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Product Liability and Reasonable Product Use

Product liability and reasonable product use*

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Abstract

We analyze a monopolist who offers different variants of a possibly dangerous product to heterogeneous customers. Product variants are distinguished by different safety attributes. Customers choose product usage which co-determines expected harm. We find that, even with customers being perfectly informed about product variants' safety, product liability can further welfare by limiting the firm's incentives to distort product safety in pursuance of profit-maximizing price discrimination. In this context, strict liability has to be accompanied by a defense of product misuse, but reasonable use of the base product variant should be defined more leniently than what an application of the Hand rule or instructions in user manuals might prescribe.

Keywords: Comparative negligence; Price discrimination; Product liability; Product use.

JEL classification: D82; K13; L11.

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1 Introduction

Product liability has evolved as an important field in tort law and has gained much attention in both the legal and economic literature.[1] For the US and for the European Union, product liability has evolved as a field of law describing manufacturers' strict liability for defective products, where a defect may be due to design, a failure in the manufacturing process, or a failure to warn or to provide proper instructions (for the US, see, for example, Landes and Posner 1985, or Feldthusen et al. 2017; for the EU, see, for example, Sterrett 2015, or the EU Product Liability Directive (85/374/EEC)). Basically, product liability is often considered as a way to induce manufacturers to produce reasonably safe products for customers.

However, it is not only product safety determined by the manufacturer that has an impact on possible harm. After purchase, intensity and type of usage as well as maintenance of the product is determined by the customer, yielding a situation of bilateral care. In this light, a system purely based on manufacturer liability would result in inefficient outcomes due to customers' diminished incentives to take care and to use products reasonably. This is reflected in actual law which allows defenses in product liability cases *inter alia* based on comparative or contributory negligence on the side of customers or a customer's assumption of risk. Negligence on the part of the customer may be asserted if she did not take due care when using the product (e.g., not wearing safety gloves while operating with a chemical substance as in *Lee v. Crest Chemical Co., 583 F. Supp. 131 (M.D.N.C. 1984)*), but also if the customer misused the product (e.g., installing tires not intended for use on the customer's specific make of car as in *McDevitt v. Standard Oil, 391 F. 2d 364 (5th Cir. 1968)*).

With regard to customer negligence, the definition of misuse is important. There has been a long-lasting discussion focusing on the distinction between intended and foreseeable product use (for an early contribution, see, e.g., Dillard and Hart 1955; the topic of misuse is still present in recent contributions as in Keating 2017), where it is generally acknowledged that it is foreseeable use that has to be taken into account by the manufacturer when deciding on a product's safety features (see, for example, Feldthusen et al. 2017). The discussion on misuse may thereby also encompass the question of the intensity of use and possible overuse, where a more intensive use results in a higher strain also on safety-relevant product parts (see, e.g., Gardels 1978). For instance, in *McCurter v. Norton Co., 263 Cal. App. 2d 402, 69 Cal. Rptr. 492 (1968)*, a grinding wheel was

[1]The literature ranks from contributions offering a positive analysis of product liability (see, e.g., Landes and Posner 1985) to fundamental discussions about the need for product liability when other market forces (like reputation mechanisms) are in place (see, e.g., the discussion in Polinsky and Shavell 2010, and Zipursky and Goldberg 2010).

used at excessive speed resulting in severe injury.[2] Relatedly, manufacturer liability may be denied in the event of worn-out products, because only the usage itself may make the product dangerous as in the example of a well-driven tire (see Landes and Posner 1985).[3]

Manufacturers usually offer various variants of their products. The intended use of these variants can differ: For example, it appears to be reasonable to assume that private customers use products differently from professionals. Such differences are then mirrored in the products' safety features that are adjusted to the intended usage intensity. At the same time, manufacturers try to refuse to be held liable when a less safe product variant is used in a way which is not in line with intended use.[4]

As long as firms that offer different product variants designed for different types of customers have some market power, they will try to pursue a policy of profit-maximizing price discrimination. With asymmetric information about customer types, this implies a policy of offering different price-product contracts in order to screen customers who self-select to their preferred product variant.[5]

We analyze a manufacturer's decision to offer different variants of a possibly dangerous product, and investigate the optimality of different legal approaches to defining reasonable use. The manufacturer is confronted with two types of customers who differ in the intensity of intended product use. Usage of the product may be associated with harm due to product defects. Expected harm is a function of both the product variant's safety features (adverse selection) and product usage (moral hazard), where more intense use increases the benefits of higher safety investments. We assume that product liability is in place, and the manufacturer must decide how much to invest in observable product safety for each product variant offered. In our main analysis, liability takes the form of strict li-

[2]In addition, besides misuse of the product, in the case at hand, damages were denied on the ground of the product being not defective in the first place.

[3]The intensity of product use may also be linked to the concept of activity levels (for an analysis of activity levels in the tort model see, for example, Shavell 1987, chapter 2). In the literature, it is often assumed that a meaningful standard for efficient care levels or safety measures can be determined, while courts are less able to determine efficient standards for activity levels, or may not be able to observe activity levels. In our framework, and in line with the examples provided, we assume that usage levels can be verified, and that reasonable use for different groups of consumers can be determined by courts. Taken together, the distinction between activity levels and care is a fluid one (see, for instance, Dari-Mattiacci 2006).

[4]For instance, in the instructions of a household pressure cooker, the manufacturer stresses that buyers must "(...) not use the pressure cooker for a purpose other than its intended use. This pressure cooker is intended for domestic use only and is not designed for commercial use. The manufacturer accepts no liability if the appliance is used for commercial purposes or in a manner which does not comply with the instructions in this manual." (page 2 of the user manual for the *Equip 2.7 Litre Stainless Steel Pressure Cooker* produced by *Morphy Richards*). Similar restrictions laid down in the description of use can be found for different product variants of lawn mowers or other electrical appliances and machines.

[5]Overviews of the classic monopoly with nonlinear tariffs (or second-degree price discrimination) can be found in, e.g., Varian (1989) and Fudenberg and Tirole (1991, Ch. 7).

ability. Furthermore, taking customer behavior into account, a customer's usage intensity may be considered as comparative negligence. The fact that product safety is observable would imply that – absent transaction costs and heterogenous customer harm levels – the liability rule applied is irrelevant for the market equilibrium (as customers' willingness to pay is responsive to safety; see, for example, Shavell 1987, chapter 3). However, consideration of comparative negligence is only relevant with some form of product liability in place. We illustrate our analysis for strict liability where the main results would also hold with product liability based on a regime of negligence. The assumption of observable product safety allows us to focus our analysis on the definition of the standard regarding comparative negligence.

The contribution of our paper is to combine the analysis of product liability and investment in product safety with price discrimination to investigate possible interactions. The welfare effects of market power combined with the offer of differentiated product variants to screen customers will depend on what is interpreted as reasonable product use. We first establish the market equilibrium if reasonable product use is defined according to the Hand rule, and describe that a similar standard for reasonable behavior would be prescribed by firms. An application of the Hand rule implies that customer negligence is assumed if a lower intensity of product use results in a reduction in expected harm that more than compensates the loss in consumption value. We will argue that a welfare gain can be achieved by opting for a more lenient definition of reasonable product use for base product variants.

More precisely, with reasonable product use determined by the Hand rule, we establish that the firm offering two product variants will distort safety of the base product variant downward. This is due to the fact that it is beneficial for the firm to increase the degree of differentiation between the base and its premium high-safety product variant. The higher degree of differentiation allows the firm to absorb a larger part of the customer surplus enjoyed by high-end buyers. This gain is balanced to the loss due to the base product being less in line with its buyers' safety preferences, which reduces their willingness to pay. At the same time, the application of the Hand rule ensures efficient use by customers, such that the firm could not do better by deviating from the usage levels if it were allowed to prescribe reasonable product use itself (e.g., via instructions in user manuals).

Deviating from the Hand rule to determine customer negligence for the base product variant can lead to an increase in welfare by curbing the firm's incentive to excessively differentiate the product variants. By inducing higher usage rates by customers through a more lenient definition of reasonable use, the policy maker makes it more expensive for the firm to distort its safety features downward. However, the resulting higher use is inefficient given the product variant's safety features. The optimal policy for the base product variant results from a trade-off regarding the two effects. Because no distortion is to be expected for the high-end product variant's safety features, no such adjustment in reasonable use is necessary for this product variant. These results have important policy implications with regard to the relevance of product liability even when asymmetric information with respect to product safety is not an issue.

Related literature

Our paper relates to the law and economics literature on product liability and to the well-established literature in industrial organization on screening and price discrimination (for the latter see, the citations above). The literature on product liability is vast, and we refer to the recent surveys by Daughety and Reinganum (2013) or Geistfeld (2009). Central stage in our analysis takes the observation of different types of customers and asymmetric information about customer type. An early contribution explicitly taking account of customer heterogeneity is Oi (1973) who *inter alia* points out the cross-subsidization of high-harm customers by low-harm customers with product liability in place. Baumann et al. (2016, 2018) investigate one-product firms' safety choices with heterogeneous customers for the monopoly and the duopoly case. While product safety might decrease with liability for a monopolist, product liability reduces product differentiation in a duopoly which – to some extent – is welfare enhancing. In contrast to these contributions, in this paper, we investigate a multi-product monopolist. With screening, our study is related to Choi and Spier (2014) who base their study on Ordover (1979). The authors investigate a perfectly competitive market in which firms screen customers with diverging accident probabilities via contractually stipulated damages in combination with differentiated products. Similar to our conclusion, mandatory liability rules may improve on the unregulated market equilibrium. While sharing some similarities in the results, the investigation of regulation of product usage is completely novel in our analysis. The importance that heterogeneous customers should self-select the appropriate product variant is also analyzed in Miceli et al. (2015) who consider a competitive market. The idea of customers determining the intensity of use of a possibly dangerous product has been used by, among others, Baniak and Grajzl (2017) who, in contrast to our study, investigate the consequences of possible customer misperceptions about future usage, but do not focus on the repercussions between liability, product differentiation, and price discrimination.

