

Product liability in markets for vertically differentiated products

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Abstract

This paper explores the impact of product liability in markets for vertically differentiated products when product safety is perfectly observable. In a two-stage competition, duopolistic firms are subject to strict liability and segment the market such that a low-safety product is marketed at a low price to consumers with relatively small harm levels whereas the safer product is sold at a high price to consumers with high levels of harm. Firms' expected liability payments are critically influenced by how the market is segmented. We vary the liability system's allocation of losses between firms and consumers. Shifting more losses to firms increases the safety levels of both products, but decreases the degree of product differentiation. Some shifting of losses is always socially beneficial, but the optimum may require that some compensable losses stay with the consumers.

Keywords: product liability, accident, harm, imperfect competition, product safety, vertical product differentiation.

JEL classification: D43, K13, L13.

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1 Introduction

1.1 Motivation and main results

Product liability makes manufacturers of defective products liable for harm caused to their consumers. Product liability has gained major importance in the USA and increasingly does so in Europe (e.g., Lovells 2003). Controversies about its use and potential excessiveness receive attention in the media and in academia (Polinsky and Shavell 2010a, 2010b, Goldberg and Zipursky 2010). Polinsky and Shavell (2010a) argue that there are three main benefits of product liability, namely, improvements in product safety, induction of better consumer purchase decisions by causing product prices to reflect risks, and the compensation of victims of product-related accidents. At the same time, however, the authors point out that the high transaction costs associated with product liability will make its use unwarranted for products for which other mechanisms (e.g., reputation) work towards achievement of the same benefits.

This paper analyzes the influence of product liability on the incentives for vertical product differentiation, thereby exploring potential social benefits and costs of product liability not dealt with in the literature heretofore. The market for bicycles is an example for a market in which product varieties with different safety levels are traded. Product defects may cause serious injury to the bicyclist even in solo accidents. The Australian Competition & Consumer Commission writes on their websites: “Cyclists can suffer: broken bones, head injuries or death if aspects of the bicycle fail, such as the braking system, steering or pedal cranks; serious injury or death if the bicycle’s head stem cracks or fails, causing the rider to have no steering control; ...”¹. The adverse repercussions of an accident will vary across victims due to heterogeneity in wealth, professional status or health, for example. While product safety is valuable for all potential victims, the heterogeneity in harm levels implies heterogeneity in the willingness to pay for higher safety. The interrelation of product safety and product price was described, for example, in an interview-based article of a German news-channel under the header “Dangerous product defects: Purchase of cheap bicycles involves risk”: “... ‘A low price may not be tantamount to low quality. However, cheap bicycles may involve some risk’, said Roland Huhn from the German Cyclist’s Association (ADFC) in Bremen. Technical defects can be

¹<http://www.productsafety.gov.au/content/index.phtml/itemId/973470>

the cause of accidents. Especially, the intensive use of cheap bicycles creates hazards. Also overweight people may face higher risks because of the higher strain on parts pertinent to security. ...”²

In our analysis, we show that product liability influences market outcomes (including safety levels) despite perfect information about product safety and transaction costs being absent in a setting with imperfect competition and heterogeneous consumers. We consider two firms that sell their products with different risk attributes to consumers with heterogeneous harm levels. The risk attributes of the products that firms commit to in a first stage are observed perfectly by consumers. Price competition takes place in stage 2 for given safety levels. Like, for example, Daughety and Reinganum (2006), we assume that compensation is determined by the tort system and not by contracting between firms and consumers. Firms are subject to strict liability with incomplete compensation of victims of product-related accidents.³ In practice, the divergence of the level of total accident losses and the level of compensation may be traced back to, for instance, non-pecuniary harm components, harm components which are difficult to evaluate or to foresee, statutorily established limits on awards, or uncompensated litigation costs (see, e.g., Endres and Lüdeke 1998, Posner 1998, Shavell 2004).⁴ In the spirit of Daughety and Reinganum (1995), we vary the liability system’s allocation of losses between injurers and victims and trace out the implications for accident risk, the level of product differentiation with respect to product safety, the intensity of price competition, and welfare.

In our set-up, firms compete in both prices and safety, always covering the full market. In equilibrium, there will be a firm offering a risky product at a low price and a high-safety firm asking for a high price. In the presence of product liability, when choosing price and safety levels, firms must bear in mind that their expected compensatory payments are critically influenced by which consumers they attract. For example, an increase in the

²Own translation from <http://www.n-tv.de/ratgeber/Billig-Fahrrad-Kauf-mit-Risiken-article278059.html>.

³Strict liability is the basic principle of the European Directive on Product Liability (85/374/EEC), for example, and assumed in most contributions to the literature such as Daughety and Reinganum (1995, 2006, 2008). The assumption about the liability rule and the one about the level of compensation are separable because from a legal standpoint, one set of norms describes the requirements for liability and another set of norms details the level of compensation due (e.g., Visscher 2009, Schäfer and Müller-Langer 2009).

⁴Following the practical importance of incomplete compensation of victims of product-related accidents, contributions to the literature on product liability usually assume that firms and consumers bear some losses when an accident occurs (e.g., Daughety and Reinganum 2006, 2008).

low-safety firm's market share implies that the expected liability per consumer increases for both the low-safety firm and the high-safety one. This increase results for both firms because the consumers switching from the high-safety firm to the low-safety one represent the consumers with the highest (lowest) harm level out of the pool of consumers of the low-safety (high-safety) firm. This makes the interaction of product liability and product differentiation complex and distinguishes our analysis from previous contributions on endogenous quality differentiation.

We find that shifting losses to firms has sizable efficiency consequences—despite consumers' perfect information about safety levels. Without product liability, the equilibrium level of product differentiation exceeds the first-best level; the low safety level falls short of the socially optimal low safety level and the high safety level exceeds its socially optimal counterpart. Shifting losses to firms induces both firms to increase their safety investments in a way that decreases the level of product differentiation. Whereas the increase in the low-safety firm's care level is socially desirable, the even higher care investment by the high-safety firm is inefficient.

The fact that shifting more losses to firms changes equilibrium safety in our setup stands in a sharp contrast with the *irrelevance result* from the literature on product liability when (homogeneous) consumers are perfectly informed about both the level of safety and the level of losses (see, e.g., the survey by Daughety and Reinganum 2013). In our context, the simple intuition that shifting losses to firms always makes products safer applies, which was denied for the standard framework (e.g., Shavell 1980). The explanation for our finding runs as follows. Firms design the products' safety characteristics with strategic motives, the marginal consumer, and a firm-specific *average consumer* in mind. Shifting more losses to firms makes safety less important for consumers, causing a reallocation of consumers to the low-safety firm such that both firms face an average and marginal consumer with a higher harm level (all else equal), and a moderation of the importance of the strategic motives. Both implications cause higher safety by the low-safety firm and in equilibrium also a higher safety level results for the high-safety firm.

With regard to prices set in stage 2, we find that firms' expected liability influences competition asymmetrically. This results from the relevance of prices for firms' expected liability payments. Whereas the low-safety firm faces an additional marginal benefit from

increasing its price (as a higher price and the resulting decrease in demand lowers its expected liability per consumer), the high-safety firm experiences an additional marginal cost from increasing its price, losing its cheapest consumers in regarding expected liability payments. When losses are shifted to firms, consumers care less about the difference in safety and more about the price difference. This implies a more intense price competition and lower mark-ups for firms, *ceteris paribus*. However, whereas the high-safety firm's mark-up clearly falls in equilibrium, the asymmetric impact of product liability on firms' pricing decisions described above may result in a higher mark-up for the low-safety firm. Furthermore, shifting more losses to firms entails that the low-safety firm attracts a greater share of consumers because the surcharge for the additional safety investment by the high-safety firm and cross-subsidization of high-harm individuals is worthwhile only for consumers with sufficiently high own levels of harm. Allocating a greater share of accident losses to firms thus changes firms' profits asymmetrically.

Importantly, it is not only firms that are asymmetrically affected when a greater share of expected accident losses is imposed on them. In fact, when the importance of product liability is increased, some types of consumers may gain whereas others lose. The intuition for this result is straightforward. In response to greater expected liability payments, the low-safety firm responds by increasing the level of safety and possibly the price. These changes may indeed be detrimental to consumers with low levels of harm, when the increase in safety does not compensate the increase in the level of the price. We find that it is possible that even the totality of consumers is worse off after an increase in the firms' share of losses.

When assessing the overall effect using a utilitarian welfare function, we find that allocating more losses to firms is socially optimal in most (that is, *not all*) scenarios, while allocating some losses to firms is always socially optimal. In our analysis, we thus establish that efficiency hinges upon the share of losses borne by firms. Interestingly, in some circumstances, it is socially desirable to cap the losses borne by firms. With regard to the impact of different components of welfare, it may be that the increase in welfare results from firms gaining profits and consumers losing utility, that is, very counterintuitive distributional consequences may result from a greater reliance on product liability.

Our paper contributes to the literature in the following ways (see Section 1.2 for a discussion of the relationship to the literature): in a market with imperfect competition,

we identify the influence of product liability on the degree of product differentiation as an important area to be included in the discussion of the pros and cons of product liability. We establish that the use of either no liability or strict liability is of critical importance to welfare even when consumers perfectly observe the level of safety and their level of harm. We vary the liability system's allocation of losses in a model of vertical product differentiation and detail the implications for accident risk, product differentiation, price competition, and welfare.

1.2 Related literature

Our work studies the interaction of product liability and vertical product differentiation. Accordingly, our paper can be related to contributions on product liability and the industrial-organization literature on endogenous product differentiation.

There is a vast literature on product liability, surveyed by Daughety and Reinganum (2013) and Geistfeld (2009), for example. The standard set-up considers perfectly competitive firms, identical risk-neutral consumers, as well as care costs and expected harm that are constant per unit of output. It delivers the result that strict liability and no liability are equally efficient when consumers are perfectly informed about care and do not misperceive risk (e.g., Hamada 1976, Shavell 1980). In our set-up, the extent to which product liability is made use of has important efficiency implications even when we maintain the assumptions regarding consumer information. The early literature has argued that misperceptions of risk make liability of the firm desirable relative to no liability (e.g., Shavell 1980, Polinsky and Rogerson 1983). Endres and Lüdecke (1998) analyze the implications of consumers' misperceptions when the product is supplied by a monopolist offering variants of the product with different safety features in order to induce self-selection of consumers with varying harm levels. In our analysis, the products with different safety attributes are supplied by two imperfectly competitive firms and delivered to consumers without misperceptions about product risk. With regard to the second informational assumption—observability of product safety—, many contributions to the literature consider the possibility that consumers are unable to perfectly observe risk attributes of products, exploring the outcomes that result with signaling or disclosure (e.g., Daughety and Reinganum 1995, 2008).

More related to our study, Daughety and Reinganum (2006) analyze a scenario in

which perfectly informed consumers are served by horizontally differentiated firms engaging in Cournot competition and consumers are only incompletely compensated by firms in the event of an accident.⁵ Firms commit to safety in the first stage and choose quantity in stage 2. Daughety and Reinganum compare the market equilibrium when symmetric firms are subject to strict liability with the outcome that results when a planner can choose product safety taking the implications on the Cournot competition as given. Their study delivers a host of interesting findings—*inter alia*—about the effects of changes in the number of firms or the substitutability of products. In contrast, we focus on price competition between two vertically differentiated firms and compare different allocations of losses between firms and consumers achieved by the liability system. The low-safety firm and the high-safety firm are asymmetric due to the different types of consumers served. Nevertheless, there are a number of commonalities with Daughety and Reinganum (2006), for example, the fact that firms consider a “business stealing” effect when determining safety, that the safety choice is not independent of the firm’s decision about output, that both firms and harmed victims always bear some costs resulting from a product-related accident, and that safety is a durable attribute committed to on an earlier stage in comparison to output/prices.⁶

Another related recent paper is Choi and Spier (2014) building on Ordover (1979). In that paper, perfectly competitive firms choose precautions facing consumers with either a high or a low accident probability, where safety is firms’ private information and risk type is consumers’ private information. When contracts comprise a price and stipulated damages to be paid in the event of an accident, firms have an incentive to lower the latter to screen risk types, providing a welfare rationale for mandatory product liability. We do not consider two contract components that would allow for a screening of consumer types. Instead, in our setup, firms understand that the price and safety levels imply an allocation of consumers to firms, allowing them to anticipate their respective *average* consumers in equilibrium.

The present analysis responds to Oi (1973), who discusses the scenario of consumers with heterogeneous harm levels when the safety levels of products may differ, and foresees

⁵Their model also permits vertical differentiation by different levels of safety investments, but they focus on symmetric equilibria where firms choose the same level of safety. Their model is also used to consider third-party victims, something we abstract from in the present contribution.

⁶Chen and Hua (2015) provide another recent study analyzing the impact of product liability on the competition among horizontally differentiated firms.

the extreme case that strict liability of firms will eliminate product differentiation when there is full compensation and no possibility of price discrimination. We analyze the endogenous safety choice of two firms which compete in prices when consumers cannot be fully compensated, such that consumers with a high level of harm continue to strictly prefer a safer product to another one, when all else is held equal. Whether or not, by extension of Oi's argument, a marginal shift of expected losses from consumers to firms lowers the degree of product differentiation is of key interest in the present contribution. While our results support the hypothesis of product liability diminishing the degree of product differentiation, we point out the rather complex implications of product liability for efficiency and welfare in a setting with vertical product differentiation.

