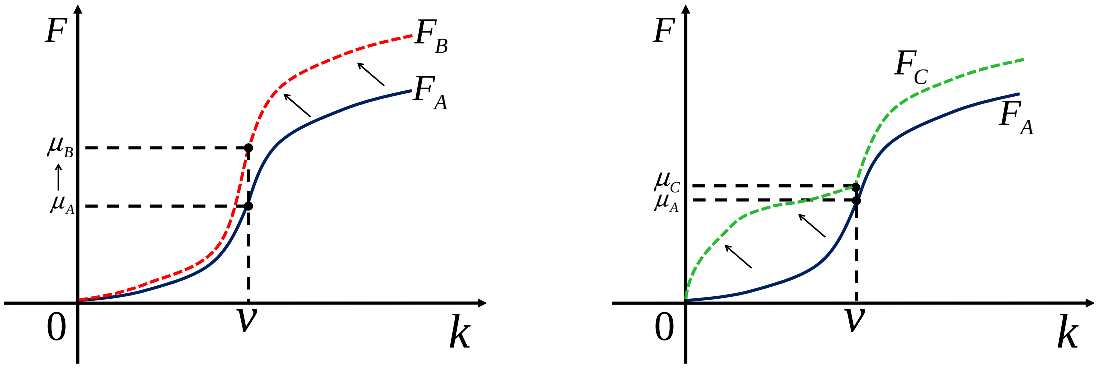
To take care of this issue we restrict the set of distributions to those that guarantee that a reduction in consumers' claiming cost will be *all-claimants-beneficial* in the sense that increase both the number of claimants μ and the benefit from requesting a replacement α. Formally, we say that distribution F' represents an *all-claimants-beneficial* reduction in consumers' claiming cost with respect to a distribution F if and only if the following two conditions hold:

(i) $\mu(F') \geq \mu(F)$, and

(ii) $\alpha(F') \geq \alpha(F)$.

[32] Notice that these two effects impact on α which may ultimately increase or decrease.

[33] Notice that the opposite is not true: there is not always a distribution F satisfying the FOSD criteria that motivates an increase in reliability and/or a decrease in profits. For instance, suppose k follows a uniform distribution F_u in $[0,\bar{k}]$. There exists a $\bar{k}$ for which there is no F with $F_u \succ_1 F$ such that x increases and/or Π decreases.



(a) Shift in F encouraging claimants

(b) Shift in F benefiting claimants

Figure 1: Claimants-encouraging reduction in consumers' claiming cost that mainly impacts in the number of claimants μ (a) or in the benefit of requesting a replacement $\int_0^v F dk$ (b).

An *all-claimants-beneficial* reduction in consumers' claiming cost not only encourages consumers to be claimants (being a *claimants-encouraging*), but also reduces all claimants expected cost of doing so. This condition is a relaxed version of assumptions 1 and 2, as we do not impose any continuity or differentiability condition on the relation between μ and α; however it generalizes our results to a bigger set of distributions $\mathbb{F}$ preserving the same intuition.

As conditions (i) and (ii) focus on how the values of μ and α are affected by changes in distribution F, the FOSD partial order is neither sufficient nor necessary for these conditions to hold. More generally we can also consider a mean-preserving spread change in consumers' claiming cost.[34] However, as I motivated in the introduction it seems reasonably to argue that consumers' claiming cost has moved downward during the last decades satisfying a FOSD criteria.

Our results in Proposition 3 extends in Proposition 10 when relaxing assumptions 1 and 2 to conditions (i) and (ii),

Proposition 10. *If the consumer benefit from replacements is high enough, any all-claimants-beneficial reduction in consumers' claiming cost motivates a reduction in product reliability and an increase in profits. Given F with α high enough, any F' such that $\mu' \geq \mu$ and $\alpha' \geq \alpha$, implies $x(F') \leq x(F)$ and $\Pi(F') \geq \Pi(F)$.*

[34]This mean-preserving spread change in F may be motivated by firms and third parties. For example, if substituting the complaining system for an easier procedure but which is available only through fidelity programs, a firm simplifies complaining to loyal consumers and entangles it to non-loyal consumers. As we do not introduce formally endogenous changes in F, we leave this extension for further research.

Proposition 10 extend our results considering a general set of distributions that are: a) continuous, discrete, mixed and/or any mixture of them, b) with one and/or several parameters characterizing a particular family of distributions, c) satisfying the FOSD or not.

As there is no implication when α is not high, Proposition 10 admits the possibility of both an increase or a decrease in reliability x and profit Π as the number of complaints increases. These non-monotonic results are driven by the same two forces mentioned before: the existence of consumers' claiming cost, and incomplete contracting in consumers' complaining behavior.

To conclude this section we comment on the sufficiency of assumptions over an *all-claimants-beneficial* reduction in F. As we mentioned above, conditions (i) and (ii) are not strong and we introduce them only to simplify the exposition of our results. Restricting to *claimants encouraging* reduction of consumers' claiming cost satisfying FOSD criteria, the benefit from requesting a replacement may be non-monotonic in the number of claimants (i.e., α may increase or decrease when μ increases). However, for our results to hold we only require α to be high enough when $\mu = 1$ and that α increases as the distribution F shifts down if $\mu \in [\underline{\mu}, 1]$ for some $\underline{\mu} < 1$. In words, we only require that the reduction in consumers' claiming cost for those consumers who request replacements to be *more than proportional* when the number of claimants is high enough. Since the partial order defined by *first order stochastic dominance* has a minimum element defined by $F(k) = 1$ for all $k \in [0, +\infty)$, where $\alpha = 1$ and $\mu = 1$; then, it is straightforward to show that profits will eventually increase and reliability will decrease (and, as will be clear later on, welfare will increase) as consumers' claiming cost decreases and the number of claimants increases.