The remainder of the paper is organized as follows. In the next section, we provide a numerical example to highlight the main idea and insights. Section 3 describes the more general model, and derives the first-best allocation as a reference point. Section 4 analyzes the market equilibrium for different legal rules. Section 5 concludes.

2 Numerical example

Assume a firm that serves two customers, a high type denoted by H and a low type denoted by L, with two product variants which may differ in their safety features. For the sake of simplicity, we assume that customers may use products with three different intensities, S_j, $j = 1, 2, 3$, and that four possible safety levels are feasible, X_i, $i = 0, 1, 2, 3$.[6] The relevant data on gross benefits from product usage, expected harm, and costs of care for each unit produced are summarized in Tables 1 and 2.

Table 1: Gross benefit form usage.

		Usage		
		S_1	S_2	S_3
Type	H	\$25	\$40	\$50
	L	\$20	\$23	\$24

Table 2: Expected harm and costs of care.

		Expected harm			Cost per unit
		S_1	S_2	S_3	
Safety	X_0	\$5	\$15	\$30	\$0
	X_1	\$0	\$5	\$15	\$1
	X_2	\$0	\$0	\$5	\$3
	X_3	\$0	\$0	\$0	\$6

The data convey the idea that high-type customers obtain higher absolute and marginal utility from product use, and expected harm weakly increases (decreases) in usage levels (safety levels), where we assume – without loss of generality – that harm may be prevented by high levels of safety measures. The benefit from safety investments in the form of lower expected harm is more pronounced for higher usage rates.

Efficient solution. Consider a benevolent and omniscient social planner. As the data convey, optimal safety investments depend on the level of product usage, and, in our example, efficiency implies that the product should be made safe given actual usage rates. That is, with high usage S_3, the safety investment X_3 should be chosen which implies overall costs per unit of \$6. Likewise, for the lower usage rate S_2, optimal safety consists of X_2 at costs of \$3, and for the small usage rate S_1, a safety investment of X_1 at costs of \$1 is sufficient. Given optimal safety, high-type customers should be offered a high-end

[6]We need the possible levels of usage to outnumber the number of customer types, and the possible safety levels to be larger than the number of possible usage modes.

product variant with safety features X_3 which they use intensely at the level S_3, because the marginal gain in gross benefits (\$10) more than offsets additional safety costs (\$3) compared to the usage level S_2. The low-type customers instead should be provided with a base product variant featuring safety investments X_2 which they use with intensity S_2. The gain in gross utility from moving from usage level S_1 to S_2 amounts to \$3 which surmounts the additional safety costs of \$2. At the same time, a further increase in product usage and safety would be associated with additional costs of \$3 exceeding the additional gross benefit of \$1. With one low-type customer and one high-type customer, maximum aggregated welfare amounts to $\$23 - \$3 + \$50 - \$6 = \$64$. We now turn to the market equilibrium.

Market equilibrium with reasonable use defined according to the Hand rule (Scenario 1). We assume that customers are informed about safety features, but the firm is not able to ascertain a customer's type. With respect to the liability system, we assume that the firm is strictly liable for harm incurred by customers but is allowed to use the defense of unreasonable product use. Product use is considered unreasonable if the gross benefit from more intense usage for the targeted customer group falls short of the increase in expected accident costs given the product's safety features. In our numerical example, this implies that for the base product variant that is targeted at low-type customers, reasonable product use is given by S_2 for the safety investment X_2, but only S_1 if the base product variant features safety investments of only X_0 or X_1.

Given the firm's informational constraint on customer type, it has to take into account that customers may not buy the product targeted at them. In particular, the firm must make sure that high-type customers who are characterized by a high willingness to pay do not divert to the product targeted at low-type customers. In our example, if the firm offers the efficient product variants, it can charge a price of $p^L = \$23$ for the base product variant which leaves low-type customers just indifferent between buying and abstaining. A high-type customer buying the base product variant would choose a usage rate of S_3 bearing the expected accident costs of \$5 due to unreasonable product use. This leaves the high-type customer with a net utility of $\$50 - \$5 - \$23 = \$22$. To induce the customer to buy the high-end product variant targeted to her, the price of this product variant must not exceed $p^H = \$28 = \$50 - \$22$. The firm is left with a profit of $p^L - \$3 = \$20$ for the low-type customer and a profit of $p^H - \$6 = 22$ for the high-type customer which sums up to \$42.

The firm can earn higher profits by reducing the base product's safety features. In our example, maximum profits are obtained by offering a base product variant with safety feature X_0 which implies reasonable use amounting to S_1. Consequently, the firm has to bear (expected) liability of \$5 for each base product sold. With low-type customers compensated for harm, the maximum price for the product variant the firm can charge is given by $p^L = \$20$ (the customer's willingness to pay), and the firm obtains a profit of $p^L - \$5 = \$15$ for the low-type customer. A high-type customer would use the product with intensity S_2 (as the additional harm of \$10 that will not be compensated is less than the increase in gross utility amounting to \$15). Obtaining only an expected compensation of \$5, while expected harm amounts to \$15, utility enjoyed from buying the base product variant would amount to $\$40 - \$15 + \$5 - p^L = \$10$ for the high-type buyer.[7] Accordingly, the firm can charge a price of $p^H = \$50 - \$10 = \$40$ for the high-end product variant guaranteeing a profit of $p^H - \$6 = \$34$. Total profits increase to \$49, whereas welfare decreases to $(\$20 - \$5) + (\$50 - \$6) = \$59$. Note that if the firm could determine reasonable product use itself (for example, by statements in the manual coming with the product variant), it can do no better than with a definition following the Hand rule. This holds because it is optimal for the firm that product variants are used efficiently given the safety choices made.[8]

Market equilibrium with a more lenient definition of reasonable use (Scenario 2). Now assume that courts may allow for a more lenient definition of reasonable product use. In the following, we concentrate on the definition of reasonable use for the base product variant, since safety features of the high-end product variant were not distorted. In our numerical example, a more lenient definition of reasonable use for the base product variant may be understood as asserting the firm's full liability for the base product also if product use amounts to S_2 – even if safety investments are given by X_0 or X_1.

To determine the firm's behavior, again we compare the possible profit levels. With X_0 as the base products variant's safety level and the firm's liability being full up to product usage S_2, low-type customers increase usage to this level which would also be chosen by high-type customers. Low-type customers enjoy a gross benefit of \$23 which will be absorbed by the product price p^L. The net utility a high-type customer using the base product variant would enjoy amounts to $\$40 - p^L = \$17$, such that the price the firm

[7] Note that we assume that the defense of unreasonable product use is only applicable when the unreasonable product use was causal for harm incurred. Following, for example, Kahan (1989) this can be understood as limiting expected damages payments to the harm to be expected for non-negligent behavior.

[8] If the firm offered the base product variant with safety features X_1 (instead of X_0), it would earn \$48. Reasonable use for the targeted low-type customers amounts to S_1, and the firm charges a price of $p^L = \$20$ for the base product. High-type customers would be indifferent between usage rates S_2 and S_3, if they were to buy the base product, and would obtain a rent of $\$40 - \$5 - p^L = \$50 - \$15 - p^L = \$15$. Accordingly, the firm could charge a price $p^H = \$50 - \$15 = \$35$, leading to overall profits of $p^L - \$1 + p^H - \$6 = \$48$.

can charge for the high-end product is now equal to $p^H = \$50 - \$17 = \$33$. The firm bears liability of \$15 per unit of the base product sold. The firm's profit now amounts to $p^L - \$15 = \$8$ per low-type customer and $p^H - \$6 = \$27$ per high-type customer. Taken together, total profits are reduced to \$35.

With a safety investment of X_1 for the base product, low-type customers still choose product usage S_2, whereas a high-type customer buying the base product variant would be indifferent between the usage levels S_2 and S_3. As above, the firm can charge a price of $p^L = \$23$ for the base product variant resulting in a rent for high-type customers equal to \$17 and a price $p^H = \$33$ for the high-end product variant. In summary, the only difference to the above is the higher safety level for the base product which results in a saving of $\$15 - \$5 = \$10$ in expected liability for the firm which more than compensates the additional safety costs of \$1. Accordingly, profits increase by \$9 to \$44.