We next address the relationship of our paper to the industrial-organization literature on vertical product differentiation. Vertical product differentiation between competing firms is studied in the seminal article by Shaked and Sutton (1982). There, firms first choose their quality level before they compete in prices. In line with our results, the authors show that firms decide to offer different levels of quality in order to mitigate the intensity of price competition in the second stage.⁷ This allows firms to increase their profits.

In the present paper, we investigate how product liability influences firms' product differentiation in an imperfectly competitive market. In contrast, the preceding industrial-organization literature on vertical product differentiation has focused on minimum-standard requirements as the policy instrument of choice (Ronnen 1991, Crampes and Hollander 1995).⁸ A robust result in this literature is that the use of a mildly restrictive minimum quality standard leads to an increase in the profits of the low-quality firm whereas the high-quality firm always loses profits when a quality standard is imposed. With respect to consumer surplus, Crampes and Hollander (1995) show for a fully covered market that all consumers gain from the introduction of a minimum-standard requirement if the response of the high-quality firm to the quality choice of its rival is weak. If the response is strong, those consumers who have only weak preferences for quality are worse off. Turning to welfare, the authors show that welfare increases if the quality response by the high-quality

⁷Motta (1993) shows that this also holds when firms compete in quantities instead of prices.

⁸Note that both contributions differ in their assumptions on the quality cost; whereas Ronnen (1991) assumes a quality-dependent fixed cost, Crampes and Hollander (1995) investigate the case where firms' unit costs increase in quality.

firm is less than the increase in quality by the low-quality firm (i.e., if the introduction of the standard reduces the level of product differentiation) despite the lower profits for the high-quality firm and the potential loss in surplus for some consumers.

Our analysis highlights the similarities and differences between the results obtained from using either product liability as a policy instrument or a minimum-standard requirement. Allocating a greater share of losses to firms reduces the difference in the products' risk attributes which may also result from an increasingly strict minimum-standard requirement. However, due to the rather complex interaction of product liability and product differentiation, the welfare effects of resulting changes in market shares and safety levels are less clear-cut when compared to the case with a minimum quality standard. In addition, there is an important difference between product liability and minimum quality standards. If firms have to compensate a larger share of losses, this reduces their scope for vertical differentiation because consumers perceive products as more similar even when holding the difference in care levels constant (i.e., differences in safety are less important for consumers). In contrast, the use of or change in the level of a minimum-standard requirement does not influence consumers' perception of quality differences. In addition, the minimum-standard requirement effectively determines safety of the low-safety firm whereas product liability does not similarly restrict the firms' choice set. In the remainder of the paper, we will repeatedly highlight differences between product liability and minimum-standard requirements.

1.3 Plan of the paper

Section 2 presents the model used for our analysis. Section 3 derives the socially optimal allocation as a benchmark for the market outcome analyzed in Section 4. In Section 5, the influence of product liability on the market equilibrium (e.g., product differentiation) and welfare is explained. Section 6 highlights the importance of the fact that firms take into account how price and safety levels influence their firm-specific liability payments for the working of product liability in our main analysis; to this end, we consider a uniform burden of liability instead. Section 7 concludes.

2 The model

We consider a market with two firms competing in prices and safety for the demand of a continuum of consumers whose mass is normalized to one. Both firms and consumers are risk-neutral. Each firm sells one variety of the good traded in the market and each consumer buys one unit from either one of the two firms. With regard to the consumption features, consumers value both varieties according to the parameter v which is assumed to be large enough to ensure full market coverage in equilibrium. The two product varieties may differ with respect to price and product safety, that is, the observable firm-specific probability of a product-related accident. The individual level of utility is the valuation less the price paid and less the uncompensated expected harm. Firms commit to a specific level of product safety which may be influenced by using better inputs or a more advanced technology, for example. Consumers differ with respect to the level of total (expected) harm h incurred in the event of an accident, where h is uniformly distributed on the interval $[\underline{h}, \underline{h}+1]$, $1/4 \leq \underline{h} \leq 1$.⁹ Consumers may differ with respect to their level of harm for several reasons. For example, the level of harm could be a function of consumer-specific characteristics such as wealth, professional status, health. Some consumers' susceptibility to greater harm could be due to prior exposure (as in the case of mercury, for example). Firms cannot observe the specific level of harm when selling the product to a consumer and we do not consider contract schemes that allow firms to screen consumer types.¹⁰ Our assumptions are reasonable in mass markets, for example, where products are distributed through retailers.

Strict product liability makes firms liable for the harm suffered by their consumers. In this regard, we assume that only βh is principally compensable, where $0 < \beta < 1$. This may be due to the fact that only a share β of the harm is verifiable (since this part involves goods with a market price readily available), whereas share $1 - \beta$ is not verifiable. The non-verifiable part may be due to, for example, the unobservability of emotional attachment to property destroyed in the product-related accident or individual-specific disutility from requiring medical treatment or engaging in litigation after the accident. The commonly assumed divergence of the level of total losses incurred in the event of an accident and

⁹It is standard to assume that the heterogeneity is due to a parameter with a uniform distribution on an interval with unit length (see, e.g., Kuhn 2007). For a different approach, see Wauthy (1996).

¹⁰For an analysis along these lines, see Choi and Spier (2014).

the level of compensation for the consumer may also be traced back to litigation costs under the American rule (e.g., Daughety and Reinganum 2006).¹¹ Since only expected values are essential in our analysis, another interpretation is that β is the probability of receiving compensation and $1 - \beta$ the one of receiving no compensation (as a result of difficulties in establishing causation, for instance). The level of β is common knowledge.

For most practical scenarios, policy decisions about statutory caps, for example, determine the level of compensation actually due in the event of an accident. Similarly, when part of the accident loss is due to property damage, arriving at a more or less accurate estimate of the property value is often difficult and can be guided by policy decisions about what kinds of references may be used and what kinds of evidence are admissible before court to inform about the level of the loss (e.g., Kaplow and Shavell 1996). Similar issues may arise in the context of temporary or permanent physical harm and lost earnings. The *generosity* of different legal regimes with respect to pain and suffering is a case-in-point (e.g., Shavell 2004). In order to take this into account, we explore the implications of varying the allocation of compensable losses between firms and consumers by using a policy variable γ , $0 \leq \gamma \leq 1$. In other words, the level of compensation transferred from the liable firm to the harmed consumer is $\gamma\beta h$, such that setting $\gamma = 1$ implies that all compensable losses on the part of consumers are actually compensated by firms.¹² Variations in the level of γ may also be interpreted in terms of the ease of receiving compensation, for example, by changing the burden of proof. In contrast to β which we assume to be not malleable and representing the possibility that some immanent issues make perfect compensation infeasible, the level of γ is a parameter that is adjustable and follows from public policy decisions. For the agents in the model, the product of $\beta\gamma$, that determines the share of losses compensated, is key to economic decision making.¹³

With x_i , $x_i \in [0, 1]$, denoting the firm's product safety features, unit production costs of firm i are given by $ax_i^2/2$, $a \geq 2$.¹⁴ The probability of a product-related accident

¹¹For firms, litigation costs following from an individual case may be subsumed under the costs of the legal department.

¹²We do not consider the possibility that a level $\gamma > 1$ may fully compensate for having $\beta < 1$ —which would result from setting $\gamma = \beta^{-1}$ —because consumers would in that case be indifferent regarding different levels of product safety, implying that firms would interact in a standard price-competition framework.

¹³We could consider $\beta\gamma$ as one parameter for the following analysis. However, we prefer to represent the limited ability to principally compensate consumers with the parameter β on the one hand and the policy decision with γ that may come from $[0, 1]$ on the other.

¹⁴This cost function is widely used in the context of competition in quality (see, e.g., Motta 1993).

is defined by $1 - x_i$. In the rest of the paper, firms' labels are chosen (without loss of generality) such that firm 1 is the low-safety firm and firm 2 the high-safety one (i.e., that $x_1 \leq x_2$). In addition to production costs, per-unit costs of firm i also comprise expected liability payments, which are critically influenced by which consumers firm i serves (in a way made precise below).

In our analysis, we focus on a pure-strategy equilibrium and for that reason impose a parameter restriction that rules out so-called *leapfrogging* incentives first discussed in Motta (1993). Whereas leapfrogging is a dominated strategy in Motta (1993), the cost asymmetry imposed by the different levels of average compensable consumer harm may make it profitable for the high-safety firm to deviate by choosing a safety level below the low-safety firm's one in our set-up. For given production costs and a given location of the interval of consumer harm (i.e., a and \underline{h}), the incentive to leapfrog to circumvent high liability payments depends on the share of losses shifted to firms, $\beta\gamma$. Allowing $\gamma \rightarrow 1$, we obtain that an upper bound on the share of compensable losses β rules out leapfrogging incentives. Appendix A shows that it is sufficient to make the following assumption:

Assumption 1 *It holds that $\beta \leq 6/(6\eta + 1)$.*

where $\eta = a - \underline{h}$.¹⁵

In the analysis described in the main part of the paper, we concentrate on interior solutions for the safety levels, that is, we focus on the case where the high-safety firm's safety level is less than one (as the accident probability is defined as $1 - x_2$). This is true whenever Assumption 2 holds which is, however, not necessary to obtain our qualitative findings.

Assumption 2 *It holds that $\eta \geq 5/4 + \beta/4(4 - 3\beta)$.*

In Appendix D, we establish that our key results continue to hold when Assumption 2 is not fulfilled and the corner solution $x_2 = 1$ results. Figure 1 summarizes the parameter combinations that are analyzed in the body of the paper (light-grey area), that are analyzed in Appendix D (dark-grey area), and that are not considered to allow us to abstract from leapfrogging complications (white area).

¹⁵In Appendix A, we also demonstrate that this restriction implies that the second-order conditions and the requirement that both firms are active also hold.

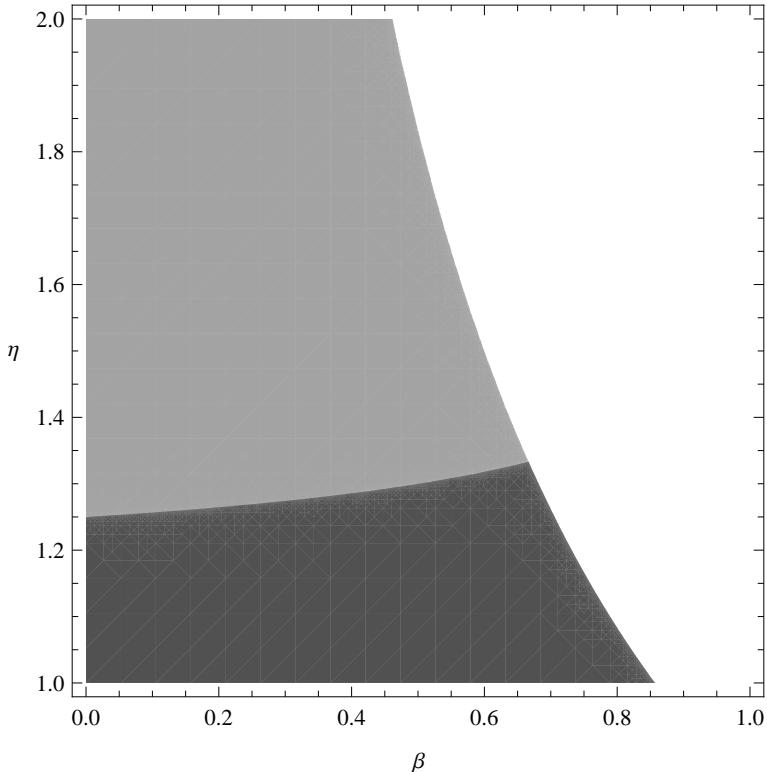


Figure 1: Combinations of β and η analyzed in the body (light-grey area) or in Appendix D (dark-grey) of the paper.

The timing of events is as follows. In stage 1, firms simultaneously choose levels of product safety. In stage 2, with common knowledge about safety levels, firms simultaneously set prices and then consumers decide from which firm to buy. Finally, accidents occur according to the accident risks of firms 1 and 2, and compensatory payments mandated by the liability regime are transferred.

3 Benchmark: First-best safety levels and split of consumers

We start our analysis by deriving the first-best levels of product safety and the socially optimal split of consumers as a benchmark. For this, we identify the safety levels x_1 and x_2 , and the allocation of consumers to firms 1 and 2 that maximize social welfare defined as the sum of producer and consumer surplus. Given a fully covered market and the uniform gross benefit from products v , the maximization of social welfare is tantamount to minimizing total social costs SC , consisting of production costs and expected harm.

If a social planner finds it optimal that firms 1 and 2 differentiate their products by choosing different safety levels ($x_1 < x_2$), it is clear that the products of the low-safety firm should be allocated to consumers with low levels of harm and vice versa. Denote by \hat{h} the harm level of the consumer who separates the population such that consumers with $h \leq \hat{h}$ obtain the product from firm 1 and consumers with $h > \hat{h}$ receive the product of firm 2. Social costs can be stated as

$$SC = (\hat{h} - h) \left(\frac{ax_1^2}{2} + (1 - x_1) \frac{\underline{h} + \hat{h}}{2} \right) + (\underline{h} + 1 - \hat{h}) \left(\frac{ax_2^2}{2} + (1 - x_2) \frac{\hat{h} + \underline{h} + 1}{2} \right) \quad (1)$$

where $(\underline{h} + \hat{h})/2$ and $(\hat{h} + \underline{h} + 1)/2$ represent the average expected harm of consumers served by firm 1 and firm 2, respectively.

The analysis of the first-order conditions yields the conclusion that the socially optimal level of safety of firm i minimizes the sum of precaution costs and expected losses suffered by consumers of firm i . The first-best split of consumers is attained when the marginal saving in production costs from reallocating consumers from firm 2 to firm 1 (i.e., $ax_2^2/2 - ax_1^2/2$) is equal to the marginal increase in expected accident costs (i.e., $(x_2 - x_1)\hat{h}$).

