Innovation, Tort Law, and Competition

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Abstract:

In this paper, we examine the link between innovative activity on the part of firms, the competitive pressure to introduce innovations and punitive damage awards. While innovative activity brings forth valuable new products for consumers, competitive pressure in the ensuing innovation race induces firms to launch innovations too early, thereby raising the likelihood of severe product risks above the optimal failure rate. Introducing innovations too early may call for the application of punitive damages instead of mere compensation of harm caused, in order to decelerate such welfare-reducing innovation races.

Keywords: competition, innovation, punitive damages, tort law

1 Innovation, tort law, and competition: a 'ménage à trois'

There is clearly a link between a firm's innovative activity, competitive pressure and the tort law regime: one might intuitively consider that a firm's innovative activity is stimulated by competition, while the threat of tort liability dampens a firm's appetite for innovation. For example, a pharmaceutical firm may feel the competitive pressure to be the first on the market with a new kind of drug against cancer. But at the same time the firm might fear that the drug could cause adverse reactions, which may result in tort cases and subsequently high compensation payments, and even punitive damages. This example is ad hoc, but may not be too far from reality. Many firms may feel the tension between the prospective rewards of being the winner in a race for innovation and being cursed as a tortfeasor, if it turns out later that the innovation triggers unforeseen harm.

It needs no brains to see that the relation between innovation, tort law and competition is not a simple one. An economic analysis which involves innovation is always dynamic in its character, and has to appreciate the occurrence of unforeseeable events. Due to this it is no wonder that today there are a huge number of models in innovation economics addressing all the different circumstances under which innovation does or does not occur (for an overview, see Shavinina 2003).

However, innovation is a topic that not only plays a leading part in academia, but is also a topical policy issue. Countries are very interested in breeding and attracting innovative firms, implying that those countries also have to develop an innovation-friendly legal infrastructure. For example, in an article in *Science* on the impact of punitive damages on the innovativeness of firms, one can read that: “Elizabeth B. Connell, chairman of the FDA Obstetrics and Gynecology Devices Panel, says that the United States is losing its leadership role in the area of contraceptive technology, ‘with potentially disastrous consequences for women and men in this country and elsewhere’. Now, Johnson & Johnson and American Home Products are the only U.S. companies conducting contraceptive research, and the remaining researchers are three nonprofit, publicly funded organizations with a total annual budget of $16 million” (Mahoney/Littlejohn 1989, p. 1397).

The variety of innovation economics models at hand as well as the policy relevance of a legal infrastructure which triggers innovation keeps one wondering why there is still no literature at all on the interrelationship between innovation, tort law, and competition. Seemingly, this ‘ménage à trois’ is an important part of a firm’s strategic decision making. A firm may ask almost daily: does it pay to invest in innovative activity, if there are competitors also striving for the winner’s cup, and if introducing the innovation may incur harm and trigger the subsequent necessity of providing large compensation payments?

We may speculate why there is still no literature on this important aspect of a firm’s daily business. A first explanation can be derived from taking a look at the profession of economics. Scholars who are specialized in the fields of innovation and/or competition are seldom also specialists in the field of tort law, while tort law scholars are usually no experts in innovation economics and competition. However, this argument is, of course, nothing more than idle speculation about the profession of economics (for an overview of the economics profession, see Colander 2001). Therefore another, more analytical explanation would be that in the economic analysis of tort law it is implicitly assumed that technological development is indirectly dependent on the inherent incentives provided by a liability rule to acquire knowledge about hidden risks (Shavell 1992). However, the analysis of innovations and tort law remains difficult. For example, under negligence liability in a torts case, it is often not possible for a court to verify whether a firm has chosen the appropriate level of effort with regard to research and development, in order to bring potential harm down to an optimal level (Dari-Mattiacci/Franzoni 2011). In addition, there are seemingly subtle trade-offs between the ‘activity level’ of and the ‘due standard of care’ for tortfeasors (firms) and victims (consumers), which cannot be overcome easily. In the end one may come to the conclusion that it is not possible to design a liability rule which gives optimal incentives to tortfeasors and victims at the same time (Shavell 1980). Given these difficulties the role of innovative activity is an issue seldom explored in economic torts analysis (Dari-Mattiacci/Franzoni 2011).