The profit obtained with safety investments X_1 for the base product variant are indeed the maximum profits obtainable by the firm. A further increase in safety investments to the efficient level of X_2 (resulting in a usage rate S_2) would result in a profit level of \$42 as already calculated above in Scenario 1. Accordingly, the firm will stick to X_1, and social welfare amounts to $(\$23 - \$5 - \$1) + (\$50 - \$6) = \$61$. The welfare level obtained is higher than the one with reasonable use for the base product variant defined in line with the Hand rule (welfare increases by 3.4% in the example). This shows our main result that in a setting with producers enjoying market power and serving differentiated products, a more lenient definition for reasonable use for a base product variant can result in a welfare gain. The welfare gain is obtained by reducing the firm's excessive incentive to lower the safety features of its base product. To realize this benefit, an additional distortion is introduced by inducing usage rates higher than optimal given the base product variant's actual safety features.[9]

3 The general model with two types

3.1 Model ingredients

Customers. Customers consider to buy and use one unit of a product. Their well-being can be described by a quasi-linear utility function

$$U = u(\theta, s) - m,$$

[9]The achieved welfare gain is an application of the theory of second best generally described in Lipsey and Lancaster (1956).

where θ, $\theta = L, H$, $L < H$, is the customer's type, s, $s \geq 0$ measures the customer's intensity of product use, and m denotes the customer's total product-related costs including the price paid and non-reimbursed harm. The share of customers of type L (type H) amounts to α $(1 - \alpha)$. Let subscripts denote partial derivatives. We assume that

$$u(\theta, 0) = 0, \quad u_s(\theta, 0) > 0, \quad u_{ss}(\theta, s) < 0, \quad u_{\theta s}(\theta, s) > 0.$$

No usage, $s = 0$, yields no utility from the product under consideration. The marginal benefit from higher usage is positive initially but declining, and may become negative for high usage levels. In this case, for a given type, gross utility $u(\theta, s)$ reaches a maximum for some usage level. A higher type enjoys higher marginal and, hence, larger absolute benefits from using the product. For example, the product at hand may be a power tool, where s denotes the number of hours the product is in use. Working with the tool first increases utility, but the additional utility from more intensive use diminishes, since less important jobs are undertaken Some customers have more opportunities to make beneficial use of the power tools than others translating into higher marginal utility from product use.

Harm. Product usage may be associated with harm incurred by the customer. Harm may be (partly) compensated by the producer. Harm is monetary and in expected terms amounts to $h(x, s)$, where x is the product's safety feature (sometimes briefly related to as safety). We assume

$$h(x, 0) = 0, \quad h_s(x, s) > 0, \quad h_{ss}(x, s) \geq 0, \quad h_x(x, s) < 0, \quad h_{xx}(x, s) \geq 0, \quad h_{xs}(x, s) < 0.$$

Expected harm only occurs with positive product use and increases with product use at a non-decreasing rate. Expected harm can be reduced by additional safety features where the reduction in harm is non-increasing. Safety features reduce harm by more if the risks are larger due to more intense product use. In the power tool example, harm may be caused by accidents pertaining to technical problems due to, e.g., overheating of the appliance or material fatigue. An increase in safety may be associated with the use of better and more robust materials, better dispatch control, the installation of a powerful fan, or other additional safety features like an emergency stop system. Additional safety features are more effective in reducing expected harm when the product is used more intensively, because, for instance, material fatigue or problems of overheating are of higher concern in this case which explains the assumption of a negative cross-derivative h_{xs}. The assumption on the sign of the cross-derivative is important for our results, and we think that it is the most reasonable assumption for the interplay of safety, product use, and harm. Beside the example described above, a similar relationship can be based on the idea that harm can occur each time the product is used, and higher safety reduces the expected harm per occasion of use. Also in this situation, the cross-derivative $h_{xs}(x,s)$ is negative.[10]

Firm. We consider a monopolist which can produce different variants of the product at hand, distinguished by the variants' safety features. The costs per unit produced depend on the safety features of the product variant and are denoted by $c(x)$. We assume $c(0) = 0$ and increasing and convex costs, i.e., $c'(x), c''(x) > 0$.

Information. The model ingredients are common knowledge, but only customers know their type. We assume that a product variant's safety features are public knowledge, such that given customer homogeneity with regard to expected harm, product liability is not necessary to induce firms to provide safe products (because customers' willingness to pay increases in a product's safety attributes; see, for instance, Shavell 1987, Ch. 3).[11] The ex post realized level of harm becomes common knowledge. Product usage is private information of customers but can be verified in a court proceeding in the event harm occurred.

Liability system. We consider the firm to be strictly liable but able to invoke the defense of product misuse. The standard for reasonable product use can depend on the product variant's safety attributes and the type of customer the product variant is targeted to. We denote by $\bar{s}^j$ the standard for product variant j, $j = l, h$, where product l (product h) is addressed to type L (type H).[12] Product misuse is considered as comparative negligence by the customer resulting in a reduction in damages payments, such that expected damages amount to the level of expected harm for reasonable product

[10] One might think of situations in which the sign is different. For example, if a product is used seldom, safety concerns may result from rusting of important safety-relevant parts (brakes in a car, for instance). *Ceteris paribus* this may argue for safety investments being more effective for lower rates of use. However, this effect would still be counteracted by the higher harm potential coming with higher usage ratesxs. Nevertheless, if the cross derivative were not negative, our policy conclusion that a more lenient application of reasonable product use is called for would not survive.

[11] This allows us to focus our analysis on the interplay between the distortion in product characteristics due to profit-maximizing price discrimination and the liability system. At the same time, the assumption implies that we can stick to the one-shot set-up, because reputation concerns would only be relevant with asymmetric information about product safety (as, for example, in the contributions by Ganuza et al. 2016 and Chen and Hua 2017). Heterogeneous harm levels can distort firms' product safety decisions even when safety is public knowledge (see, e.g., Baumann et al. 2016, 2018).

[12] Because customers could choose product variants not targeted to them, we use different symbols for customer type (capital letters) and product variants (small letters).

use, $h(x, \bar{s}^j)$. This interpretation follows the lines of the description of injurer negligence in Kahan (1989), and embeds the idea that the product misuse must have been causal for harm incurred in order for the firm to be freed from liability.

Reasonable product use. We mainly compare two scenarios with regard to the definition of reasonable product use:

Scenario 1: Reasonable use is defined by the welfare-maximizing use of a product given product safety and the type of customer the product is designed for. This rule corresponds to ideas like the application of the Hand rule to product use by customers.

Scenario 2: A welfare-minded policy maker decides on the level of appropriate usage ex ante, taking into account possible repercussions on the firm's decisions on safety. In this case, reasonable usage may deviate from efficient usage given product safety.

Note that, as explained above, customer type is private information. Therefore, the reasonable use standard is not defined with regard to the customer's type but with regard to the customer type to which the product variant is targeted, where the product variant's characteristics are public information.

Timing. At Stage 1, the policy maker determines the definition of reasonable product use before the firm chooses safety features and prices in Stage 2. Product purchase and usage is determined by customers at Stage 3. Afterward harm may occur and possible damages payments are made.

Second order conditions. For all maximization problems, the second-order conditions are assumed to be fulfilled.[13]

3.2 Benchmark: The first best

With quasi-linear utility functions, we take the sum of customer utility and the firm's profit as the welfare criterion to establish efficient use of a product variant and each product variant's optimal safety. With differentiated product variants for the two customer types characterized by safety levels x^j and type-specific usage described by s^θ, welfare amounts

[13] In Appendix E, we provide an example with specific functional forms in line with the assumptions made. In the example, all optimization problems are well-defined. Appendix A, pertaining to Lemma 1 below, for instance, illustrates that generally uniqueness and existence of the first-best allocation requires the absolute value of the cross-derivate $h_{xs}(x, s)$ to be not too large.

to

$$W = \alpha \left(u(L, s^L) - c(x^l) - h(x^l, s^L) \right) + (1 - \alpha) \left(u(H, s^H) - c(x^h) - h(x^h, s^H) \right), \qquad (1)$$

which is maximized for

$$W_{x^j} = 0 \quad \Leftrightarrow \quad -c'(x^{j,*}) - h_x(x^{j,*}, s^{\theta,*}) = 0 \qquad (2)$$

$$W_{s^\theta} = 0 \quad \Leftrightarrow \quad u_s(\theta, s^{\theta,*}) - h_s(x^{j,*}, s^{\theta,*}) = 0 \qquad (3)$$

defining first-best usage $s^{\theta,*}$ and first-best safety $x^{j,*}$ for the combinations $\theta = L, j = l$ and $\theta = H, j = h$. Marginal safety costs are equalized to the marginal reduction in harm given usage (equation (2)), and optimal usage equates marginal utility with the marginal increase in expected harm given safety (equation (3)). We obtain:[14]

Lemma 1 *The first-best allocation is characterized by two product variants tailored to the needs of the two customer types. High-type customers enjoy a high-end product variant with higher safety than the base product variant used by low-type customers ($x^{h,*} > x^{l,*}$). High-type customers use their product variant more intensely than low-type customers use theirs ($s^{H,*} > s^{L,*}$).*

Intuitively, high-type customers should use the product more often and, due to the additional risk created by higher usage, be provided with a product variant with enhanced safety features. For the following, we define $s^*(\theta, x)$ as the welfare-maximizing product usage for a customer of type θ given product safety x, and $x^*(s)$ as the welfare-maximizing safety given use s.[15] Accordingly, $s^{\theta,*} = s^*(\theta, x^{j,*})$ and $x^{j,*} = x^*(s^{\theta,*})$ for the combinations $\theta = L, j = l$ and $\theta = H, j = h$.

4 Market equilibrium

In this section, we derive the market equilibrium for the two scenarios considered. Because customers' considerations regarding product use and purchase are the same in both scenarios, we describe these decisions first.

4.1 Choice of product use and product variant

At Stage 3, the customer can choose between the two product variants j described by the vector $(p^j, x^j, \bar{s}^j)$, where $\bar{s}^j$ is the (maximum) prescribed product usage for which

[14] All proofs are in the Appendix.