Our findings for the first-best allocation are summarized in the following lemma:

Lemma 1 *The socially optimal safety levels are $x_1^* = (4\underline{h} + 1)/4a$ and $x_2^* = (4\underline{h} + 3)/4a$, implying the socially optimal degree of product differentiation $\Delta_x^* = x_2^* - x_1^* = 1/2a$. The market is segmented such that consumers with harm level $h \leq (>)\hat{h}^* = \underline{h} + 1/2$ obtain the product from firm 1 (firm 2).*

Proof. The first-order conditions for x_1 and x_2 of the minimization problem according to (1) result in $x_1 = (\underline{h} + \hat{h})/2a$ and $x_2 = (\hat{h} + \underline{h} + 1)/2a$. Inserting these values into the first-order condition for \hat{h} , we obtain after collecting terms

$$-\frac{2(\hat{h} + \underline{h}) + 1}{8a} + \frac{\hat{h}}{2a} = 0$$

which leads to the results stated in Lemma 1. ■

The social planner uses product differentiation to account for consumers' heterogeneity regarding the level of harm in a product-related accident. Optimal safety levels increase with the average level of harm (reflected by the minimum harm level \underline{h}) and decrease in the costs of safety a . The socially optimal level of product differentiation decreases in the

costs of safety. The socially optimal split of consumers is such that each firm serves half of the market.

In the next section, we address the outcome that results under decentralized decision-making by firms potentially subject to strict product liability.

4 The market equilibrium

In this section, we derive the market equilibrium using backward induction. Accordingly, we start our analysis in stage 2 in which firms simultaneously set prices for given levels of product safety. Next, we analyze firms' decisions regarding product safety in stage 1.

4.1 Stage 2: Price competition

We start by analyzing price competition between firms 1 and 2 for given product safety levels. For this, we derive the demand of firm i as a function of price and safety levels.

In the event of an accident, a consumer with harm h receives a damage payment from his supplier amounting to $\beta\gamma h$ (i.e., he receives a share $\gamma \in [0, 1]$ of the compensable harm βh). Let p_i denote the price set by firm i . Then, all consumers with h weakly below (strictly above) \hat{h} will buy from the low-safety firm 1 (high-safety firm 2), where the harm level of the consumer indifferent between buying from firm 1 and buying from firm 2 denoted \hat{h} follows from¹⁶

$$p_1 + (1 - x_1)\hat{h}(1 - \beta\gamma) = p_2 + (1 - x_2)\hat{h}(1 - \beta\gamma), \quad (2)$$

such that

$$\hat{h}(x_1, x_2, p_1, p_2) = \frac{p_2 - p_1}{(1 - \beta\gamma)\Delta_x} \quad (3)$$

when $\Delta_x = x_2 - x_1 > 0$. In that case, firm 1 serves consumers with $h \in [\underline{h}, \hat{h}]$ and firm 2 serves those with $h \in (\hat{h}, \underline{h} + 1]$, such that $q_1 = \hat{h} - \underline{h}$ and $q_2 = \underline{h} + 1 - \hat{h}$ refer to the demand of firm 1 and firm 2, respectively. Equation (3) highlights that consumers care about prices, but discount a positive price difference by the difference in product safety to the extent that consumers remain uncompensated. Accordingly, the responsiveness of the firms' market shares to changes in price levels is critically determined by the difference in

¹⁶Without loss of generality, we assume that the indifferent consumer chooses the low-safety variant of the product.

product safety levels (i.e., the extent of product differentiation) and the specifics of the liability regime (represented by the level of γ). When $\Delta_x = 0$, all consumers would buy the cheaper product. When $\Delta_x = 0$ and $p_1 = p_2$, all consumers are indifferent between the two products and we assume that, in this case, they are randomly allocated to firms.

Firm i 's profit equation can be written as

$$\pi_i = \underbrace{\left(p_i - \frac{ax_i^2}{2} - (1 - x_i)\gamma\ell_i(x_1, x_2, p_1, p_2) \right)}_{=: \delta_i} q_i(x_1, x_2, p_1, p_2), \quad i = 1, 2 \quad (4)$$

where $\ell_1 = \beta(\underline{h} + \hat{h})/2$ and $\ell_2 = \beta(\hat{h} + \underline{h} + 1)/2$ represent expected compensable harm in the event of a product-related accident for consumers of firm 1 and firm 2, respectively. The specification of ℓ_i incorporates that each consumer will be compensated in proportion to the level of harm suffered, because compensatory payments as a function of the actual losses is a principle in most legal systems (Shavell 2004: 237).¹⁷ The term δ_i corresponds to the mark-up δ_i charged by firm i .

Profit maximization with respect to prices yields the first-order conditions

$$\frac{\partial \pi_i}{\partial p_i} = q_i + \delta_i \frac{\partial q_i}{\partial p_i} - (1 - x_i)\gamma \frac{\partial \ell_i}{\partial p_i} q_i = 0, \quad i = 1, 2 \quad (5)$$

which highlight a particularity of the relationship between vertical product differentiation and product liability. The first two effects in expression (5) are well-known: charging a higher price increases the firm's profits due to the higher profit margin for all units sold but induces some consumers to change their supplier. The third term is a novel aspect resulting from firms' liability. It measures the impact of a marginal increase in the price level on the firm's expected liability (due to the implied change in the firm's clientele). Whereas the loss of firm-specific demand due to an increase in the own price level is the same for firms 1 and 2 the change in the firm's expected liability due to an increase in the own price level is asymmetric such that $\partial \ell_1 / \partial p_1 < 0 < \partial \ell_2 / \partial p_2$. The intuition for the latter result is as follows: whereas firm 1 loses consumers with the highest expected harm when raising its price – thereby depressing the average harm of the consumers served by firm 1 – firm 2 loses consumers with the lowest expected harm. More generally speaking, shifting demand towards firm 1 implies a higher expected liability for both firm 1 and firm 2.

¹⁷This assumption need not carry over to class action, that is, scenarios in which a group of victims join their claims (e.g., Spier 2007).

Solving for equilibrium prices, we obtain the equilibrium mark-ups

$$\delta_1(x_1, x_2) = q_1(x_1, x_2) \left(\Delta_x (1 - \beta\gamma) + \frac{\beta\gamma(1 - x_1)}{2} \right) \quad (6)$$

$$\delta_2(x_1, x_2) = q_2(x_1, x_2) \left(\Delta_x (1 - \beta\gamma) - \frac{\beta\gamma(1 - x_2)}{2} \right). \quad (7)$$

Both firms charge a mark-up on their average costs per unit produced.¹⁸ For both firms, the mark-up at stage 2 depends positively on the own market share (i.e., q_i) and the degree of product differentiation (i.e., Δ_x weighted by the share of non-compensated harm). In contrast, the additional direct influence of the liability parameter γ (the second term in parentheses) is asymmetric, increasing firm 1's mark-up and decreasing firm 2's mark-up. The intuition lies with the additional effect of price increases on profits described above which leads firm 1 to charge relatively higher prices.

With price levels given by the sum of production costs, expected liability payments, and the mark-up, the harm level of the indifferent consumer results as

$$\hat{h}(x_1, x_2) = \frac{2(1 + 2h)(1 - \beta\gamma) + a(x_1 + x_2)}{2(3 - 2\beta\gamma)}. \quad (8)$$

Having derived firm i 's profit-maximizing price and its market share as a function of safety levels alone, we can state the (reduced) profit equation as a function of safety levels only

$$\pi_i = \delta_i(x_1, x_2)q_i(x_1, x_2), \quad i = 1, 2 \quad (9)$$

where $\delta_i(x_1, x_2)$ refers to the mark-up of firm i (explicated in expressions (6) and (7), respectively), and where firm i 's demand is given by $q_i(x_1, x_2)$ and is derived using expression (8).

This concludes our analysis of the second stage.

4.2 Stage 1: Product safety

In stage 1, firms simultaneously choose product safety levels. From expression (9), the first-order conditions are given by

$$\frac{\partial \pi_i}{\partial x_i} = \frac{\partial \delta_i(x_1, x_2)}{\partial x_i} q_i + \delta_i \frac{\partial q_i(x_1, x_2)}{\partial x_i} = 0. \quad (10)$$

¹⁸If $\Delta_x = 0$, given the constant production costs per unit and consumers being randomly allocated to firms, the only possible equilibrium is the Bertrand outcome $p_1 = p_2 = ax_1^2/2 + \beta\gamma(1 - x_1)(n + 1/2)$ where $\beta\gamma(1 - x_1)(n + 1/2)$ is the expected compensable harm per consumer who select randomly between firms. The mark-up is equal to zero.

It follows from expression (8) that a higher level of x_1 increases the market share of firm 1. This means that the second term in expression (10) is positive. For fulfillment of the first-order condition, the first term must be negative, implying that the mark-up of firm 1 must be decreasing when x_1 is in the relevant range. This is intuitive because a higher level of x_1 lowers the degree of product differentiation for a given level of x_2 . For firm 2, an increase in product safety is associated with a decrease in firm-specific demand. This holds because the higher variable costs translate into higher prices that only consumers with higher levels of harm are willing to afford, whereas other consumers switch to firm 1. In the optimum, the decrease in demand is offset by an increase in the mark-up firm 2 can charge because of the higher level of product differentiation.

Solving the first-order conditions for the equilibrium product safety levels, we find

$$x_1^M = \frac{4h - 1}{4a} + \beta\gamma \frac{8\eta + 1}{4a(4 - 3\beta\gamma)} - \beta^2\gamma^2 \frac{6\eta + 1}{4a(4 - 3\beta\gamma)} \quad (11)$$

and

$$x_2^M = \frac{4h + 5}{4a} + \beta\gamma \frac{8\eta - 9}{4a(4 - 3\beta\gamma)} - \beta^2\gamma^2 \frac{6\eta - 7}{4a(4 - 3\beta\gamma)}, \quad (12)$$

where the superscript M denotes market equilibrium outcomes.¹⁹ From firms' safety choices, the degree of product differentiation results as

$$\Delta_x^M = \frac{3}{2a} - \frac{\beta\gamma(5 - 4\beta\gamma)}{2a(4 - 3\beta\gamma)}. \quad (13)$$

The use of expressions (11) and (12) allows us to give a complete description of the market equilibrium where Assumption 1 guarantees that no profitable deviation strategy exists and Assumption 2 warrants $x_2^M < 1$.²⁰ We start with how consumers are allocated to firms 1 and 2 and arrive at the indifferent consumer's harm level:

$$\hat{h}^M = \underline{h} + \frac{1}{2} + \beta\gamma \frac{2\eta - 1}{4(3 - 2\beta\gamma)} \quad (14)$$

which implies

$$q_1^M = \frac{1}{2} + \beta\gamma \frac{2\eta - 1}{4(3 - 2\beta\gamma)} \quad (15)$$

and

$$q_2^M = \frac{1}{2} - \beta\gamma \frac{2\eta - 1}{4(3 - 2\beta\gamma)}. \quad (16)$$

¹⁹The firms' first-order conditions for safety at stage 1 display a discontinuity when $x_1 \rightarrow x_2$ and $x_2 \rightarrow x_1$, respectively, due to the way demand allocates when $\Delta_x = 0$. However, since zero mark-ups result for $\Delta_x = 0$, there is no equilibrium featuring equal safety levels.

²⁰See Appendix D for a description of the market equilibrium if Assumption 2 is not fulfilled.

Note that $\eta = a - h \geq 1$. Accordingly, firm 1 achieves a market share higher than (equal to) one half for $\gamma > 0$ ($\gamma = 0$). For the equilibrium mark-ups, we obtain

$$\delta_1^M = \frac{(2 - \beta\gamma)(6 + \beta\gamma(2\eta - 5))^2}{32a(3 - 2\beta\gamma)} = (q_1^M)^2 \frac{(2 - \beta\gamma)(3 - 2\beta\gamma)}{2a} \quad (17)$$

and

$$\delta_2^M = \frac{(2 - \beta\gamma)(6 - \beta\gamma(2\eta + 3))^2}{32a(3 - 2\beta\gamma)} = (q_2^M)^2 \frac{(2 - \beta\gamma)(3 - 2\beta\gamma)}{2a} \quad (18)$$

such that

$$\frac{\delta_1^M}{\delta_2^M} = \left(\frac{q_1^M}{q_2^M} \right)^2 \geq 1. \quad (19)$$

This establishes that firm 1's mark-up exceeds that of firm 2 when product liability plays a role (i.e., when $\gamma > 0$). This pattern, favoring firm 1, also shows with respect to profits which are given by

$$\pi_i^M = (q_i^M)^3 \frac{(2 - \beta\gamma)(3 - 2\beta\gamma)}{2a} \quad (20)$$

for $i = 1, 2$, such that

$$\frac{\pi_1}{\pi_2} = \left(\frac{q_1^M}{q_2^M} \right)^3 \geq 1. \quad (21)$$

We summarize the results from this section regarding the market equilibrium in the following proposition.

Proposition 1 *Suppose Assumptions 1 and 2 hold. The market equilibrium is described by safety levels x_1^M and x_2^M given by expressions (11) and (12), the indifferent consumer's harm level \hat{h}^M given by expression (14), and mark-ups δ_1^M and δ_2^M given by expressions (17) and (18).*

Proof. The proof follows from the discussion above. ■

We now move on to our main research interest, that is, how incentives for product differentiation are shaped by product liability in our framework.