However, even if one chooses to take a broader focus on the issue and asks more generally how tort law should be designed to stimulate the optimal amount of innovative activity, the literature on this topic is scarce. Parchomovsky and Stein (2008, p. 286) speak of a "previously underappreciated connection between innovation and tort law." From the small body of literature available, one gains the impression that contemporary tort law regimes are seen as a hindrance to the socially beneficial amount of innovation, implying that there is too little innovation because of overdeterrence. The implied policy conclusion is, then, that there should be a tort law reform, which removes those features from tort law that trigger overdeterrence (Parchomovsky/Stein 2008; Shavell/van Ypersele 2001; Shavell 2004).

While there is not yet much literature on the effect of liability rules on firms' innovative activity in general, there is some literature on the effect of punitive damages on innovation. However, no clear picture emerges; while some have called for punitive damages to be abolished, others have praised them, with others still making pleas for a more balanced system of punitive damages. For example, Mahoney and Littlejohn (1989) claim that strict liability, in conjunction with huge jury awards and "uncontrolled" punitive damages in addition, creates immense legal uncertainty for innovators. As a result, innovators abstain from introducing new and safer products, in order to avoid punitive damages. The authors present as affirmative examples basic research, health care and aviation, where the rate of innovations has dropped over the years and smaller companies in particular have had to close their businesses. In a more recent article, Epstein (2006) echoes this opinion, particularly with regard to pharmaceutical innovations.

It is argued in favor of punitive damages that they stimulate research on safer technologies, which is seen as directly socially beneficial for consumers. Moreover, relaxing punitive damages would mean that more explicit criminal sanctions ought to be applied, in order to deter managers effectively from introducing unsafe products (Rustad 1992; Daniels/Martin 1990).

Between these two camps there are some authors who hold an intermediate position. One of these is Viscusi (1998), who argues that disproportionally high punitive damages suppress innovation and may lead to the withdrawal of firms from the market, while more modest and tailor-made punitive damages may set incentives for firms to innovate and to search for safer technologies (see also Viscusi/Moore 1993). However, the question of how high punitive damages should be in a particular case is left open. Rather, it is proposed that punitive damages be abandoned completely and that a compensatory damages regime is constructed which satisfies economic criteria and sets efficient incentives for potential tortfeasors (Viscusi 1998). This conclusion is somewhat unsatisfactory, and in this contribution we will try to give an answer to the problem of which factors should determine optimal punitive damages.

Another strand of literature is concerned with the relation between punitive damages and competition. This body of literature is even smaller; to our knowledge there are only two articles that address this relation explicitly. Daughety and Reinganum (1997 and 2011 with a more general outline) examine how punitive damages and competitive forces generate separating equilibria, which reveal the safety of a product. It results that competition and punitive damages can substitute each other, in order to set incentives for firms to reveal the true level of safety of a product. However, while very high levels of punitive damages would force firms to reveal the true safety of a product, it is not reasonable for rule makers to introduce such high amounts. In this case firms would not enter the market or they would withdraw, because they would not be willing to run the risk of being sued. On the other hand, very fierce competition could also incentivize firms to reveal the product's true safety level, by forcing firms to lower the price of the good to its safety-type-specific costs. From these 'cost-signals' the consumer can indirectly deduce the quality of the good. In reality one would assume that competition can be stronger or weaker within the various markets, which implies that punitive damages should range within a certain bandwidth. Baumann and Friehe (2011) consider the use of punitive damages in the case of oligopolistic competition, arguing that, since firms may not take into account the beneficial effects of safer products on the consumer surplus in the market, punitive damages may be called for. Without punitive damages, only in the event of perfect competition is the firms' behavior totally aligned with the maximization of the joint producer and consumer surplus. Although the contributions by Daughety and Reinganum (1997) and Baumann and Friehe (2011) address the important relation between competitive pressure, on the one hand, and punitive damages, on the other, they are not concerned with innovation.

In this paper we address the presumption that tort law regimes lead to a lack of innovation. We argue that taking into account the fierceness of competition between innovators plays a decisive role in achieving a better understanding of whether or not innovations are welfare enhancing in a torts context. Our main finding is that competition forces innovators to introduce innovations too early, thereby raising the risk of harm for buyers. This finding suggests that punitive damages are an appropriate means of placing additional costs on innovations and slowing down the innovation race. That is, punitive damages prevent innovations being introduced prematurely, and will lead to a higher chance of defects of innovations being detected in time.

We derive our findings within a stylized model, in which we assume a 'time-cost trade-off' for introducing innovations (see, e.g., Scherer/Ross 1990), meaning that introducing innovations earlier results in higher costs. In addition, planning to introduce the product at an earlier date implies that the probability of harm arising from using the product will be higher as less time will have been spent investigating the associated risks. With respect to competition, a 'patent race' is assumed, in which the winner of the patent race wins a monopoly, while the competitors receive nothing (see, e.g., Loury 1979). The competitive pressure to come up with the innovation is described by a hazard rate, which is modeled analogously to that used by Kamien and Schwartz (1972).