[15] Note that welfare-maximizing safety is not type-dependent given a specific level of usage.

comparative negligence by the customer is denied, i.e., *reasonable usage.* Product variant l is a base product, targeted at customers of type L, whereas product variant h is a high-end product, targeted at customers of type H. Courts cannot observe the customer type implying that the standard for prescribed usage can only depend on the product variant purchased.

Customers may deviate from reasonable usage. In the event of harm, actual product use can be perfectly verified in court. As a result and given the liability system as described in Section 3.1, expected utility of a customer of type θ consuming product variant j, $U^{\theta j}$, is given by[16]

$$U^{\theta j} = u(\theta, s) - p^j - \begin{cases} 0 & \text{if } s \leq \bar{s}^j \\ (h(x^j, s) - h(x^j, \bar{s}^j)) & \text{if } s > \bar{s}^j. \end{cases}$$

Up to the reasonable usage level, the customer does not incur any net costs of harm, but she is confronted with full marginal harm if she extends usage beyond the prescribed level, as expected compensation stays constant at $h(x^j, \bar{s}^j)$. Accordingly, marginal utility is given by

$$U_s^{\theta j} = u_s(\theta, s) - \begin{cases} 0 & \text{if } s < \bar{s}^j \\ h_s(x^j, s) & \text{if } s > \bar{s}^j. \end{cases}$$

and features a downward jump at the level of reasonable product use.

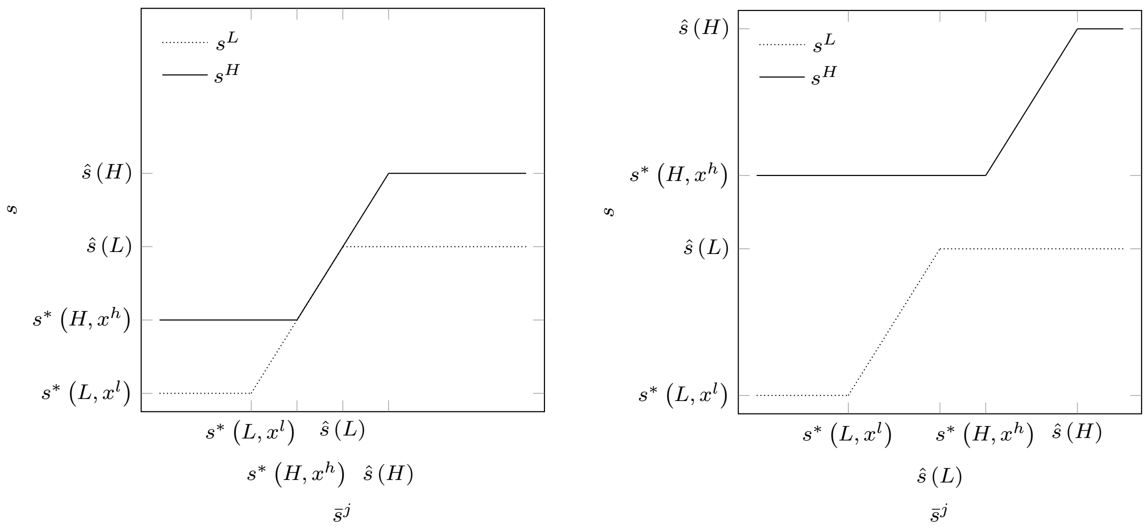
To describe the customer's usage decision, we define by $\hat{s}(\theta)$ the usage level the customer would choose if marginal harm were always fully compensated, i.e., resulting from $u_s(\theta, \hat{s}(\theta)) = 0$, which is necessarily higher than the optimal usage level $s^*(\theta, x^j)$ (due to $h_s(x^j, s) > 0$). The actual usage decision is then given by

$$s^\theta(x^j, \bar{s}^j) = \begin{cases} s^*(\theta, x^j) & \text{if } \bar{s}^j < s^*(\theta, x^j) \\ \bar{s}^j & \text{if } s^*(\theta, x^j) \leq \bar{s}^j \leq \hat{s}(\theta) \\ \hat{s}(\theta) & \text{if } \bar{s}^j > \hat{s}(\theta). \end{cases}$$

For low levels of reasonable usage, the customer's choice surpasses this value, and the usage level is chosen to equate marginal utility and marginal harm, $s^*(\theta, x^j)$. The prescribed usage level is binding for the customer, if it is in between $s^*(\theta, x^j)$ and $\hat{s}(\theta)$. Finally, the customers never has an incentive to surpass the usage level $\hat{s}(\theta)$ even for more lenient definitions of reasonable use.

Figure 1 depicts product usage as a function of reasonable usage for the two types of customers. Given safety, high-type customers always have a weekly higher level of

[16]Technically, the assumptions on the liability system ensure that customer utility is a continuous function with regard to usage and does not exhibit a jump at the level of reasonable usage.



(a) Intermediate difference between type L and type H.

(b) Large difference between type L and type H.

Figure 1: Reasonable and actual product usage.

usage due to their higher marginal utility. The left panel in Figure 1 illustrates the case of an intermediate difference in marginal utility such that usage levels may overlap (i.e., $s^*(H, x^j) < \hat{s}(L)$). For high differences in marginal utility, depicted in the right panel, it holds that $s^*(H, x^j) > \hat{s}(L)$, such that high-type customers would always use a product variant with safety x^j more intensely than low-type customers.

Anticipating product use, the customer decides which product variant to buy. With two product variants on offer, the customer buys the product variant targeted to her only if, first, it yields a (weakly) higher utility than not buying any product, i.e.,

$$U^{Hh} \geq y, U^{Ll} \geq 0 \tag{4}$$

and, second, utility is higher than if buying the product targeted at the other customer group , i.e.,

$$U^{Hh} \geq U^{Hl}, U^{Ll} \geq U^{Lh}. \tag{5}$$

The first condition is known as the participation constraint, the second as the incentive compatibility constraint.[17]

[17]The firm may also choose to serve only one of the two customer types. We concentrate on the case in which it is optimal for the firm to serve both types of customers. Note that (4) and (5) also exclude any possibility of profitable arbitrage.

4.2 Scenario 1: Reasonable use corresponds to ex post efficient use

Comparative negligence. Following standard definitions of negligence like the one proposed by the Hand rule, maximum reasonable product use is obtained when the marginal utility from product use just offsets the marginal increase in harm due to more intensive use. The burden of care is the sacrifice in utility not obtained by more intensive use which, as an opportunity costs, is compared to the gain in reduced expected accident costs. With different types of customers and differentiated product variants, the definition of reasonable product use should account for the product's known safety features and marginal utility of the customer type for whom the product variant is designed.

The firm offers one base product variant with safety x^l targeted at low-type customers and one high-end product variant with safety $x^h > x^l$ targeted at high-type customers. With the firm observing conditions (4) and (5), self-selection by customers is induced. Accordingly, in Scenario 1, the definition of reasonable product use results in the standards $\bar{s}^h = s^*(H, x^h)$ and $\bar{s}^l = s^*(L, x^l)$. In the following, we will show that this definition of reasonable product use will lead to an inefficiently low safety level for the base product variant in our setting.

Product usage. We start by considering a customer's usage decision as described in Section 4.1 before turning to the firm's pricing and safety decisions. With reasonable use being equal to efficient use given product safety, we obtain that both low- and high-type customers choose product use efficiently and equal to defined reasonable use when consuming the product variant designed for them, i.e., for $\theta = L, j = l$ and $\theta = H, j = h$,

$$s^\theta := s^\theta(x^j, \bar{s}^j) = \bar{s}^j = s^*(\theta, x^j). \tag{6}$$

For lower levels of product usage, product use would be increased since marginal utility is still positive but marginal costs are zero due to the firm's duty of full compensation. For higher usage rates, customers bear the full marginal increase in harm which is higher than marginal utility for inefficiently high usage levels.

Customers could also choose to purchase the product variant designed for the other customer type. In this case, as is also obvious from Figure 1, we would obtain usage levels of

$$s^{Hl} := s^H(x^l, \bar{s}^l) = s^*(H, x^l) > \bar{s}^l \text{ and } s^{Lh} := s^L(x^h, \bar{s}^h) = \min\{\bar{s}^h, \hat{s}(L)\}, \tag{7}$$

where the first superscript refers to customer type and the second to the product variant. Due to their higher marginal utility from product usage, high-type customers would use the base product variant more intensely than low-type customers. Given that by exceeding reasonable product use, high-type customers bear full marginal harm, they would use the product efficiently given safety features and their higher marginal utility. A low-type customer using the high-end product variant will never exceed reasonable product use (which is determined using the higher marginal utility of high-type customers). Bearing no liability at the margin up to reasonable product usage, usage may either be the same as for high-type customers or, if differences between customer groups loom large, the possible lower level $\hat{s}(L)$, where marginal utility approaches zero. In either case, product use would be inefficiently high for this group of customers.