5 Product liability, market equilibrium, and welfare

In this section, we assess the implications of product liability for the market equilibrium and explore both welfare and distributional consequences of different allocations of accident losses between firms and consumers. Specifically, we investigate the repercussions of product liability by describing the effects of an increase in the firms' share of compensable harm γ . In Section 5.1, we start with the comparative-statics properties of the market equilibrium before turning to welfare considerations in 5.2.

5.1 Product liability and market equilibrium: comparative-statics results

As a first step, we suppose that firms are not subject to strict product liability (i.e., we set $\gamma = 0$) and compare the market equilibrium with the first-best benchmark derived in Section 3.

Lemma 2 *Suppose Assumptions 1 and 2 hold. Without product liability, the market equilibrium displays an excessive degree of product differentiation with suboptimal product safety investments by firm 1 and supraoptimal product safety investments by firm 2. Both firms serve one half of the market, charge symmetric mark-ups, and earn the same level of profits.*

Proof. The proof follows from Lemma 1 and Proposition 1. From expressions (11) and (12), equilibrium care levels amount to $x_1^M = (4\underline{h} - 1)/4a = x_1^* - 1/2a$ and $x_2^M = (4\underline{h} + 5)/4a = x_2^* + 1/2a$, highlighting the divergence of equilibrium safety and first-best safety levels. ■

In order to soften price competition, firms choose a socially excessive degree of product differentiation with the low-safety firm offering a variety with lower than first-best safety and the high-safety firm offering a variety with higher than first-best safety. The market equilibrium is symmetric in that the market is equally split between firms with the indifferent consumer being located at $\hat{h}^M = \underline{h} + 1/2 = \hat{h}^*$. Moreover, both firms charge the same mark-up (equal to $\delta_1 = \delta_2 = 3/4a$) and earn profits amounting to $\pi_1 = \pi_2 = 3/8a$.

Our contribution to the literature lies in the consideration of product liability. Accordingly, the novelty of our analysis shows when product liability is introduced (i.e., when γ becomes positive). First, we consider the influence on product safety levels, the degree of product differentiation, and the split of consumers:

Proposition 2 *Suppose Assumptions 1 and 2 hold. An increase in the firms' share of accident losses (i) increases both firms' product safety levels, (ii) decreases the degree of product differentiation, and (iii) increases the equilibrium market share of firm 1, such that firm 1 serves more than half of the market when $\gamma > 0$.*

Proof. The proof of parts (i) and (ii) follows from equations (11) to (13) (see Appendix B). Part (iii) follows from the expression for the indifferent consumer (14). ■

For given safety levels, an increase in the firms' share of losses has a direct impact on how consumers are split between firms (as described by expression (8)). Consumers are less concerned about the accident risk, implying that some consumers switch from firm 2 to firm 1.²¹ The reality that \hat{h}^M increases connotes for firms 1 and 2 that average compensable harm levels ℓ_1 and ℓ_2 increase, providing an argument for higher safety investments. In addition, the fact that consumers care less about the difference in product safety levels means that product differentiation has less potential to soften price competition, thus lowering the incentives of firm 1 to bias x_1 downwards and the incentives of firm 2 to distort x_2 upwards. In other words, there are two effects resulting from an increase in the firms' share of losses. While both point towards a higher level of x_1 , the effects are mixed when it comes to the choice of x_2 . More specifically, firm 2 ought to increase product safety because its consumers' average harm level is higher, but it should decrease x_2 since product differentiation is less important.

In order to understand this reasoning formally, we scrutinize firms' decision-making in stage 1. Firms' first-order conditions for product safety in stage 1 (see expression (10)) anticipate how price competition will unfold in stage 2 and can be rearranged as best-response functions, that is, functions that yield the profit-maximizing level of product safety of firm i for a given safety level of firm j . Specifically, we obtain

$$x_1^{BR} = \frac{4(\underline{h} - 1) + 2\beta\gamma(3 + \eta - \beta\gamma) + a(2 - 3\beta\gamma)x_2}{3a(2 - \beta\gamma)} \quad (22)$$

$$x_2^{BR} = \frac{4(\underline{h} + 2) + 2\beta\gamma(\eta + \beta\gamma - 4) + a(2 - 3\beta\gamma)x_1}{3a(2 - \beta\gamma)}. \quad (23)$$

Under Assumptions 1 and 2, the best-response functions have a positive slope, indicating strategic complementarity between firms' product safety levels. Shifting more losses to firms decreases the slope of the best-response functions, indicating that strategic motives become less important. Matching our preceding informal arguments, an increase in the level of γ shifts x_1^{BR} outwards, that is, makes it privately optimal for firm 1 to choose a higher product safety level for any x_2 .²² The shift of firm 2's best-response function

²¹This is true when prices are given and when taking the second-stage price adjustment into account. From (8), we obtain the partial derivative $\partial\hat{h}/\partial\gamma = \beta(-(1 + 2\underline{h}) + a(x_1 + x_2))/((3 - 2\beta\gamma)^2)$, where from (11) and (12) $a(x_1 + x_2) = 1 + 2\underline{h} + \beta\gamma(2\eta - 1)/2$ in market equilibrium. Consequently, $\partial\hat{h}/\partial\gamma = \beta^2\gamma(2\eta - 1)/(2(3 - 2\beta\gamma)^2) \geq 0$.

²²After due simplification, the derivative of x_1^{BR} with respect to γ follows as $2\beta(2a(1 - x_2) + (2 - \beta\gamma)^2)/3a(2 - \beta\gamma)^2 > 0$.

prescribes higher or lower x_2 depending on the level of x_1 .²³ However, the shift of firm 1's reaction function implies that firm 2's safety level will move into the direction of higher safety on firm 2's new reaction function; the new equilibrium will display higher safety levels for both firms.

Figure 2 illustrates the best-response functions for the extreme scenarios in which the firm's share of compensable losses is either equal to zero or equal to one, that is, $\gamma = 0$ and $\gamma = 1$, respectively, assuming $\underline{h} = 1$, $a = 5/2$, and $\beta = 1/2$. The figure clearly illustrates the outward shift of x_1^{BR} and the fact that the shift of x_2^{BR} depends on the level of x_1 . Holding firms responsible for compensable accident losses results in a higher equilibrium safety level for firms 1 and 2 and a diminished degree of product differentiation Δ_x^M .

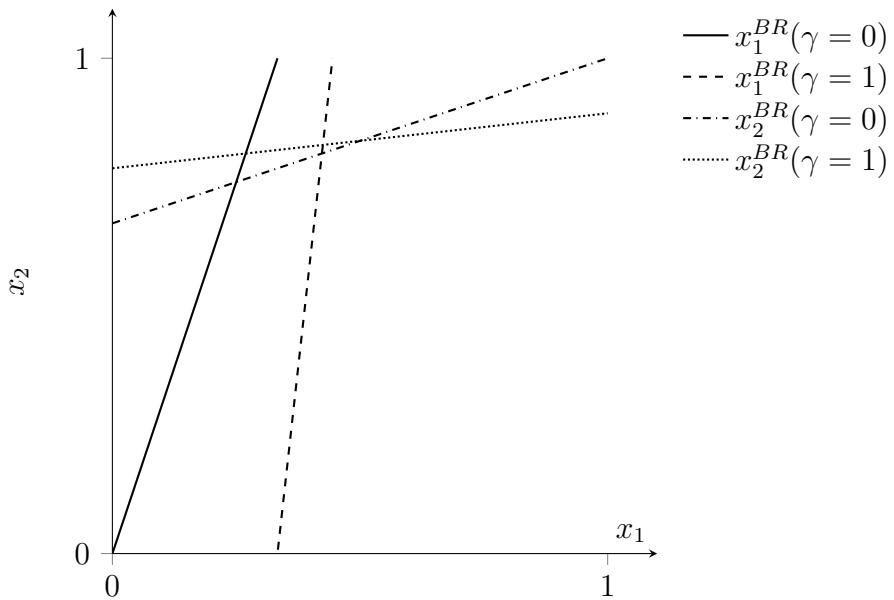


Figure 2: Firms' product safety best-response functions under no compensation ($\gamma = 0$) and full compensation ($\gamma = 1$) for $\underline{h} = 1$, $a = 5/2$, and $\beta = 1/2$.

Thus changes in the firms' product safety best-response functions explain the results put forward in Proposition 2 about the increase in the equilibrium levels and the diminishing degree of product differentiation. The resulting effect of an increase in γ on consumers' choice between firms 1 and 2 follows. As soon as $\gamma > 0$, firms no longer split the market equally. This is due to the asymmetric effect of product liability on firm 2's costs (including safety costs and expected liability payments).

²³More specifically, we obtain $2\beta(2a(1 - x_1) - (2 - \beta\gamma)^2)/3a(2 - \beta\gamma)^2$ as change of x_2^{BR} with γ .

We note that—despite perfect information—product liability has a direct bearing on firms’ safety levels in our setup. This contrasts sharply with the result that equilibrium care is independent of the liability regime obtained for markets in which consumers share the same level of harm (see, e.g., Shavell 1980). In the present framework, shifting losses to firms lowers firms’ incentives to aim at product differentiation because its pacifying influence on price competition becomes weaker. Instead, firms’ safety levels are increasingly shaped by how they relate to total expected costs (including their production costs and expected consumer harm).

Before we turn to the influence of the share of accident losses borne by firms on mark-ups, let us briefly highlight an important difference between product liability and minimum quality standards. Under the latter, a low-quality firm must increase its quality level to abide by the higher minimum quality standard. In contrast, under product liability with a higher compensatory mandate, the low-safety firm is free to consider balancing the higher liability payments by shifting its focus more on low-harm consumers (through an even lower safety level). Our findings show that this is not optimal for the low-safety firm. In our analysis, we find a positive relationship between the firms’ share of losses and safety choices, respectively. In other words, the pattern we find for equilibrium safety levels under product liability bears some resemblance with that obtained for a minimum-quality standard. Nevertheless, the mechanism at work is quite different.

Proposition 3 *Suppose Assumptions 1 and 2 hold. An increase in the firms’ share of accident losses (i) decreases firm 2’s mark-up, whereas the mark-up of firm 1 may increase or decrease, and (ii) increases the relative mark-up of firm 1.*

Proof. The proof follows from equations (17) to (19) in combination with Proposition 2. ■

The fact that safety becomes less important for consumers shifts demand towards the low-safety firm. This makes firm 1 want to increase its price (see the first term in (5)). In addition, firm 1 tolerates consumers switching to firm 2 to a greater extent due to the higher expected liability (see the third term in (5)). Firm 2’s lower demand and higher expected liability makes a lower p_2 optimal for firm 2, for the same reasons. In addition, both firms consider the fact that demand is more elastic when γ is raised. In addition to the effects just described, it is clear that the smaller degree of product differentiation

makes price competition fiercer, again resulting in downward pressure on mark-ups. In summary, the high-safety firm will lower its mark-up in response to an increase of the firms' share of accident losses, whereas the low-safety firm may even increase its mark-up (but only if the overall gain in demand of the firm dominates the direct and indirect effects of the lower level of product differentiation).

The above considerations have a direct impact on the firms' expected profit levels which is summarized in the following proposition:

Proposition 4 *Suppose Assumption 1 and (2) hold. An increase in the firms' share of accident losses (i) decreases firm 2's profits, whereas firm 1's profit level may increase or decrease, and (ii) increases the relative profit of firm 1.*

Proof. The proof follows from expressions (20) and (21) in combination with Proposition 2. ■

The results described in Propositions 3 and 4 make clear that allocating more accident losses to firms harms the high-safety firm and has an ambiguous impact on the low-safety firm's profits. This asymmetry parallels the repercussions of an increase in the minimum quality standard. It is a robust result in the literature that the high-quality firm suffers from a tightening of the minimum quality standard (Ronnen 1991, Crampes and Hollander 1995).²⁴ As is the case for a higher share of accident losses borne by firms in our setup, the picture is less clear with respect to the profit implications of a stricter minimum quality standard for the low-quality firm because it may or may not benefit from a stricter standard (Ronnen 1991, Crampes and Hollander 1995).

The analysis in this section has established that allocating a greater share of accident losses to firms lowers the accident risk associated with consuming either variety of the good. Whether or not these changes are welfare-improving will be discussed in the next section in which we also relate to distributional implications.

²⁴The intuition is that the stricter minimum quality standard serves as a commitment device for the low-quality firm not to lower its quality and induces the high-quality firm to set an even higher quality to differentiate itself from the low-quality firm. This lowers the market share of the high-quality firm, meaning that the low-quality firm enjoys some sort of first-mover advantage. This commitment aspect is not present in our analysis. However, given that the low-safety firm has an incentive to increase its safety level, the implication for the high-safety firm is the same: it makes a lower profit.

5.2 Product liability, welfare, and distributional effects

In many circumstances, it is realistic to assume that policy makers take how competition unfolds as a given and seek welfare improvements by influencing the circumstances under which firms compete. In the present setting, it is thus interesting to explore how welfare responds to changes in the level of γ . In practice, legislators can determine what kinds of harm have to be compensated in principle and what references may be used to measure the value of the compensable harm βh .

When the policy maker influences the outcome indirectly with only one instrument, namely, the liability system's allocation of losses, the first-best level of welfare will not be attainable. The variables that are relevant to welfare are the safety levels implemented by firms 1 and 2, and the segmentation of consumers. In other words, there are three policy targets. Remember that our focus on a fully covered market implies that the volume of trade is not affected by changes in the level of γ , implying that price levels are directly relevant only with regard to distributional effects and the allocation of consumers to firms. In the following sections, we first concentrate on the effects of the policy instrument on overall welfare, i.e., the sum of social costs. Afterwards, we consider distributional effects with regard to consumers with heterogeneous harm levels and with respect to the population of consumers on the one hand and firms on the other.