In the following, we begin by outlining the simple generic model, in which we draw links between innovation, tort law and competition (section 2). In the next step we analyze the firms' behavior in our setting and compare it to the social optimum (section 3). This comparison reveals that, depending on the competitive pressure, a social planner is well advised to complement tort liability by punitive damages, in order to equilibrate innovative activity to an optimal level. The fourth section critically discusses the findings and proposes suggestions for future research. Finally, in the fifth section the policy implications of our model are discussed.

2 A simple generic model

Even though the model presented here is simple and generic, it captures various important features of a firm's strategic decision making process with regard to innovation, competition and tort law. Moreover, the model is the first to introduce competitive pressure as an important variable in the puzzle of innovation and tort liability. We argue that the chosen time-to-market of an innovation not only depends on the incentives which are set by a torts regime, but also those set by the interaction between a firm and its competitors. Fierce competition may induce a firm to develop an innovation as early as possible, fearing that another firm will come up with the innovation and take over the market. However, these innovation races come at a price. The innovation costs increase if the date of the innovation is set earlier, an effect which is well known as the 'time-cost trade-off' of innovation (Scherer/Ross 1990). An example of this is the XEROX 1045 copier that was developed in the early 1980s on an accelerated schedule, which should have been introduced to the market more quickly in response to competition from Japanese firms. While the copier was already in pilot production, an important design problem was detected: a wire harness, holding about 40 wires connecting internal components, failed to meet the quality standards. Although the wire harness was swiftly redesigned, it could not then be built in using existing automated manufacturing equipment, which eventually had to be replaced at a cost of more than $1 million (Graves 1989). This is an example of a typical trade-off faced in industrial R&D projects. Products have to be introduced quickly to be competitive, but this acceleration of development can increase costs.

However, there is also another type of cost involved if innovations are brought onto the market at an earlier date: the risk increases that there are more undetected failures, which harm buyers. This cost category increases strongly when the innovation process is shortened, the reason being that it takes time to detect hidden failures of innovations. One may speak of an "information loss of acceleration" (Graves 1989, p. 2). For example, adverse reactions to some drugs can be seen only after some time has passed. Another source of an increasing failure rate can be a firm's managers, who may be tempted to deliberately ignore potential failures of innovations, in order to keep an early date for the introduction of an innovation, if there is fierce competition. Tort liability will, of course, ensure that the victims of an innovation introduced to early will be compensated, and deters wrongdoing by forcing the potential wrongdoer to internalize the costs of harming others. However, deterrence might be too low to obtain an optimal amount of innovative activity, if there is also competitive pressure to introduce the innovation.

For the purpose of our investigation, we consider n firms competing for a market of given size with demand for one unit of a good. The consumer's valuation of the good is equal to v and exceeds the possible harm d that might occur when consuming the good. The n firms have to invest in a research process associated with uncertainty about the time at which the product can be introduced into the market. Each firm i, $i=1,\dots,n$, chooses the hazard rate h_i at which it might succeed with its innovation, where the firm incurs costs $c(h_i)>0$, in each time period until innovation occurs. Costs are strictly convex in the hazard rate h_i, $c'(h_i)$, $c''(h_i)>0$, and the term $1/h_i$ indicates the expected time until the innovation can be realized. To ensure that there is a time-cost trade-off, we assume that the costs $c(h_i)$ are characterized by an elasticity with respect to the hazard rate h_i of above one, i.e., that the average expected costs of an innovation, $c(h_i)/h_i$, increase in the hazard rate:

$$\frac{d(c(h_i)/h_i)}{dh_i}=\frac{c'(h_i)h_i-c(h_i)}{h_i^{\,2}}=\frac{c(h_i)}{h_i^{\,2}}\left[\frac{c'(h_i)h_i}{c(h_i)}-1\right]>0 \qquad (1)$$

The innovator retains the exclusive right to make use of the innovation; the firm may, for example, obtain a patent. This firm can sell the one unit of the innovative good, and we abstract from further production costs. The firm charges a monopoly price, which relates to the perceived safety of the product. We assume that the probability of harm arising from the new product is inversely related to the expected time of its being marketed, or, equivalently, is positively related to the hazard rate. Consumers cannot observe the chosen hazard rate directly, but form rational expectations about it. The expected hazard rate is denoted by $\overline{h}$, and the probability of harm is $x(h_i)$, where $x(h_i)$, $x'(h_i)$, $x''(h_i) > 0$. Consequently, the willingness of consumers to pay, which equals the price the monopolist can charge, is given by

$$p=v-(1-\gamma)x(\overline{h})d \qquad (2)$$

where γ denotes the damages factor applied to the firm, such that γd equals the firm's liability in the event of an accident. All actors within the economy discount future payments using the interest rate r and are assumed to be characterized by risk-neutral behavior.