Pricing. As a monopolist, the firm charges the maximum prices possible, such that prices are still compatible with each group of customers buying the product designed for them, i.e., prices must fulfill the participation and incentive compatibility constraints for both customer types as explained in Section 4.1. With two prices to be determined, two of the four restrictions will be binding. Note that, due to higher utility obtained, the high-type customer displays the higher willingness to pay, whereas the firm has to be more careful in rising prices for the base product variant in order not to lose low-type customers. In consequence, the participation constraint for low-type customers will be binding. Given the firm's incentive to benefit from high-type customers' high willingness to pay for the high-end product variant, the binding restriction for high-type customers is the incentive compatibility constraint, because the firm must ascertain that this customer does not switch to the base product variant.[18] Profit-maximizing prices are then given by

$$p^l = u(L, s^L) \text{ and } p^h = u(H, s^H) - IR^H, \tag{8}$$

where customers of type H enjoy an information rent of

$$IR^H = u(H, s^{Hl}) - \left[h(x^l, s^{Hl}) - h(x^l, s^L)\right] - p^l.$$

The firm is able to absorb the full surplus of low-type customers that, with full compensation of harm, amounts to gross utility $u(L, s^L)$. High-type customers always have the option to switch to the base product variant, which guarantees them a net utility gain equal to the information rent IR^H consisting of gross utility minus uncompensated harm

[18]Note that according to our model we have $U^{Hh} > U^{Lh}$ and $U^{Hl} > U^{Ll}$. This implies that the participation constraint for high-type customers cannot be binding due to $U^{Hh} = 0 \geq U^{Hl} > U^{Ll}$ violating the low-type customers' participation constraint. If $U^{Ll} > 0$ the incentive compatibility constraints would imply that also $U^{Lh}, U^{Hh}, U^{Hl} > 0$. In this case profits can be increased by raising both p_l and p_h. For a more detailed description of this standard reasoning, see, e.g., Bolton and Dewatripont (2005).

and product price. Accordingly, the price charged by the firm for the high-end product variant equals high-type customers' gross utility minus the information rent.

Product safety. With each customer buying the product designed for her and staying in the confines of reasonable product use, expected profits per customer are given by price minus expected harm and safety costs. Given the above price setting, the firm's profit π amounts to total welfare minus high-type customers' information rents:

$$\begin{aligned}\pi &= \alpha\left[p^l - h(x^l, s^L) - c(x^l)\right] + (1-\alpha)\left[p^h - h(x^h, s^H) - c(x^h)\right] \\ &= W - (1-\alpha)IR^H \end{aligned} \tag{9}$$

From these observations, we obtain our main result for the first scenario:

Proposition 1 *With reasonable product use being defined according to the Hand rule for the customer group targeted by a product variant, (i) the firm chooses the first-best safety level for the high-end product variant, and (ii) distorts the safety level for the base product variant downward compared to the first-best level, while (iii) customers use both product variants efficiently given safety features.*

Proposition 1 establishes that a definition of reasonable use according to the Hand rule leads to distortions in safety for the base product variant. In contrast, as in standard models of product liability, no distortion is to be expected for the high-end product variant. Given product safety, product use is necessarily efficient given the ex post efficient definition of reasonable use.

The latter two results seem straightforward: The ex post efficient definition of reasonable use coincides with the efficient standard for comparative negligence which combined with strict liability leads to efficient victim behavior (see, Shavell 1987, Ch. 2). Furthermore, since in equilibrium product characteristics of the high-end product are only relevant for the purchase decision of high-type customers, whereas it has no bearing on the contract offered to low-type customers, the firm has no incentive to distort safety but balances marginal safety costs and the marginal reduction in harm. The result mirrors earlier results established for product liability as in Hamada (1978). The effect that is new and that deserves some more attention is the distortion of the base product variant's safety level to which we turn now.

Product safety of the base product variant is distorted downward by the firm. As for the high-end product variant, the firm considers the profit repercussions that result from higher safety offered to the targeted customer type. However, when deciding on product safety for the base product variant, the firm experiences an additional trade-off that is not relevant for the high-end product variant's safety. In contrast to the high-end product variant adjustments in safety for the base product variant also affect profit opportunities for the non-targeted group of high-end customers, because it alters their information rent. As pointed out, the information rent is given by the net utility a high-type customer would obtain from buying the base product variant. Because high-type customers would use the base product variant with a higher intensity compared to low-type customers, they also enjoy higher benefits from an increase in the product variant's safety. This is mirrored in the effect that uncompensated harm of high-type customers decreases in the safety level of the base product variant resulting in an increase in the information rent. To illustrate, the total effect of an increase in the base product's safety x^l on a high-type customer's information rent is given by[19]

$$\begin{aligned}\frac{dIR^H}{dx^l} &= h_x(x^l, s^{Hl}) - h_x(x^l, s^L) + \left[u_s(H, s^{Hl}) - h_s(x^l, s^{Hl})\right] \frac{ds^{Hl}}{dx^l} \\ &\quad - \left[u_s(L, s^L) - h_s(x^l, s^L)\right] \frac{ds^L}{dx^l} \\ &= h_x(x^l, s^{Hl}) - h_x(x^l, s^L) = IR^H_{x^l} > 0.\end{aligned}$$

Given the increase in the information rent enjoyed by high-type customers, the monopolist is reluctant to increase safety of the base product variant, instead distorting it downward to decrease the information rent, and to increase profits earned with the high-end product variant. The costs for the firm are lower profits obtained with low-type customers, because the lower safety implies that they do not obtain their first-best product variant. The profit-maximizing reduction in the base product's safety level equates the marginal loss in profits obtained for low-type customers with the marginal increase in profits obtained for high-type customers. Consequently, as long as the firm offers two product variants, the distortion will be more pronounced the higher the share of high-type customers.[20]

Two remarks. We make two additional remarks regarding the liability system:

Corollary 1 *The effective market equilibrium is unchanged when (i) a system of no liability or negligence with the defense of unreasonable product use is applied, or when (ii) the firm is allowed to determine reasonable product use.*

[19]The fact that high-type customers would also use the product even more intensely after an increase in safety has no direct bearing on the information rent, because, due to efficient use in this case, the additional consumption benefit cancels with the increase in expected harm borne by high-type customers.

[20]For a very large share of high-type customers, the firm may stop offering both product variants but only serve high-type customers. By canceling the base product variant the firm avoids the information rent for the high-type customers.

With customers fully informed about product safety, strict liability with the defense of product misuse as described above has no direct bearing on the market equilibrium. Without liability by the firm, customers willingness to pay adjusts downward by the expected level of harm which at the same time no longer enters the firm's profit equation directly. Consequently, the net effects are unchanged, because prices charged by the firm are adjusted downward by exactly the level of expected harm leaving the firm's optimization problem with respect to safety decisions unchanged. The only other difference in addition to the adjustment in prices is that a low-type customer choosing the high-end product variant would use it less intensely. Because, as described above, the incentive compatibility constraint for the low-type customer is not binding in equilibrium, this has no bearing on the results. The same holds for product liability in the form of negligence with a defense of product misuse which – given perfect information about safety – is a combination of strict liability and no liability. With the due care standards for the product variants defined as the fist-best safety levels, the firm would choose to be negligent for the baseline product variant, and adhere to the standard for the high-end product variant. If product use is assessed according to the Hand rule given actual product safety the market equilibrium is the same as with strict liability with a defense of comparative negligence. In the next section, some liability will be necessary to obtain a gain in welfare, because only in this case, the policy maker has the instrument of a more lenient definition of reasonable product use at her disposal. Again, we will perform the analysis for strict liability.[21]

If the firm is strictly liable but can determine reasonable product use ex ante by, for example, determining reasonable product use in the instructions accompanying the different product variants, it would never opt for higher levels than those resulting from the application of the Hand rule. An increase in reasonable product use for the high-end product variant would result in its inefficient use and a loss in profits that cannot be compensated by an adjustment in its price. Likewise for the base product, a more lenient definition of reasonable product usage would lower profits obtained with low-type customers due to the distorted usage decision and, in addition, can only increase the information rent enjoyed by high-type customers. Any lower prescriptions regarding reasonable use would not alter the equilibrium outcome, as customers would surpass these thresholds resulting in unaltered usage decisions (with actual use equating marginal harm and marginal utility). Accordingly, the above result can also be interpreted as the market equilibrium obtained if the firm is allowed to determine reasonable product use ex ante.

[21]The irrelevance of liability also requires the assumption of risk neutrality for all parties, which is given in our set-up.

4.3 Scenario 2: A more lenient definition of reasonable use

In the last section, we have shown that a definition of reasonable use according to the Hand rule leads to a situation in which the firm distorts safety of the base product variant downward in order to increase profits earned with the high-end product variant. In this section, we provide an argument how adjustments in the level of reasonable use for the base product variant will allow for a welfare gain.

Comparative negligence, product usage, and pricing. To introduce the idea of a more lenient definition of reasonable product use, we start from the solution from Proposition 1. We denote the absolute value for reasonable product use that results in Scenario 1 by $\bar{s}^{j,1}$. In the following, we analyze whether an increase in the definition of reasonable use in the vicinity of the original solution results in an increase in welfare, i.e., we contemplate levels of reasonable use given by

$$\bar{s}^j = \bar{s}^{j,1} + \gamma^j,$$

where $\gamma^j \geq 0$ is a possibly variant-dependent adjustment which is the additional policy variable in this section. We concentrate on the case of a weakly more lenient definition of reasonable use, because any downward adjustment in reasonable use has no bearing on actual use in our setting with perfect information about product safety (see the discussion on Corollary 1). Despite the fact that reasonable use is now defined ex ante independent of the actual safety level, for $\gamma^h = \gamma^l = 0$, we would obtain the outcome described in Proposition 1.