5.2.1 Implications of increasing the firms' share of losses for social costs

The benevolent policy maker chooses the level of his only policy instrument, namely, the liability system's allocation of losses, in order to minimize the level of social costs defined by

$$SC^M = (\hat{h}^M - \underline{h}) \left(\frac{a(x_1^M)^2}{2} + (1 - x_1^M) \frac{\underline{h} + \hat{h}^M}{2} \right) \\ + (\underline{h} + 1 - \hat{h}^M) \left(\frac{a(x_2^M)^2}{2} + (1 - x_2^M) \frac{\underline{h} + \hat{h}^M + 1}{2} \right), \quad (24)$$

taking into account how privately optimal decisions by firms and consumers depend on the level of γ (i.e., $\hat{h}^M = \hat{h}^M(\gamma)$ and $x_i^M = x_i^M(\gamma)$, $i = 1, 2$). It is clear from (24) that the allocation of accident losses between firms and consumers bears no direct implication for the level of social costs such that its only role is in guiding private decisions.

The marginal change in the level of social costs in response to an increase in γ is given by

$$\begin{aligned} \frac{dSC^M}{d\gamma} = & \underbrace{\frac{d\hat{h}^M}{d\gamma} \left(\hat{h}^M(x_2^M - x_1^M) - \frac{a((x_2^M)^2 - (x_1^M)^2)}{2} \right)}_{=:A} \\ & + \underbrace{\frac{dx_1^M}{d\gamma} \left(\hat{h}^M - \underline{h} \right) \left(ax_1^M - \frac{\underline{h} + \hat{h}^M}{2} \right)}_{=:B} + \underbrace{\frac{dx_2^M}{d\gamma} \left(\underline{h} + 1 - \hat{h}^M \right) \left(ax_2^M - \frac{\underline{h} + 1 + \hat{h}^M}{2} \right)}_{=:C}, \end{aligned} \quad (25)$$

where x_i^M and \hat{h}^M are increasing in γ (see Proposition 2). The total marginal effect in expression (25) is composed of three different terms: term A indicates the change in social costs due to the reallocation of consumers from firm 2 to firm 1, terms B and C describe the changes in social costs that result from the change in care levels for given firm-specific demand levels. These implications will be discussed in turn.

When $\gamma > 0$, the market is not split equally between firms 1 and 2 which, however, is a characteristic of the first-best allocation. Instead, more consumers buy from firm 1. However, given that equilibrium product safety levels differ from socially optimal care levels, the first-best split of consumers may not be second best. Given x_1^M and x_2^M (as in expressions (11) and (12)), we use term A in expression (25) to derive that the second-best level for the harm level of the indifferent consumer \hat{h}^{SB} is

$$\hat{h}^{SB} = \hat{h}^* + \beta\gamma \frac{2\eta - 1}{4} \quad (26)$$

which indeed exceeds the first-best level when $\gamma > 0$. Comparing the harm level of the indifferent consumer in the market equilibrium \hat{h}^M , from expression (14), with the one in the second-best allocation, we arrive at

$$\hat{h}^M - \hat{h}^{SB} = \frac{-\beta\gamma(1 - \beta\gamma)(2\eta - 1)}{2(3 - 2\beta\gamma)} \leq 0. \quad (27)$$

This connotes that the benevolent policy maker would like to allocate even more consumers to firm 1, given the safety levels that result in equilibrium. In the market equilibrium, the relatively higher mark-up of the low-safety firm prevents the second-best allocation of consumers for given safety levels. In other words, the influence that the liability system's allocation of losses bears on how consumers are split up between firms suggests raising

the share γ to one.²⁵

The terms B and C indicate whether the privately optimal safety levels fall short of or exceed what the policy maker would implement given the market equilibrium split of consumers \hat{h}^M . For $\gamma = 0$, we have established that the market equilibrium features an excessive degree of product differentiation, coming about via $x_1^M < x_1^*$ and $x_2^M > x_2^*$. For $\gamma > 0$, the first-best safety levels may not be socially optimal for the allocation of consumers to firms described by h^M . From expression (25), setting either $B = 0$ or $C = 0$, we obtain the second-best levels of care x_i^{SB} for the given split of consumers \hat{h}^M as

$$x_i^{SB} = x_i^* + \frac{\beta\gamma(2\eta - 1)}{8a(3 - 2\beta\gamma)}, \quad (28)$$

where $\Delta_x^{SB} = 1/2a = \Delta_x^*$. For $\gamma > 0$, the second-best safety levels exceed the first-best care levels because both firms serve consumers with higher expected harm levels (due to $\hat{h}^M > h^*$). Comparing the product safety levels in the market equilibrium with the ones in the second-best allocation, we arrive at

$$x_1^M - x_1^{SB} = -\frac{6 - \beta\gamma(6\eta + 1)}{12a} - \frac{\beta\gamma(6(\eta - 1) + 18\eta(1 - \beta\gamma) + 5\beta\gamma)}{24(3 - 2\beta\gamma)(4 - 3\beta\gamma)} < 0 \quad (29)$$

and

$$x_2^M - x_2^{SB} = \frac{1}{2a} + \frac{\beta\gamma\left(\eta - 5/4 - \frac{\beta\gamma}{4(4 - 3\beta\gamma)}\right)(5 - 4\beta\gamma)}{4a(3 - 2\beta\gamma)} > 0, \quad (30)$$

where the signs follow from Assumption 2. The equilibrium degree of product differentiation exceeds the second-best level for all levels of γ . This is intuitive because firms' decision-making is still influenced by the desire to soften price competition. Firm 1's safety choice falls short of the second-best safety level. Accordingly, term B in expression (25) is negative since an increase in firm 1's safety level is cost justified in that it reduces the expected harm of firm 1's consumers by more than it increases production costs. In other terms, the influence that the liability system's allocation of losses bears on firm 1's safety level also suggests raising γ to one. At the same time, firm 2's safety level is excessive compared to the second-best safety level x_2^{SB} . Term C is positive since a decrease in firm 2's safety expenditures would result in a decrease in precaution costs that more than offsets the increase in expected harm given the allocation of consumers to firms. This argues against a high liability parameter γ .

²⁵However, note that term A is equal to zero when $\gamma = 0$ because the market equilibrium segmentation of consumers is second best in that scenario, meaning that this effect cannot rationalize the marginal introduction of product liability.

In summary, we have argued that the policy maker perceives two kinds of marginal benefits and one marginal cost from increasing the share of losses borne by firms, namely, the influence on \hat{h}^M and x_1^M on the one hand and the implication for x_2^M on the other. From a policy standpoint, it is important to know whether the optimal level of γ is positive and, if so, if it is equal to or lower than one. The corresponding results are summarized in

Proposition 5 *Suppose Assumptions 1 and 2 hold. The firms' share of compensable accident losses that minimizes social costs (i) is positive and (ii) may be less than one.*

Proof. Part (i): For $\gamma = 0$ the term A in expression (25) is equal to zero, term B amounts to $-1/2$, term C is equal to $1/2$ and demand is split equally between firms. Due to $dx_1^M/d\gamma = \beta(8\eta + 1)/16a > dx_2^M/d\gamma = \beta(8\eta - 9)/16a$, it holds that $dSC^M/d\gamma < 0$ at $\gamma = 0$. Part (ii) is established by reference to an example at the end of Section 5.2.2. ■

We find that the cost-minimizing level of γ is strictly positive. This connotes that the beneficial effect of product liability on the lower safety level dominates its adverse effect on the higher safety level. In fact, it may be argued that the introduction of product liability is socially desirable because it dampens firms' excessive incentives for product differentiation. When $\gamma > 0$, further increases in the firms' share of losses may still be worthwhile; possibly, the shift in consumers rationalizes a marginal increase even if it would no longer be justified looking only at the adjustments in care levels.

The optimal value of γ may be lower than one for certain parameter constellations. This finding is interesting particularly since there is a non-compensated share of harm $1 - \beta$ by assumption even when $\gamma = 1$.²⁶ From our discussion of the different marginal effects, it is clear that scenarios featuring a cost-minimizing level of γ less than one must be such that firm 2's deviation from the second best regarding the safety choice bears heavily on the level of social costs. This will result, for example, when the marginal safety cost parameter a is high. However, the fact that the inappropriate safety choice of firm 2 is relevant only to a relatively small set of consumers at high levels of γ , shifting all of the compensable losses to firms minimize social costs in the bulk of scenarios. However, this qualification is not necessarily applicable when the share of compensable losses (i.e., β) is low, because the high-safety product variety remains of interest for many consumers

²⁶Baumann et al. (2011) describe a dynamic context where consumers cannot verify the current product safety levels. In that setup, it also need not be optimal to get as close to full compensation as possible.

in that scenario. We will continue to discuss this aspect at the end of Section 5.2.2 where we provide results for a specific example. The example illustrates that it is most likely for a value of $\gamma < 1$ to maximize welfare when a high level of a is combined with a low level of β .

5.2.2 Implications of increasing the firms' share of losses for consumer surplus and total profits

The analysis in the preceding section has described how a change in the liability system's allocation of losses influences the level of social costs, proxying welfare by the sum of producer and consumer surplus. In many circumstances, policy makers have other objectives in mind when making decisions on public policy. For example, with regard to competition policy, it is argued for many jurisdictions that antitrust policy concentrates on the implications for consumers.²⁷ To follow along these lines, we will explore how changes in the level of γ influence consumer surplus.

An individual consumer (with expected harm h) who purchases the good from firm i enjoys utility equal to

$$U = v - (p_i^M + (1 - x_i^M)h(1 - \beta\gamma)), \quad (31)$$

where it clearly shows that in the event of an accident the level of harm is relevant to the consumer's well-being only to the extent that the harm is not compensated (measured by $1 - \beta\gamma$). A marginal increase in the firms' share of losses from product-related accidents influences the utility of a consumer who does not switch suppliers as follows

$$\frac{dU}{d\gamma} = -\frac{dp_i^M}{d\gamma} + \beta h(1 - x_i^M) + \frac{dx_i^M}{d\gamma}h(1 - \beta\gamma). \quad (32)$$

Any increase in the price lowers the amount of money available for alternative uses. However, the consumer benefits from a higher level of γ due to the direct effect on the level of losses that remain with the consumer and the indirect effect on firm i 's level of safety. It is important to note that the price of the good need not increase when γ is raised even though both the costs of precaution and expected liability payments of firm i

²⁷Salop (2010) comments on the evidence which concludes that the consumer standard is indeed the one legislated by US Congress in adopting the Sherman Act. Moreover, from a normative point of view, he points out that the consumer standard is better than a total welfare standard for achieving the goals of antitrust legislation. Lyons (2003) notes, in the context of merger policy, that most major competition authorities apply a consumer welfare standard.

increase. This is due to the fact that mark-ups change as well (see expressions (17) and (18)). In such a scenario, the consumer is unambiguously made better off by an increase in the level of losses borne by firms. However, this will also occur when prices increase with γ as long as the two marginal benefits are sufficiently high. Breaking up the variation in the price level into its different components (according to $p_i^M = a(x_i^M)^2/2 + \gamma(1-x_i^M)\ell_i + \delta_i^M$), we can rewrite the change in utility as

$$\frac{dU}{d\gamma} = (1 - x_i^M) \left(\beta h - \ell_i - \beta \gamma \frac{d\hat{h}^M}{d\gamma} \frac{1}{2} \right) + ((1 - \beta\gamma)h + \gamma\ell_i - ax_i^M) \frac{dx_i^M}{d\gamma} - \frac{d\delta_i^M}{d\gamma}. \quad (33)$$

In our setup, shifting losses to firms has real consequences. In the standard product liability framework with homogeneous consumers and perfect information, such consequences are absent (see, e.g., Hamada 1976, Shavell 2004). In the latter scenario, neither mark-ups nor safety levels are influenced by the design of the liability regime. Furthermore, a consumer's harm level equals average expected harm, and the advantage of a higher compensation in the event of an accident is just offset by the increase in prices reflecting the increase in firms' liability costs. Contrary to that, in our setup, the liability system has a direct bearing on mark-ups (i.e., $d\delta_i^M/d\gamma \leq 0$), increases safety levels (i.e., $dx_i^M/d\gamma > 0$), and changes firms' expected liability payments by reallocating consumers from firm 2 to firm 1 (i.e., $d\hat{h}^M/d\gamma > 0$). Moreover, the direct change in firms' per-unit costs does not cancel out with the direct benefit for consumers from higher damages payments for each single consumer (i.e., $\beta h \neq \ell_i$ for most consumers).

In expression (33), a higher level of expected harm makes it more likely that the consumer benefits from a change in the liability system's allocation of losses because a higher level of h magnifies a part of the marginal benefits resulting from an increase in the level of γ without similar implications for the marginal costs therefrom. This also implies that a consumer of firm i with harm level $h + \epsilon$, $\epsilon > 0$, will always benefit from the change in the allocation of losses when the consumer of firm i with harm level h does so. For concreteness, we consider the utility implications of introducing product liability (i.e., the value of expression (33) at $\gamma = 0$) for the consumers at both ends of the harm interval $h = \underline{h}$ and $h = \bar{h} + 1$. We obtain

$$\frac{dU_{h=\underline{h}}}{d\gamma}|_{\gamma=0} = \beta \frac{69 - 40\eta}{64a} \geq 0 \quad (34)$$

and

$$\frac{dU_{h=\underline{h}+1}}{d\gamma}|_{\gamma=0} = \beta \frac{29 + 40\eta}{64a} > 0. \quad (35)$$

In other words, starting to shift some of the compensable accident losses to firms is necessarily increasing the utility of individuals with very high levels of harm. The benefit accruing from the higher product safety level dominates any price increase. Firms' prices reflect average damages payments in the event of an accident as a cost component. Accordingly, high risk consumers benefit from a cross-subsidization by low-risk consumers of the same firm, dampening potential price increases. In contrast, individuals with low levels of harm will benefit from introducing product liability only when $\eta = a - \underline{h}$ is sufficiently small (implying that the additional care costs must be small enough or that even the lowest harm level must be sufficiently high).