Given the description of reasonable product use that is weakly more lenient than the results obtained in the last section, in equilibrium actual use will coincide with reasonable product use, i.e., $s^H = \bar{s}^h$ and $s^L = \bar{s}^l$. At the same time, in the vicinity of the solution for Scenario 1, it will still hold that the use of the base product variant by a high-type customer exceeds reasonable use, $s^{Hl} = s^*(H, x^l) > \bar{s}^l$, and that a low-type customer would use of the high-end product variant according to $s^{Lh} = \min\{\hat{s}(L), \bar{s}^h\}$. Likewise, the firm's price setting continues to be described by (8).

Product safety. As before, taking account of the firm's price setting, the firm's profits are given by total welfare minus the information rent of high-type customers (see (9)), and we obtain the first-order conditions for a profit maximum

$$\pi_{x^h} = (1-\alpha)\left[-h_x(x^h, s^H) - c'(x^h)\right] = 0 \tag{10}$$

$$\pi_{x^l} = \alpha\left[-h_x(x^l, s^L) - c'(x^l)\right] - (1-\alpha)\left[-h_x(x^l, s^{Hl}) + h_x(x^l, s^L)\right] = 0. \tag{11}$$

For product safety of the high-end product variant, the firm minimizes the sum of expected harm and care costs. For the base product variant instead, as before, the firm also considers the effect of higher safety on the information rent earned by high-type customers. Enhanced safety features for the base product variant increase the information rent due to the fact that high-type customers – by using the product more intensely – benefit from increased safety to a larger extent.

For later use, we obtain:

Lemma 2 *In the vicinity of the solution described in Proposition 1, an increase in the definition of reasonable product use for a product variant results in the firm increasing the product variant's safety features. Despite the increase in safety, resulting product use is inefficiently high.*

Intuitively, product safety increases for higher actual usage induced by a more lenient definition of reasonable product use. For both product variants, it holds that higher product usage raises the benefits of harm reduction which incentivizes the firm to choose a higher safety level. In addition and importantly, for the base product variant, an additional effect emerges. A higher level of reasonable use reduces the difference in usage rates of high-type and low-type customers for the base product variant. By reducing the difference, an increase in product safety has a less pronounced effect on the information rent enjoyed by high-type customers. In consequence, the firm will be less reluctant to increase product safety of the base product variant. For both, the high-end and the base product variant, the increase in safety does not fully compensate for the increase in usage; consequently, usage becomes inefficiently high given the product variant's safety features.

Welfare. We are now in the position to evaluate the welfare repercussions of the definition of reasonable use. From the definition of welfare in expression (1) we obtain in the vicinity of the market equilibrium described in Proposition 1

$$W_{\gamma^h} = (1-\alpha)\left[u_s(H, s^H) - h_s(x^h, s^H)\right] + (1-\alpha)\left[-h_x(x^h, s^H) - c'(x^h)\right]\frac{dx^h}{d\gamma^h} \tag{12}$$

$$W_{\gamma^l} = \alpha\left[u_s(L, s^L) - h_s(x^l, s^L)\right] + \alpha\left[-h_x(x^l, s^L) - c'(x^l)\right]\frac{dx^l}{d\gamma^l}. \tag{13}$$

In setting the definition of reasonable use, both the direct effect on product use as well as the indirect effect on product safety have to be taken into account. Using the firm's first-order conditions for product safety (10) and (11) to substitute for the respective second terms in (12) and (13), we finally arrive at

$$W_{\gamma^h} = (1-\alpha)\left[u_s(H, s^H) - h_s(x^h, s^H)\right], \tag{14}$$

$$W_{\gamma^l} = \alpha\left[u_s(L, s^L) - h_s(x^l, s^L)\right] + (1-\alpha)\left[-h_x(x^l, s^{Hl}) + h_x(x^l, s^L)\right]\frac{dx^l}{d\gamma^l}. \tag{15}$$

We have that the change in product safety has a direct effect on welfare only for the base product variant. Evaluating expression (14) and (15) at $\gamma^h = 0$ and $\gamma^l = 0$ for which use is efficient, we obtain

$$\begin{aligned} W_{\gamma^h}|_{\gamma^h=0} &= 0 \\ W_{\gamma^l}|_{\gamma^l=0} &= (1-\alpha)\left[-h_x(x^l, s^{Hl}) + h_x(x^l, s^L)\right]\frac{dx^l}{d\gamma^l} > 0. \end{aligned}$$

From this we obtain our main result:

Proposition 2 *(i) Optimally determined reasonable use for the high-end product coincides with the first-best usage level and is also the level of ex post efficient use, because safety will be set at the first-best level. (ii) Starting from the equilibrium described in Proposition 1, a more lenient definition of reasonable product use for the base product variant leads to an increase in welfare. Both use and safety of the base product variant are higher in the new equilibrium.*

For the high-end product variant, the firm's incentives regarding safety are already efficient, such that any deviation from efficient product use can only lead to a loss in welfare. This is described by equation (14) which is equal to zero for $\gamma^h = 0$. Accordingly, no deviation should be applied in reasonable product use for the high-end product variant. In contrast, we have established that the firm has an incentive to lower product safety of the base product variant in order to reduce the information rent enjoyed by high-type customers. From a welfare perspective, the redistribution from high-type customers to the firm has no effect on welfare, but the distortion in product safety reduces welfare obtained with the base product variant. With product usage of high-type customers surpassing that of low-type customers if consuming the base product variant ($s^{Hl} > s^L$), equation (15) together with equation (13) illustrate that it is not possible to fulfill both the condition for efficient safety and efficient use at the same time. By setting $\gamma_l > 0$, the policy maker introduces a distortion in product use to reduce the distortion in the base product's safety level. Such a policy is welfare-improving, because it allows the policy maker to induce first-order welfare gains from higher product safety, while – starting from efficient product use – losses due to excessive usage are of second order.

The solution in Scenario 1 implied ex post efficient product use but an inefficiently low level of safety for the base product variant. The analysis of Scenario 2, in line with the theory of second best, shows that welfare can be increased by abolishing the requirement of ex post efficient product usage. By defining a more lenient reasonable product use for the base product variant, the policy maker incentivizes the firm to increase product safety. The resulting welfare gain is of first-order given the distorted safety decision in the equilibrium with reasonable use defined according to the Hand rule. In contrast, at first, the loss due to higher usage is of second order and marginally zero. Reasonable product use should be extended until the marginal gain from higher safety is balanced with the marginal loss from excessive product use. The second-best equilibrium is characterized by ex post inefficiently high product use for the base product variant (given its safety features) and, because safety still bears on the information rent enjoyed by high-type customers, an inefficiently low safety level for the base product variant. The latter distortion, however, is ameliorated in comparison to Scenario 1, because, as described above, the higher level of product use by low-type customers diminishes the positive effect of the base product variant's safety on the high types' information rent.

Note that second-best optimal reasonable product use will remain below a level equating high- and low-type product use for the base product variant ($\bar{s}^l < s^{Hl}$) or making it non-binding for low-type customers ($\bar{s}^l < \hat{s}(L)$). In the first case, if $s^{Hl} = s^L = \bar{s}^l$, the incentive for the firm to reduce safety to minimize high-type customers' information rent would be absent at the margin. Consequently a welfare gain can be obtained by reducing the excessive level of product usage by low-type customers. In the second case, for $s^L = \hat{s}(L) < \bar{s}^l$, an increase in reasonable product use has no effect on low types' actual usage and, hence, no effect on safety, i.e., $dx^l/d\gamma^l = 0$ in this case. Again, the policy maker would like to reduce excessive product use by low-type customers in this case.

As a direct consequence from the discussion above and Corollary 1, the following remark with regard to the firm's liability seems in order:

Corollary 2 *Also if the firm is subject to negligence with the defense of unreasonable product use, a definition of reasonable use for the baseline product that is more lenient than a definition according to the Hand rule given safety furthers welfare.*

Finally, let us briefly discuss minimum safety requirements as an alternative policy. Indeed, in our simple model, an optimally set minimum safety requirement according to the first-best level for the product targeted at low-type customers should result in a first-best allocation. Still, our results and the recommendation of a more lenient approach regarding reasonable product remain important. First, we may assume more than two customer types. In this case, product safety levels are distorted for all product variants except for the top quality. A minimum safety standard would only heal the problem with the baseline variant, whereas for intermediate product variants, our recommendation of a more lenient definition of reasonable use increases welfare.[22] Second, transaction costs associated with the determination of a minimum safety requirement may be high, because they have to be ascertained beforehand, and require that the regulator has access to precise information about how additional safety expenditures affect harm levels. The informational requirements of a lenient definition of reasonable product use are lower, because information about product use and its effect on harm given safety are necessary. Because firms may invoke the possible defense of unreasonable product use, information about efficient product use would have to be presented at court also absent the application of our policy recommendation, that is, the additional information requirements are rather limited. Certainly, as a consequence, the more lenient definition of reasonable product use may rather lead to a welfare improvement and not to a first-best outcome, but given lower transaction costs, this policy can well be preferable.

5 Conclusion

In our model, a strictly liable manufacturer determines observable product safety for the two product variants it offers. Customers buy different variants, because they are heterogenous with regard to the optimal intensity of product use. Depending on a product variant's safety features, excessive usage rates may be viewed as comparative negligence by customers. We analyze the effects of two definitions of reasonable use: (i) a definition aligned to the Hand rule and (ii) a more lenient approach.