This finding may be compared to the related result from the scenario in which a minimum-safety requirement is introduced. In that case, the combination of both a minimum-standard requirement only slightly above the level chosen by the low-safety firm in the unregulated equilibrium and a modest response of the high-safety firm can assure that all consumers benefit from the policy (see Crampes and Hollander 1995). In our setting, a similar result is possible for the introduction of product liability.

In summary, we assert that

Proposition 6 *Suppose Assumptions 1 and 2 hold. The marginal introduction of product liability (i) benefits consumers with a very high harm level (i.e., $h \approx \underline{h} + 1$) and (ii) may harm or benefit consumers with lower harm levels.*

Proof. Follows from the discussion above. ■

Figure 3 exemplifies the potentially asymmetric implications for consumers of the policy maker's reliance on product liability. It illustrates the costs (i.e., the sum of the product price and the expected uncompensated harm) for all consumers in the two extreme scenarios in which there is either no product liability (i.e., $\gamma = 0$) or product liability mandates compensation of all compensable losses (i.e., $\gamma = 1$), assuming $\underline{h} = 1$, $a = 9/2$, and $\beta = 1/3$. The kink identifies the indifferent consumer's harm level at which the slope changes from $-(1 - \beta\gamma)(1 - x_1^M)$ to $-(1 - \beta\gamma)(1 - x_2^M)$. Clearly, when $\gamma = 1$, almost all consumers buy the low-safety firm variety. The figure also illustrates that the switch

to full product liability benefits consumers with sufficiently high levels of harm, whereas others are better off when $\gamma = 0$.

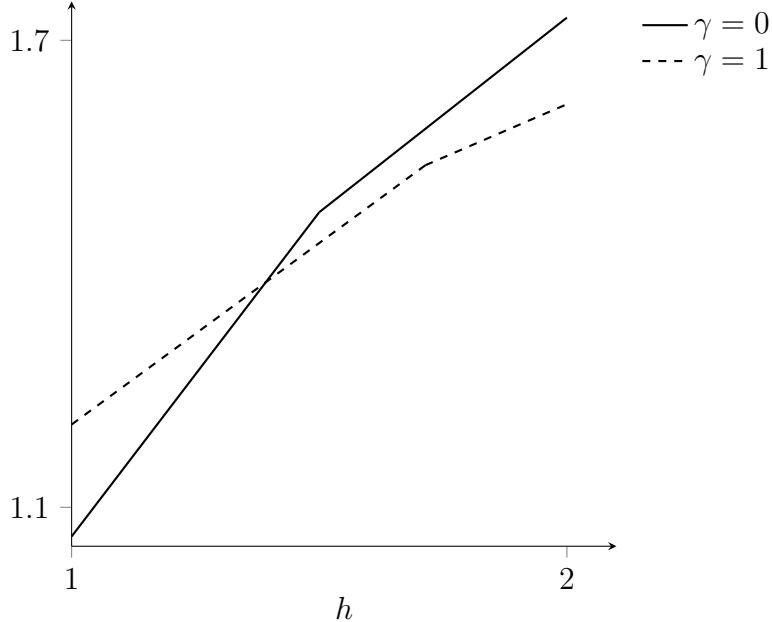


Figure 3: Costs of consumers under no compensation ($\gamma = 0$) and full compensation ($\gamma = 1$) for $\underline{h} = 1$, $a = 9/2$, and $\beta = 1/3$.

In addition to the type-specific effects of a change in the level of γ analyzed before, it is interesting to explore whether the population of consumers as a whole is always better off when firms bear a greater share of losses. Consumer surplus is given by

$$CS = v - \int_{\underline{h}}^{\hat{h}^M} (p_1^M + (1 - x_1^M)(1 - \beta\gamma)h)dh - \int_{\hat{h}^M}^{\underline{h}+1} (p_2^M + (1 - x_2^M)(1 - \beta\gamma)h)dh. \quad (36)$$

The marginal effect of increasing firms' share of losses on the level of consumer surplus thus represents the sum of the implications for the different types of consumers discussed above. Since some consumers may very well be worse off after a marginal increase in γ as argued above, $dCS/d\gamma$ may sum over positive and negative terms. Again, it is of key interest whether we can make statements about the change in consumer surplus as well as profits for the introduction of product liability (i.e., an increase in γ at $\gamma = 0$) and when completing the shifting of compensable losses (i.e., at $\gamma = 1$).

Proposition 7 *Suppose Assumptions 1 and 2 hold. An increase in the firms' share of accident losses γ (i) increases consumer surplus and decreases total profits at $\gamma = 0$ and (ii) may increase or decrease consumer surplus and total profits at $\gamma = 1$.*

Proof. The first part follows from the evaluation of the derivative of CS with respect to the firms' share of accident losses at $\gamma = 0$ (which gives $33\beta/32a$) and the evaluation of the derivative of $\pi_1^M + \pi_2^M$ with respect to the firms' share of accident losses at $\gamma = 0$ (which gives $-7\beta/8a$). Part (ii) is established by reference to an example at the end of this section. ■

Proposition 5 established that the marginal introduction of product liability is socially desirable. Proposition 7 explains that this is due to the increase in consumer surplus dominating the decrease in total profits. This gain for consumers follows from the fact that the excessive degree of product differentiation is attenuated by the introduction of product liability, bringing about fiercer price competition. However, for marginal increases in the firms' share of losses starting from $\gamma > 0$, it is no longer assured that consumers as a whole benefit. With respect to total profits, the market dominance of the low-safety firm (due to the cost asymmetry implied by product liability) can eventually bring about an increase in total profits.

We conclude this section by presenting some numerical illustrations to convey an idea of the different possible patterns for the variables of interest. For this, we assume $h = 1$ and consider the scenarios (S1) $a = 5/2$ and $\beta = 1/2$, (S2) $a = 9/2$ and $\beta = 1/3$, and (S3) $a = 9$ and $\beta = 1/10$ such that the cost of safety is increasing when the share of compensable harm is decreasing. We are interested in the distributional and welfare patterns that emerge when we vary the allocation of losses between firms and consumers (i.e., when we increase γ). To make the scenarios easily comparable even though the different parameter configurations create distinct levels of variables, we present normalized levels for the variables of interest, using the level of the variable at hand evaluated at $\gamma = 0$ for normalization. Our main interest is with the impact of the level of γ on profits, consumer surplus, and social costs.

Figure 4 illustrates how the level of costs borne by consumers is influenced by the shifting of accident losses towards firms. In scenario (S1), consumers are positively affected by any marginal increase in the firms' share of accident losses. In scenario (S2), the level of costs borne by consumers first decreases and then increases, never to reach the original level again. To be precise, the level of γ that is optimal for consumers in the second scenario is interior at $\gamma \approx .55$. For scenario (S3), the level of γ that minimizes the costs borne by consumers (i.e., maximizes consumer surplus) is reached already at $\gamma \approx .33$. In

other words, the implications of increasing the firms' share of losses soon start to lower the utility of the mass of consumers; note that at $\gamma = 1$ costs are even higher than for $\gamma = 0$ in scenario (S3). However, it must be remembered that there are asymmetric effects on different types of consumers (according to the personal level of harm). For example, consumers with $h \approx \underline{h} + 1$ benefit from an increase in the level of γ for all levels of the firms' share of accident losses.

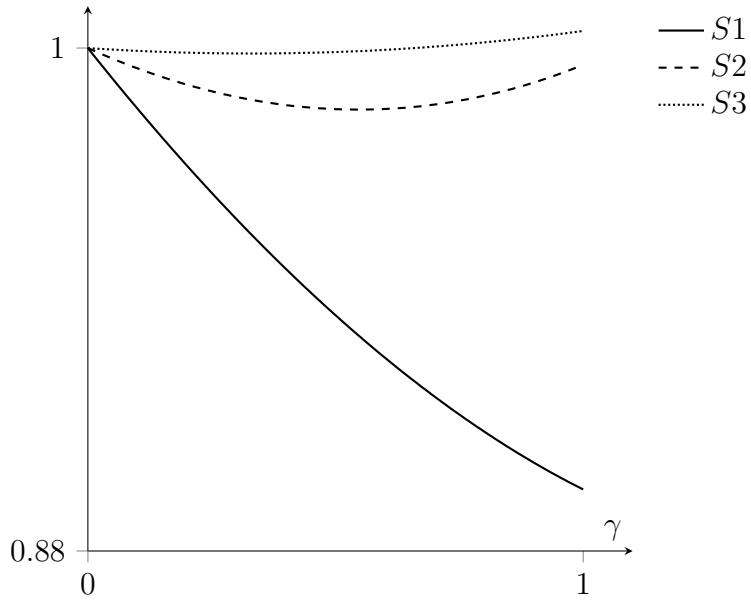


Figure 4: Costs borne by consumers as a function of γ in our three scenarios.

Figure 5 illustrates how the normalized sum of profits is affected by the shifting of accident losses towards firms. In scenario (S1), the sum of profits is decreasing everywhere in the level of the firms' share of accident losses. In contrast, in scenarios (S2) and (S3), we find that firm 1 benefits, whereas firm 2 suffers from the change in the liability regime. Our analysis has established that product liability drives a wedge between the outcome attained by firms 1 and 2. The positive effect on firm 1's profits actually dominates the adverse effect on firm 2's profits in scenario (S3) such that the sum of profits is absolutely higher when $\gamma = 1$.

Finally, we address in which way the sum of profits and consumer surplus combine to determine the social welfare implications of different liability regimes. For scenario (S1), we have asserted that consumers benefit, while firms suffer from any marginal increase in the level of γ . Figure 6 shows that shifting all compensable losses onto firms clearly

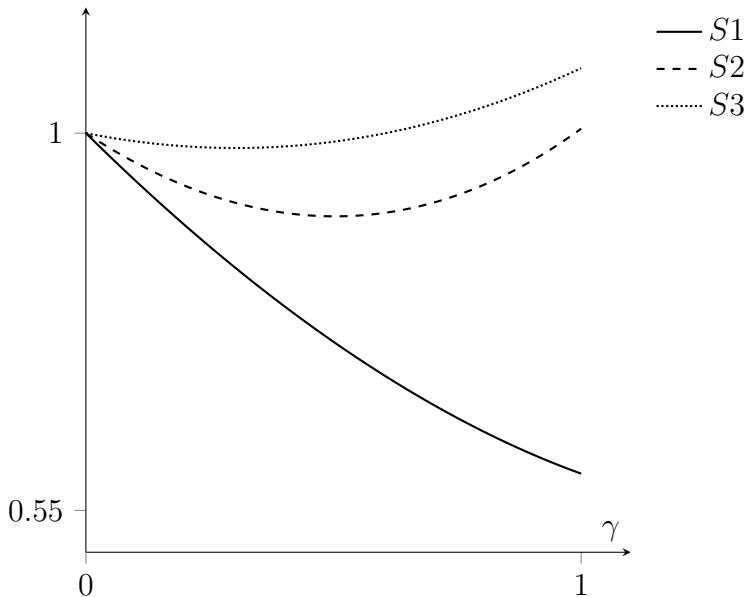


Figure 5: Sum of profits of firms 1 and 2 as a function of γ in our three scenarios.

increases social welfare. The same conclusion is reached in scenario (S2); however, in this scenario, it must be acknowledged that marginal increases in the level of γ are appreciated only by firm 1, whereas firm 2 and, ultimately, the population of consumers is worse off. In other words, increasing the level of γ after reaching $\gamma \approx .55$ is, ultimately, efficiency-enhancing, but gains are concentrated on firm 1. In scenario (S3), we find that the cost-minimizing level of the firms' share of losses is less than one. In fact, the cost-minimizing level is $\gamma \approx .68$. For higher levels of γ , the additional costs imposed on consumers are no longer offset by the increase in the sum of profits.