Our main insight from the welfare analysis is that welfare can be improved by opting for a relative lenient definition of reasonable use for the base product variant. This positive effect is not immediate: Under the Hand rule, in pursuit of profit-maximizing price discrimination, the manufacturer distorts the safety level of the base product variant downward, but customers use the product efficiently. Moving toward a more lenient treatment of reasonable use leads to a trade-off whose net effect on welfare is a priori unclear: On the one hand, higher usage rates resulting from a more lenient definition lead to increased safety investments, which dampens the downward distortion. On the other hand, usage levels are no longer efficient. We find that starting from a definition of

[22] Calculations are available from the authors upon request.

reasonable use aligned to the Hand-rule the former effect outweighs the latter.

Our analysis could be extended in several ways. Of course, one limitation in our set-up is that customers are perfectly informed about their product's safety features. This may be a realistic assumption for professional users or repeat purchasers, but less experienced users most likely lack this knowledge. Information asymmetries between producer and customers may be a further reason to rely on a system of product liability. Another aspect that could be added to the present set-up is to allow for more than two customer types (and product variants), and assume a continuum of customers instead as a limit case. Extending our analysis in these directions should not have an impact on the basic trade-off that is present when moving from the application of the Hand rule to a more lenient definition of reasonable use for base product variants.

Irrespective of these missing and/or limiting aspects, the contribution of our paper is to link the analysis of product liability and investment in product safety to price discrimination. By analyzing the interactions between these aspects, we can evaluate the optimality of different legal approaches to defining reasonable use. Our results thus point to an important implication for designing liability rules: We lend support to those considerations that argue that customer negligence should not always be tied to the Hand rule or intended use as stated by the manufacturer. Indeed, a more lenient definition of reasonable use may be beneficial from a welfare perspective. To obtain this welfare gain, product liability must be applied in the first place. That is, our analysis can also be understood as an argument for welfare-enhancing effects of product liability even when problems of asymmetric information regarding product safety are absent.

References

Baniak, A., and P. Grajzl, 2017. Optimal liability when customers mispredict product usage, American Law and Economics Review 19, 202–243.

Baumann, F., T. Friehe, and A. Rasch, 2016. Why product liability may lower product safety, Economics Letters 147, 55–58.

Baumann, F., T. Friehe, and A. Rasch, 2018. Product liability in markets for vertically differentiated products, American Law and Economics Review 20, 46–81.

Bolton, P., M. Dewatripont, 2005. Contract Theory, MIT Press.

Chen, Y., and X. Hua, 2017. Competition, product safety, and product liability, Journal of Law, Economics, & Organization 33, 237–267.

Choi, A. H., and K. E. Spier, 2014. Should customers be permitted to waive products liability? Product safety, private contracts, and adverse selection, Journal of Law, Economics, & Organization 30, 734–766.

Dari-Mattiacci, G., 2006. On the optimal scope of negligence. Review of Law & Economics 1, 331–364.

Daughety, A. F., and J. F. Reinganum, 2013. Economic analysis of products liability: Theory, in: J. H. Arlen, ed., Research Handbook on the Economics of Torts, Edward Elgar, 69–96.

Dillard, H.C., and H. Hart, 1955. Product liability: Directions for use and the duty to warn, Virginia Law Review 41, 145–182.

Feldthusen, B., M. D. Green, J. C. P. Goldberg, and C. M. Sharkey, 2017. Product liability in North America, in: H. Koziol, M. D. Green, M. Lunney, K. Oliphant, and L. Yang, eds., Product Liability. Fundamental Questions in a Comparative Perspective, DeGruyter, 357–411.

Fudenberg, D., and J. Tirole, 1991. Game Theory, MIT Press.

Ganuza J. J., F. Gomez, and M. Robles, 2016. Product liability versus reputation, Journal of Law, Economics, & Organization 32, 213–241.

Gardels, D. E., 1978. Overuse in products liability, Nebraska Law Review 57, 817–842.

Geistfeld, M., 2009. Products liability, in: M. Faure, ed., Tort Law and Economics, Edward Elgar, 357–411.

Hamada, K., 1976. Liability rules and income distribution in product liability, American Economic Review 66, 228–34.

Kahan, M., 1989, Causation and incentives to take care under the negligence rule. Journal of Legal Studies 18, 427–447.

Keating, G. C., 2017. Products liability as enterprise liability, Journal of Tort Law 10, 41–97.

Landes, W. M., and R. A. Posner, 1985. A positive economic analysis of products liability, Journal of Legal Studies 14, 535–567.

Lipsey, R. G., and K. Lancaster, 1956. The general theory of second best, Review of Economic Studies 24, 11–32.

Miceli, T. J., K. Segerson, and S. Wang, 2015. Products liability when customers vary in their susceptibility to harm and may misperceive risk, Contemporary Economic Policy 33, 468–476.

Oi, W. Y., 1973. The economics of product safety, Bell Journal of Economics and Management Science 4, 3–28.

Ordover, J. A., 1979. Products liability in markets with heterogeneous customers, Journal of Legal Studies 8, 505–525.

Polinsky, A. M., and S. Shavell, 2010. The uneasy case for product liability, Harvard Law Review 123, 1437–1492.

Shavell, S., 1987. Economic Analysis of Accident Law. Harvard University Press.

Sterrett, L. 2015, Product liability: Advancements in European Union product liability law and a comparison between the EU and U.S. regime, Michigan State International Law Review 23, 885–925.

Varian, H. R., 1989. Price discrimination. In: Schmalensee, R., Willig, R. (Eds.), Handbook of Industrial Organization. Vol. 1 of Handbooks in Economics. North-Holland, Amsterdam, pp. 597–654.

Zipursky, B. C., and J. C. P. Goldberg, 2010, The easy case for products liability law: A response to Professors Polinsky and Shavell, Harvard Law Review 123, 1919–1948.

A Proof of Lemma 1

At the welfare maximum, the assumption that second-order conditions are fulfilled implies for $\theta = L, j = l$ and $\theta = H, j = h$:

$$\begin{aligned} A^{\theta,j} &= W_{s^\theta s^\theta} W_{x^j x^j} - (W_{s^\theta x^j})^2 \\ &= \left(\alpha^\theta\right)^2 \left[(u_{ss}(s^{\theta,*}) - h_{ss}(x^{j,*}, s^{\theta,*}))(-c''(x^{j,*}) - h_{xx}(x^{j,*}, s^{\theta,*})) - (h_{xs}(x^{j,*}, s^{\theta,j}))^2\right] > 0 \end{aligned}$$

where $\alpha^L = \alpha$ and $\alpha^H = (1-\alpha)$. Comparative statics with respect to the first-order conditions (2) and (3) yields

$$\frac{dx^{j,*}}{d\theta} = \frac{-h_{xs}(x^{j,*}, s^{\theta,*}) u_{\theta s}(\theta, s^{\theta,*})}{(u_{ss}(\theta, s^{\theta,*}) - h_{ss}(x^{j,*}, s^{\theta,*}))(-c''(x^{j,*}) - h_{xx}(x^{j,*}, s^{\theta,*})) - (h_{xs}(x^{j,*}, s^{\theta,j}))^2} > 0 \tag{16}$$

$$\frac{ds^{\theta,*}}{d\theta} = \frac{(c''(x^{j,*}) + h_{xx}(x^{j,*}, s^{\theta,*})) u_{\theta s}(\theta, s^{\theta,^*})}{(u_{ss}(\theta, s^{\theta,*}) - h_{ss}(x^{j,*}, s^{\theta,*}))(-c''(x^{j,*} - h_{xx}(x^{j,*}, s^{\theta,*})) - (h_{xs}(x^{j,*}, s^{\theta,j}))^2} > 0 \tag{17}$$

which with $A^{\theta,j} > 0$ establishes the ranking for safety features and product usage.

B Proof of Proposition 1

From (9), the first-order conditions for a profit maximum with respect to product safety are given by

$$\begin{aligned} \pi_{x^h} &= (1-\alpha)\left[-h_x(x^h, s^H) - c'(x^h)\right] + (1-\alpha)\left[u_s(H, s^H) - h_s(H, s^H)\right]\frac{ds^H}{dx^h} = 0 \\ \pi_{x^l} &= \alpha\left[-h_x(x^l, s^L) - c'(x^l)\right] + \alpha\left[u_s(L, s^L) - h_s(x^l, s^L)\right]\frac{ds^L}{dx^l} \\ &\quad + (1-\alpha)\left[-h_x(x^l, s^{Hl}) + h_x(x^l, s^L)\right] \\ &\quad + (1-\alpha)\left[u_s(H, s^{Hl}) - h_s(x^l, s^{Hl})\right]\frac{ds^{Hl}}{dx^l} - (1-\alpha)\left[u_s(L, s^L) - h_s(x^l, s^L)\right]\frac{ds^L}{dx^l} = 0 \end{aligned}$$

where $ds_L/dx^l = h_{sx}(x^l, s^L)/(u_{ss}(L, s^L) - h_{ss}(x^l, s^L)) > 0$, $ds_H/dx^h = h_{sx}(x^h, s^H)/(u_{ss}(H, s^H) - h_{ss}(x^h, s^H)) > 0$, and $ds_{Hl}/dx^l = h_{sx}(x^l, s^{Hl})/(u_{ss}(H, s^{Hl}) - h_{ss}(x^l, s^{Hl}) > 0$.