The discussion in this section has shown that product liability may involve intricate distributional effects between consumers as well as between consumers and producers. While it is intuitive that consumers with the highest level of harm are likely to benefit from the increase in product safety induced by stricter product liability, it is interesting that we find that consumers with low harm levels may likewise benefit from some shifting of accident losses. This is perhaps surprising because the price increase that consumers with low harm levels have to tolerate partly cross-subsidizes other consumer types. The intuition for this possibility relates to the increase in the fierceness of price competition between firms. With an increase in γ , any difference in firms' safety levels becomes less important for consumers that give greater concern to price differences. Consequently,

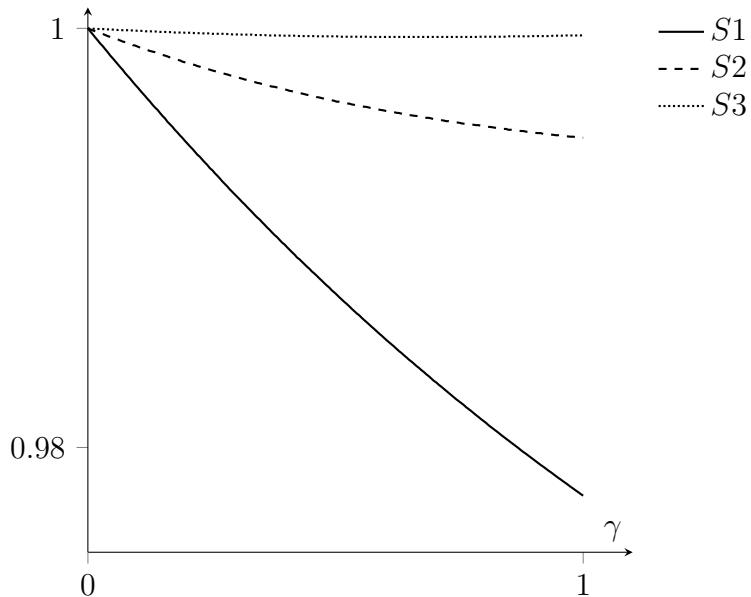


Figure 6: Social costs as a function of γ in our three scenarios.

firms have weaker incentives to differentiate their products when they are subject to product liability in the first place. However, this advantageousness at the limit does not necessarily generalize to marginal increases in γ up to one. The fact that the sum of profits may eventually increase with γ shows that the asymmetry between firms introduced by product liability may finally dampen the direct effect of fiercer price competition and may even lead to a fall in consumer surplus.

6 Decoupling firms' liability payments and consumers' damages awards

In this section, we briefly compare our findings to those from a scenario in which damages obtained by consumers and firms' liability payments are decoupled.²⁸ This chapter serves two purposes. Most importantly, the analysis serves as a contrast to our main results, highlighting the role of the responsiveness of firms' expected liability to variations in prices and safety levels. The decoupling of damages received by consumers and firms' liability payments cuts the direct link between prices and safety choices on the one hand and expected liability payments in the event of an accident on the other. We will establish

²⁸Polinsky and Che (1991) provide a seminal contribution on decoupling the award to the plaintiff from the payment made by the defendant.

that this cut implies that the equilibrium remains symmetric even in the presence of product liability and that an increase in γ leads to a reduction of the high-safety firm's care level (whereas it led to an increase in our main analysis). In addition, the results are interesting in their own right because of the importance of liability insurance and the observation that insurance companies often lump different kinds of risks (in our case the low-safety firm and the high-safety one) together (see, e.g., Wagner 2006).²⁹

We specify decoupling by assuming that consumers receive a type-specific damages payment in the event of a product-related accident that is equal to $\gamma\beta h$, while each firm pays a uniform amount m in the event of an accident to fund paying out harmed consumers. A balanced budget rule applies such that firms' expected payments are equal to the expected outlays to consumers. The payment firms have to make in the event of an accident is based on rational expectations (i.e., it is determined in expectation of the market equilibrium). Our decoupling institution bears resemblance to product liability insurance with some experience-rating because the firms' liability payments are proportional to the number of accidents.

The timing is as follows: in stage 0, the amount m payable in the event of an accident is determined. As before, firms choose their product safety levels in stage 1 and price competition unfolds in stage 2.

When firms compete in prices in stage 2, firm-specific demand continues to follow from the harm level of the indifferent consumer specified in expression (3). In particular, consumers care about both prices and safety because there is incomplete compensation in the event of an accident. Incorporating decoupling, firms' profit equations are given by

$$\pi_i = \left(p_i - \frac{ax_i^2}{2} - (1 - x_i)m \right) q_i(x_1, x_2, p_1, p_2), \quad i = 1, 2, \quad (37)$$

where $q_1 = \hat{h} - \underline{h}$ and $q_2 = 1 - q_1$. Importantly and in contrast to what was true in our main analysis, a variation in the price of firm i is inconsequential for the liability payment in the event of an accident. Using the equilibrium in prices for given safety levels, we obtain the reduced profit equations

$$\pi_i = \underbrace{\Delta_x(1 - \beta\gamma)q_i}_{=\delta_i} q_i, \quad (38)$$

²⁹Decoupling is observed, for example, in the realm of medical malpractice (see, e.g., Danzon 2000) or comes in the form of management and professional liability insurance.

where firm i 's mark-up is simplified relative to (6)–(7) because the level of the price no longer directly influences the expected liability in the event of an accident. The harm level of the indifferent consumers is

$$\hat{h}(x_1, x_2) = \frac{(4h + 2)(1 - \beta\gamma) - 2m + a(x_1 + x_2)}{6(1 - \beta\gamma)}, \quad (39)$$

where firm 1's market share is still increasing in both safety levels.

In stage 1, the firms' simultaneous product safety choice results in care levels of

$$x_1 = \frac{4h - 1}{4a}(1 - \beta\gamma) + \frac{m}{a} \quad (40)$$

and

$$x_2 = x_1 + \frac{3(1 - \beta\gamma)}{2a} = x_1 + \Delta_x. \quad (41)$$

In stage 0, the balanced budget constraint for the decoupled liability system requires that m is set equal to

$$m = \beta\gamma \frac{2h + 1}{2} - \frac{\sqrt{(2\eta - 1)^2 + 3\beta\gamma(1 - \beta\gamma)} - 2\eta + 1}{4}. \quad (42)$$

Note that the first term in expression (42) equals the expected liability, taking the average over all consumers. The second term is the adjustment necessary to account for the fact that consumers with higher (lower) harm levels are served by the high-safety (low-safety) firm such that high-harm consumers are victimized less often than low-harm consumers. Compared to our main analysis, the decoupled liability system implies some cross-subsidization from the low-safety to the high-safety firm given that $\ell_2 > m > \ell_1$.

We summarize the main results for the decoupled liability system in Proposition 8.

Proposition 8 *Suppose Assumptions 1 and 2 hold and that a decoupled liability system applies.*

- (i) *The market is split equally between firms for all levels of γ (i.e., the harm level of the indifferent consumer is $\hat{h}^{MD} = \underline{h} + 1/2 = h^*$). Both firms charge the same mark-up on variable costs, $\delta_i^{MD} = 3(1 - \beta\gamma)^2/4a$, and obtain the same level of profits $\pi_i = \delta_i^{MD}/2$, $i = 1, 2$; mark-ups and profits are continuously decreasing in the liability parameter γ .*
- (ii) *Firms' product safety levels are x_1^{MD} and x_2^{MD} resulting from expressions (40) and (41) in combination with (42), where product safety of the low-safety (high-safety) firm increases (decreases) in the liability parameter γ . The degree of product differentiation Δ_x^{MD} decreases with γ .*

Proof. See Appendix C. ■

The results from this section contrast in several ways with the findings from our main analysis. First, under a decoupled liability system, the market equilibrium is symmetric in shares, mark-ups, and profits for all levels of the firms' share of losses. In contrast, in the main part of the paper, product liability brought about an asymmetry in shares, mark-ups, and profits. Second, in the extension presented in this section, less concern of consumers for differences in safety due to higher compensation had the intuitive result of intensifying price competition and thereby reducing firms' profits. In contrast, in the main part of the paper, even though an increase in the level of γ shifted importance from any difference in safety levels to the difference in price levels, it was possible that firm 1's profits and possibly even the sum of profits increase when γ is marginally raised. Finally, the product-safety level of the high-safety firm declines with the firms' share of losses in the model with decoupled liability; this bears out the intuition from the standard literature on vertical differentiation. In contrast, the product-safety level of the high-safety firm increases in our main analysis in response to a higher level of γ .

In summary, this section highlights that consideration of the reality that firms' price-setting and product safety choices determine the clientele, which in turn determine the firms' expected liability payments, brings about unique and previously unexplored implications of product liability for product differentiation in equilibrium.

7 Conclusions

Firms' incentives for product design are shaped by both market forces and anticipated implications regarding product liability. When a product-related accident is more detrimental for some consumers than for others, varieties of the good with different risk attributes will evolve from the firms' strategic market interaction, catering to consumers with different harm characteristics. This paper provides an analysis of the interaction between product liability and vertical product differentiation in a duopoly in which firms first commit to product safety and then compete in prices. Starting from an equilibrium in which firms have no legal obligation to compensate product-related losses at which product differentiation is excessive, we trace out the implications of raising the firms' shares of compensable accident losses for accident risk, product differentiation with re-

spect to product safety, the intensity of price competition, and welfare. We establish that since firms' actions bear not only on their mark-ups and demand levels but also on their expected liability, an intricate relationship between product liability and product differentiation exists.

Our results show that allocating more losses to firms entails that both product varieties become safer but less differentiated. Moreover, in our framework in which consumers are perfectly informed about the level of harm and the level of product safety, there are, nevertheless, real consequences from changing the allocation of losses between consumers and firms. These changes increases welfare defined as the sum of consumer and producer surplus in most but, interestingly, not in all cases. Shifting losses to firms benefits consumers with high levels of harm, while possibly lowering the well-being of low-harm consumers. Similarly, shifting responsibility for losses incurred in the event of an accident to firms has asymmetric repercussions for different types of firms. The intricate effects on firms' and consumers' payoffs have important implications when the political economy of product liability is considered. Our analysis clarifies that product liability changes the market outcome of an industry with vertical product differentiation via different channels than minimum-safety requirements, which are the most prominent policy intervention in markets with vertical product differentiation.

The present analysis studies the influence of product liability on vertical product differentiation, an important aspect that was neglected in the literature heretofore. We hope that our analysis stimulates further investigations. In some models of vertical product differentiation, market coverage is incomplete. We conjecture that this will bring about additional effects of product liability because we have shown that it is high-harm consumers who benefit from shifting more losses to firms. As a result, in such a setting, allocating more losses to firms is likely to increase the volume of sales. Furthermore, one may consider the scenario in which the quality costs (at least partly) represent fixed costs (e.g., product design). Other interesting avenues for further research concern consumer information. One natural extension is the scenario in which some or all consumers are not fully informed about their expected harm levels at the time of purchase. Moreover, consumers may not be able to perfectly judge the safety features of the products they buy. In this scenario, firms' incentives for signaling or costly disclosure would be possible avenues of future research.

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Appendix

A Sufficiency of assumptions for equilibrium

For our analysis in the body of the paper, we need to ensure that several conditions are fulfilled at the same time. These are the following:

- [1] No firm has an incentive to deviate from its strategy by *leapfrogging* its rival with respect to product safety.
- [2] Second-order conditions for a maximum are fulfilled for both firms at both stages.
- [3] \hat{h}^M is a feasible split of the set of consumers.
- [4] Safety levels stay within their bounds $[0, 1]$.

Conditions [1] and [2] ensure the existence of the equilibrium, while conditions [3] and [4] concern the interior solution. In this appendix, we show that Assumption 1 results from Condition [1] and also guarantees that Conditions [2] and [3] are satisfied. Finally, the requirement of an interior solution for the high-safety firm's safety choice (Condition [4]) yields Assumption 2.

[1] Denote by $q_1(x_1, x_2)$ and by $q_2(x_1, x_2)$ the demand for the firm offering the low-safety variety of the good and the demand for the firm offering the high-safety variety, respectively. From (9), given firm 1 chooses x_1^M , firm 2's profit level obtained from leapfrogging (i.e., choosing $x_2 < x_1^M$) is given by

$$\pi_2^{LF} = \left[x_1^M - x_2 + \frac{\beta\gamma(1 + x_2 - 2x_1^M)}{2} \right] q_1^2(x_2, x_1^M)$$

which is maximized for

$$x_2^{LF} = \frac{4\underline{h} - 3}{a[4 - 3\beta\gamma]} + \gamma\beta \frac{16 + 6\eta - 9\underline{h}}{3a[4 - 3\beta\gamma]} - \gamma^2\beta^2 \frac{9 + 6\eta}{4a[4 - 3\beta\gamma]}.$$

Profits from deviating to $x_2^{LF} < x_1^M$ amount to

$$\pi_2^{LF} = \frac{[2 - \beta\gamma][6 + \beta\gamma(6\eta - 7)]^3}{3456a[3 - 2\beta\gamma]^2}.$$

From a comparison to (9) for $i = 2$ and $j = 1$, leapfrogging is a profitable strategy for

$$\gamma \geq \frac{6}{(6\eta + 1)\beta}.$$

Since the maximum value of γ is one, leapfrogging is not profitable for firm 2 for any feasible γ as long as the share of compensable harm does not exceed a threshold or, more precisely, when

$$\beta \leq \frac{6}{6\eta + 1} \quad (43)$$

which is assumption (1).

Analogously, when firm 2 chooses x_2^M , the profits from leapfrogging by firm 1 ($x_1 > x_2^M$) can be deduced from (9) and are given by

$$\pi_1^{LF} = \left[x_1 - x_2^M - \frac{\beta\gamma(1 + x_1 - 2x_2^M)}{2} \right] q_2^2(x_2^M, x_1)$$

which is maximized for

$$x_1^{LF} = \frac{7 + 4\underline{h}}{a[4 - 3\beta\gamma]} - \gamma\beta \frac{31 - 6\eta + 9\underline{h}}{3a[4 - 3\beta\gamma]} + \gamma^2\beta^2 \frac{15 - 6\eta}{4a[4 - 3\beta\gamma]}.$$

The profits from choosing $x_1^{LF} > x_2^M$ amount to

$$\pi_1^{LF} = \frac{[2 - \beta\gamma][6 - \beta\gamma(6\eta + 1)]^3}{3456a[3 - 2\beta\gamma]^2}.$$

A comparison with profits stated in (20) for $i = 1$ and $j = 2$ yields that leapfrogging would be profitable when

$$6 + \beta\gamma(6\eta - 7) \leq 0$$

which is impossible for $\gamma \geq 0$ given our assumptions $a \geq 2$ and $1/4 \leq \underline{h} \leq 1$. In other words, firm 1 never has an incentive to leapfrog.