With (6) and (7), the conditions simplify to

$$\begin{aligned} \pi_{x^h} &= (1-\alpha)\left[-h_x(x^h, s^H) - c'(x^h)\right] = 0 \\ \pi_{x^l} &= \alpha\left[-h_x(x^l, s^L) - c'(x^l)\right] + (1-\alpha)\left[-h_x(x^l, s^{Hl}) + h_x(x^l, s^L)\right] = 0 \end{aligned}$$

Proposition 1 (i) follows from the first line in combination with customers' efficient usage. Proposition 1 (ii) follows from the second line. With $s^{Hl} > s^L$ the second term is negative which must be accompanied by a positive first term resulting in

$$-h_x(x^l, s^L) > c'(x^l)$$

which requires $x^l < x^*(L, s^L)$. With s^L being increasing in x^l, it must hold that $x^l < x^*(L, s^L) < x^*(L, s^{L,*}) = x^{l,*}$. Part (iii) of Proposition 1 follows directly from (6).

For later use, note that the second-order conditions for a profit maximum imply at the equilibrium:

$$\frac{\partial^2 \pi}{\partial (x^l)^2} = -h_{xx}(x^l, s^L) - \alpha c''(x^l) + (1-\alpha) h_{xx}(x^l, s^{Hl}) - \frac{\left(h_{sx}(x^l, s^L)\right)^2}{u_{ss}(L, s^L) - h_{ss}(x^l, s^L)} + \frac{(1-\alpha)\left(h_{sx}(x^l, s^{Hl})\right)^2}{u_{ss}(H, s^{Hl}) - h_{ss}(x^l, s^{Hl})} := D^l < 0 \quad \text{(B.1)}$$

$$\frac{\partial^2 \pi}{\partial (x^h)^2} = (1-\alpha)\left(-h_{xx}(x^h, s^H) - c''(x^H) - \frac{\left(h_{sx}(x^h, s^H)\right)^2}{u_{ss}(H, s^H) - h_{ss}(x^h, s^H)}\right) := D^h < 0 \quad \text{(B.2)}$$

Whereas the sign of (B.2) follows from the assumption of the existence of a welfare maximum for type-H individuals, the assumption of (B.1) being fulfilled constitutes an additional requirement on functional forms.

C Proof of Lemma 2

Starting at the equilibrium described in Section 4.1 and assuming a marginal increase in γ^j, we have $s^\theta = \bar{s}^j$ and $ds^\theta = dx^j$ at the margin for $\theta = L, j = l$ and $\theta_H, j = H$, whereas $ds^{Hl}/dx^l = h_{sx}(x^l, s^{Hl})/(u_{ss}(H, s^{Hl}) - h_{ss}(x^l, s^{Hl}) > 0$. From (10) and (11), we obtain

$$\frac{dx^h}{d\gamma^h} = -\frac{\pi_{x^h\gamma^h}}{\pi_{x^h x^h}} = \frac{h_{xs}(x^h, s^H)}{-h_{xx}(x^h, s^H) - c''(x^h)} > 0$$

$$\frac{\partial x^l}{\partial \gamma^l} = -\frac{\pi_{x^l\gamma^l}}{\pi_{x^l x^l}} = \frac{h_{xs}(x^l, s^L)}{-h_x x(x^l, s^L) - \alpha c''(x^l) + (1-\alpha) h_{xx}(x^l, s^{Hl}) + (1-\alpha) h_{sx}(x^l, s^{Hl}) \frac{ds^{Hl}}{dx^l}} > 0.$$

The sign of the derivative $dx^h/d\gamma^h$ is straightforward; the sign of $dx^l/d\gamma^l$ relies on the assumption of a profit maximum which implies $\pi_{x^l x^l} < 0$.

To show that after the marginal increase in γ^j use is inefficiently high, define

$$\Delta^\theta = u_s(\theta, s^\theta) - h_s(x^j, s^\theta)$$

for $\theta = L, j = l$ and $\theta = H, j = h$. We obtain

$$\frac{d\Delta^H}{d\gamma^h} = u_{ss}(H, s^H) - h_{ss}(x^h, s^H) - h_{sx}(x^h, s^H)\frac{dx^h}{d\gamma^h} = \frac{u_{ss}(H, s^H) - h_{ss}(x^h, s^H)}{-hxx(x^h, s^H) - c''(x^h)} D^h < 0$$

$$\frac{d\Delta^L}{d\gamma^l} = u_{ss}(L, s^L) - h_{ss}(x^l, s^L) - h_{sx}(x^l, s^L)\frac{dx^L}{d\gamma^l} = \frac{u_{ss}(L, s^L) - h_{ss}(x^l, s^L)}{-h_{xx}(x^l, s^L - \alpha c''(x^l) + (1-\alpha) h_{xx}(x^l, s^{Hl}) + (1-\alpha) h_{sx}(x^l, s^{Hl})\frac{ds^{Hl}}{dx^l}} D^l < 0$$

where D^l and D^h are defined as in (B.1) and (B.2). Consequently, starting from $\gamma^j = 0$ an increase in γ^j leads to

$$u_s(\theta, s^\theta) < h_s(x^j, s^\theta)$$

which is equivalent to

$$s^\theta > s^*(\theta, x^j)$$

for $\theta = L, j = l$ and $\theta = H, j = H$.

D Proof of Proposition 2

Part (i) of Proposition 2 directly follows from Proposition 1 part (i) and (iii) in combination with equation (14). The first-best for high-type customers is obtained for $\gamma^h = 0$. Regarding part (ii) of Proposition 2 equation (15) in combination with Lemma 2 establishes that welfare is increasing in γ^l for $\gamma^l = 0$. Accordingly, the second-best optimum will be characterized by $\gamma^l > 0$. Inefficiently high product use as well as an increased level of safety for the base product variant follow from Lemma 2.

E Example with specific functional forms

The analysis relied on the assumption that the firm's profit maximization problem as well as the welfare maximization problems are well-behaved such that second-order conditions are fulfilled. In the following, we offer a brief example with specific functional forms to illustrate that these conditions can indeed be fulfilled.

Suppose in accordance with the description of the model ingredients that

$$\begin{aligned} u(\theta, s) &= \theta s - \frac{s^2}{2} \\ h(x, s) &= s(1 - x)d \\ c(x) &= \frac{ax^2}{2}, \end{aligned}$$

and $a > d^2$, $0 < d < L < H < a/d$, $(H - L)/H - d) < \alpha < 1$. The first parameter restriction proofs important for second-order conditions, the other parameter restrictions guarantee interior solution for safety levels x.

First-best allocation. We obtain for the combinations $\theta = L, j = l$ and $\theta = H, j = h$:

$$0 < x^{j,*} = \frac{(\theta - d)d}{a - d^2} < 1, \quad s^{\theta,*} = \frac{a}{d} x^{j,*}.$$

With $W_{s^\theta s^\theta} < 0$, $W_{x^j x^j} < 0$ and $W_{s^\theta s^\theta} W_{x^j x^j} - W_{s^\theta x^j} = (\alpha^\theta)^2(a - d^2)$, the assumption $a > d^2$ guarantees a maximum ($\alpha^L = \alpha$, $\alpha^H = (1 - \alpha)$).

Scenario 1. The equilibrium with reasonable use defined according to the Hand-rule is described by

$$0 < x^{l,1} = x^{l,*} - \frac{1-\alpha}{\alpha}\frac{(H-L)d}{a-d^2} < x^{h,1} = x^{h,*}$$

and

$$0 < s^{L,1} = s^{L,*} - \frac{1-\alpha}{\alpha}\frac{(H-L)d^2}{a-d^2} < s^{H,1} = s^{H,*}.$$

We have $\pi_{x^j x^j} = -\alpha^\theta(a-d^2)$ such that second-order conditions for a profit maximum are fulfilled.

Scenario 2. For some values $\gamma^l, \gamma^h > 0$, the firm chooses safety levels

$$x^l = x^{l,1} + \frac{\gamma^l d}{\alpha(a-d^2)+d^2}$$
$$x^h = x^{h,1} + \frac{\gamma^h d}{a}.$$

This constitutes a profit maximum according to $\pi_{x^l x^l} = -\alpha(a-d^2) - d^2 < 0$ and $\pi_{x^h x^h} = -(1-\alpha)a < 0$. Also for the increased safety levels, usage is efficiently high for $\gamma^j > 0$:

$$s^L = s^*(L, x^l) + \frac{\alpha(a-d^2)\gamma^l}{\alpha(a-d^2)+d^2}$$
$$s^H = s^*(H, x^h) + \frac{(a-d^2)\gamma^h}{a}.$$

The social planner chooses

$$\gamma^l = \frac{1-\alpha}{\alpha}\frac{(H-L)(\alpha(a-d^2)+d^2)d^2}{(a-d^2)(\alpha^2(a-d^2)+d^2)} > 0; \;\; \gamma^h = 0$$

which yields the (second-best) welfare maximum. The second-order conditions are fulfilled:

$$W_{\gamma^l\gamma^l} = -\frac{\alpha(a-d^2)(\alpha^2(a-d^2)+d^2)}{[\alpha(a-d)^2+d^2]^2} < 0,$$
$$W_{\gamma^h\gamma^h} = -\frac{(1-\alpha)(a-d^2)}{a} < 0.$$

The equilibrium is characterized by $x^{j,2}$, $s^{\theta,2}$ according to

$$x^{l,1} < x^{l,2} < x^{l,*} < x^*(s^{L,2}); \;\; x^{h,2} = x^{h,*}$$

and

$$s^{L,2} > s^{L,*} > s^*(L, x^{l,2}); \;\; s^{H,2} = s^{H,*}.$$

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