[2.1] The second-order conditions for the price-setting stage:

Inserting x_1^M and x_2^M into the second-order conditions at the second stage, we obtain

$$\frac{\partial^2 \pi_1}{\partial p_1^2} = \frac{a(4 - 3\beta\gamma)[6 + \beta\gamma(2\eta - 5)]}{4(3 - 2\beta\gamma)^2(1 - \beta\gamma)^2(-2 + \beta\gamma)}$$

and

$$\frac{\partial^2 \pi_2}{\partial p_2^2} = \frac{a(4 - 3\beta\gamma) \overbrace{[6 - \beta\gamma(2\eta + 3)]}^{:=X}}{4(3 - 2\beta\gamma)^2(1 - \beta\gamma)^2(-2 + \beta\gamma)}$$

The first expression is unambiguously negative, the second one for $X > 0$ which holds according to Assumption 1.

[2.2] The second-order conditions for the safety choice:

Inserting x_1^M and x_2^M into the second-order conditions at the first stage, we obtain

$$\frac{\partial^2 \pi_1}{\partial x_1^2} = \frac{3a(-2 + \beta\gamma)[6 + \beta\gamma(2\eta - 5)]}{16(3 - 2\beta\gamma)^2}$$

and

$$\frac{\partial^2 \pi_2}{\partial x_2^2} = \frac{3a(-2 + \beta\gamma) \overbrace{[6 - \beta\gamma(2\eta + 3)]}^{=X}}{16(3 - 2\beta\gamma)^2}.$$

The first expression is unambiguously negative, the second one is negative due to $X > 0$ as argued in [2.1].

[3]) The condition $\underline{h} \leq \hat{h}^M \leq \underline{h} + 1$:

From (14), $\hat{h}^M > \underline{h}$ obviously holds and $\hat{h}^M \leq \underline{h} + 1$ translates into

$$\begin{aligned} \beta\gamma &\leq \frac{6}{2\eta + 3} \\ \Leftrightarrow \eta &\leq \frac{3}{\beta\gamma} - \frac{3}{2}. \end{aligned}$$

Since $3/(\beta\gamma) - 3/2 > \beta^{-1} - 6^{-1}$, this restriction is always fulfilled due to Assumption 1.

[4] The condition $0 \leq x_1^M \leq x_2^M \leq 1$:

From (11), we deduce that $x_1^M \geq 0$ when $\underline{h} \geq 1/4$ for any level of γ . From the expression for the degree of product differentiation (13), it follows that $x_1^M < x_2^M$. The constraint $x_2^M \leq 1$ must be evaluated at $\gamma = 1$ because x_2^M is a function increasing with γ . Accordingly, we have

$$\begin{aligned} \frac{4\underline{h} + 5}{4a} + \beta \frac{8\eta - 9}{4a(4 - 3\beta)} - \beta^2 \frac{6\eta - 7}{4a(4 - 3\beta)} &\leq 1 \\ \Leftrightarrow (4 - 3\beta)2(2 - \beta)(\underline{h} + 1) + (2 - \beta)^2 &\leq 2a(4 - 3\beta)(2 - \beta) \\ \Leftrightarrow \frac{5}{4} + \frac{\beta}{4(4 - 3\beta)} &\leq \eta \end{aligned}$$

which is Assumption 2.

B Proof of Proposition 2

Differentiating (11) with respect to γ and collecting terms, we obtain

$$\begin{aligned}\frac{\partial x_1^M}{\partial \gamma} &= \beta \frac{8\eta + (6\eta + 1)[4 - 8\gamma\beta + 3\gamma^2\beta^2]}{4a(4 - 3\gamma\beta)^2} \\ &= \beta \frac{8\eta + (6\eta + 1)[4(1 - \gamma\beta)^2 - \gamma^2\beta^2]}{4a(4 - 3\gamma\beta)^2} \\ &= \beta \frac{6\eta(1 - \gamma^2\beta^2) + (2\eta - \gamma^2\beta^2) + (6\eta + 1)4(1 - \gamma\beta)^2}{4a(4 - 3\gamma\beta)^2},\end{aligned}$$

where all terms are positive due to $a \geq 2$, $1 \geq h \geq 1/4$, $1 > \beta > 0$, $1 > \gamma \geq 0$.

Next, differentiating (12) with respect to γ and collecting terms, we obtain

$$\begin{aligned}\frac{\partial x_2^M}{\partial \gamma} &= \beta \frac{8(\eta - 1) + (6\eta - 7)[4 - 8\gamma\beta + 3\gamma^2\beta^2]}{4a(4 - 3\gamma\beta)^2} \\ &= \beta \frac{8(\eta - 1) + (6\eta - 7)[4(1 - \gamma\beta)^2 - \gamma^2\beta^2]}{4a(4 - 3\gamma\beta)^2} \\ &= \beta \frac{(2\eta - 1) + (6\eta - 7)[4(1 - \gamma\beta)^2 + (1 - \gamma^2\beta^2)]}{4a(4 - 3\gamma\beta)^2},\end{aligned}$$

where all terms are positive due to the lower bound stated in assumption A1 (i.e., $\eta \geq 5/4$), and $a \geq 2$, $1 > \beta > 0$, $1 > \gamma \geq 0$.

Finally, differentiating (13) and collecting terms, we obtain

$$\begin{aligned}\frac{\partial \Delta_x}{\partial \gamma} &= \frac{2\beta}{a(4 - 3\gamma\beta)^2} [-5 + 8\gamma\beta - 3\gamma^2\beta^2] \\ &= \frac{-2\beta}{a(4 - 3\gamma\beta)^2} [4(1 - \gamma\beta)^2 + (1 - \gamma^2\beta^2)]\end{aligned}$$

which is negative due to $a \geq 2$, $1 > \beta > 0$, $1 > \gamma \geq 0$.

C Proof of Proposition 8

Inserting (40) and (41) into (39), we immediately obtain

$$\hat{h}^{MD} = \frac{(4h + 2 = (1 - \beta\gamma) - 2m + (2h + 1)(1 - \beta\gamma) + 2m)}{6(1 - \beta\gamma)} = h + \frac{1}{2}.$$

Firms' price mark-ups in equilibrium result as (see (38))

$$\delta_i^{MD} = \Delta_x(1 - \beta\gamma)q_i = \frac{3(1 - \beta\gamma)^2}{4a},$$

where

$$\frac{d\delta_i^{MD}}{d\gamma} = -3\beta \frac{3(1-\beta\gamma)}{2a} < 0.$$

Furthermore, from (40) and (42)

$$\begin{aligned} \frac{dx_1^{MD}}{d\gamma} &= -\beta \frac{4\underline{h}-1}{4a} + \beta \frac{2\underline{h}+1}{2a} - \frac{3\beta(1-2\beta\gamma)}{8a\sqrt{(2\eta-1)^2+3\beta\gamma(1-\beta\gamma)}} \\ &= \frac{3\beta}{8a} \left(2 - \frac{1-2\beta\gamma}{\sqrt{(2\eta-1)^2+3\beta\gamma(1-\beta\gamma)}} \right) > 0. \end{aligned}$$

Finally,

$$\begin{aligned} \frac{dx_2^{MD}}{d\gamma} &= \frac{dx_1^{MD}}{d\gamma} - \frac{3\beta}{2a} \\ &= \frac{3\beta}{8a} \left(-2 - \frac{1-2\beta\gamma}{\sqrt{(2\eta-1)^2+3\beta\gamma(1-\beta\gamma)}} \right) < 0. \end{aligned}$$

D The model for $\eta < 5/4 + \beta/(4(4-3\beta))$

In the main part of this study, the market equilibrium has been established for the case of an interior solution for the firms' safety levels which required the lower bound $\eta = a - \underline{h} \geq 5/4 + \beta/(4(4-3\beta)) = \eta_u$. In this appendix, for completeness, we describe how the results generalize for lower values of η in which event a corner solution for the safety level of the high-safety firm can emerge (i.e. $x_2^M \rightarrow 1$) due to either lower costs of safety (lower values of a) or higher expected harm levels (higher values of \underline{h}). We continue to restrict attention to the parameter space allowing a pure-strategy equilibrium (i.e., $\beta < 6/(6\eta+1)$). In addition, according to our assumptions, the natural lower bound on η is given by $\eta \rightarrow 1$ for $a = 2$ and $\underline{h} = 1$. Note, that even in this case firm 2's first-best safety level stays well below one and amounts to $x_2^* = 7/8 < 1$ (see Lemma 1).

Market equilibrium. Given the equilibrium at the price-setting stage, the equilibrium safety choices of firms are described by³⁰

$$\frac{\partial\pi_1}{\partial x_1} = 0 \text{ and } \frac{\partial\pi_2}{\partial x_2} \geq 0, \quad \frac{\partial\pi_2}{\partial x_2}(x_2 - 1) = 0$$

conveying the idea of a possible corner solution for firm 2's safety choice. Denoting the equilibrium levels by \tilde{x}_i^M , $i = 1, 2$ to distinguish results from the main analysis, we obtain

$$\tilde{x}_1^M = \min \left[x_1^M, \frac{2\underline{h}+a-2}{3a} + \beta\gamma \frac{2}{3a} \right] \tag{44}$$

³⁰In our application, the lower bound of $x_1 \rightarrow 0$ is never binding.

and

$$\tilde{x}_2^M = \min [x_2^M, 1]. \quad (45)$$

The equilibrium care levels result in the indifferent consumer being located at

$$\tilde{h}^M = \min \left[\hat{h}^M, \underline{h} + \frac{1}{2} + \frac{4\eta - 5 + 2\beta\gamma}{6(3 - 2\beta\gamma)} \right]. \quad (46)$$

With demand given by $\tilde{q}_1^M = \tilde{h}^M - \underline{h}$ and $\tilde{q}_2^M = \underline{h} + 1 - \tilde{h}^M$, the equilibrium mark-ups amount to

$$\tilde{\delta}_1^M = \begin{cases} \delta_1^M & \text{if } \tilde{x}_2^M = x_2^M \\ \frac{(2-\beta\gamma)(\eta+1-\beta\gamma)^2}{9a(3-2\beta\gamma)} & \text{if } \tilde{x}_2^M = 1 \end{cases} \quad (47)$$

and

$$\tilde{\delta}_2^M = \begin{cases} \delta_2^M & \text{if } \tilde{x}_2^M = x_2^M \\ \frac{2(1-\beta\gamma)(7-2\eta-4\beta\gamma)(\eta+1-\beta\gamma)}{9a(3-2\beta\gamma)} & \text{if } \tilde{x}_2^M = 1 \end{cases}. \quad (48)$$

Each firms profits equals $\tilde{q}_i \tilde{\delta}_i$.

Note that for $5/4 < \eta < \eta_u$, $\tilde{x}_2^M < (=) 1$ for low (high) values of γ . When $\eta \leq 5/4$, it holds that $\tilde{x}_2^M = 1$ results for every value of $\gamma \in [0, 1]$.

In contrast to our analysis of the model in the main part of the paper (see Lemma 2), when $\gamma = 0$ and $\eta < 5/4$ we find that the equilibrium is not symmetric regarding profits and market shares. Instead, the high-safety firm earns higher profits than the low-safety firm and serves more than half of the market. The asymmetry is due to the fact that the boundary on safety allows the high-safety firm to commit to refraining from further increasing its care level.

Comparative statics of the market equilibrium. Referring to equations (44) to (45), we observe that \tilde{x}_1^M and \tilde{h}^M both increase in the liability parameter γ , implying a lower product differentiation and a higher market share for firm 1. The results are thus in line with those presented in Proposition 2 with the exceptions that firm 2's safety level can no longer increase after reaching the boundary of 1 and that firm 1's market share may be lower than one half for $\eta < 5/4$ even for positive values of γ .

Next, from (47) and (48), we establish that both equilibrium mark-ups decrease in the level of firms' liability γ for $\eta < \eta_u$.³¹ For the high-safety firm, this confirms the result presented in Proposition 3, whereas for firm 1, the ambiguity regarding the mark-up is

³¹The corresponding calculations for this and the following results are rather tedious and omitted here to save space. All proofs are available on request from the authors.

resolved in this parameter range. In line with Proposition 3, the relative mark-up of the low-safety firm increases in γ .

Likewise, as described in Proposition 4, the high-safety firm's profits decrease and the relative profit of the low-safety firm increases in γ when $\eta < \eta_u$. A difference emerges only in that the low-safety firm's profit is also strictly decreasing in γ for the low values of η considered here.

Welfare and distributional effects. In Proposition 5, we present results about the firms' share of compensable losses that is socially optimal. When $\eta < \eta_u$, it continues to be the case that the marginal introduction of firms' liability is always welfare-increasing. In contrast to the main part, the optimal extent of firms' liability is always given by the corner solution $\gamma = 1$. This is due to the fact that the adverse effect of shifting more losses to firms – the increase in the already excessive high safety level – is either less important because the cost parameter a is relatively low (when $5/4 < \eta < \eta_u$) or nonexistent (when $\eta < 5/4$).

We find that the results presented in Proposition 6 are robust to the consideration of smaller levels of η . High-harm consumers gain from the introduction of firms' liability is confirmed. Now, in contrast to the analysis for interior safety levels, that is also unambiguously the case for low-harm consumers.

The results mentioned in Proposition 7 are confirmed in that the marginal introduction of firms' liability increases consumer surplus at the expense of firms' profits. The results are no longer ambiguous for the marginal change when $\gamma \rightarrow 1$. In fact, consumer surplus increases in γ whereas firms' profits decrease in γ .