3 The impact of competition: an equilibrium analysis

The description of the model so far allows us to determine the profit equations for firms and to solve for their optimal hazard rate. After doing this, we will formulate the maximization problem faced by a social planner. As is standard in the law and economics literature, we assume that the social planner aims at maximizing a utilitarian social welfare function and chooses the socially optimal hazard rates. Policy implications regarding optimal damages can then be derived from the perspective of aligning privately and socially optimal choices.

The expected profits of a firm *i* after being the first to launch an innovation are given by the price the firm can charge as a monopolist (see equation (2)) minus expected damages,

$$\pi^I(h_i) = p - \gamma x(h_i)d = v - (1-\gamma)x(\overline{h})d - \gamma x(h_i)d \qquad (3)$$

while costs $c(h_i)$ are incurred as long as no innovation takes place. The ex-ante expected present value of profits for firm *i* can accordingly be written as:

$$E\pi_i = \int_0^\infty e^{-rt}\left[e^{-\sum_{j=1}^n h_j t}(-c(h_i)) + e^{-\sum_{j\neq i} h_j t} h_i e^{-h_i t}\pi^I(h_i) + (1-e^{-\sum_{j=1}^n h_j t})0\right]dt \qquad (4)$$

where *r* denotes the continuous interest rate. If no firm has succeeded with an innovation by time *t*, firm *i* incurs costs $c(h_i)$; given that the other firms have not succeeded in developing an innovation, the density function for an innovation released by firm *i* at time *t* is $h_i e^{-h_i t}$. If a firm has already generated the innovation, then the market is already served, implying zero future profits. Straightforward manipulation of equation (4) yields:

$$E\pi_i = \int_0^\infty e^{-(r+\sum_{j=1}^n h_j)t}\left[h_i\pi^I(h_i) - c(h_i)\right]dt = \frac{h_i\pi^I(h_i) - c(h_i)}{r+\sum_{j=1}^n h_j} \qquad (5)$$

The expected present value of profits is given by expected profits per period during the innovation contest adjusted according to the appropriate discount rate. We assume that expected profits are positive in equilibrium.

Each firm maximizes ex-ante expected profits by choosing its hazard rate h_i. This yields the first-order condition

$$\frac{\partial E\pi_i}{\partial h_i} = \frac{\left[\pi^I(h_i) + h_i \,\partial\pi^I(h_i)/\partial h_i - c'(h_i)\right]\left(r+\sum_{j=1}^n h_j\right) - h_i\pi^I(h_i) + c(h_i)}{\left(r+\sum_{j=1}^n h_j\right)^2} = 0 \qquad (6)$$

which can be transformed into

$$A := \pi^I(h_i)\left(r+\sum_{j\neq i} h_j\right) - h_i\gamma x'(h_i)d\left(r+\sum_{j=1}^n h_j\right) - c(h_i)\left[\frac{c'(h_i)}{c(h_i)}\left(r+\sum_{j=1}^n h_j\right)-1\right] = 0 \qquad (7)$$

The first-order conditions state that the profit from an earlier innovation, the first-term in (7), equals the increase in costs due to higher expected damages and higher costs of developing innovations. The second-order condition for a maximum of ex-ante expected profits, which requires $\partial A/\partial h_i < 0$, is fulfilled:

$$\frac{\partial A}{\partial h_i} = \left(-2\gamma x'(h_i)d - h_i\gamma x''(h_i)d - c''(h_i)\right)\left(r+\sum_{j=1}^n h_j\right) < 0 \qquad (8)$$

From the slope of the reaction curve $h_i(h_k)$, the conclusion can be drawn that the hazard rates are strategic complements; i.e., higher rates of innovation on the part of competitors induce firms to increase their own innovation effort:

$$\frac{\partial h_i}{\partial h_k} = -\frac{\partial A/\partial h_k}{\partial A/\partial h_i} = \frac{h_i\pi^I(h_i) - c(h_i)}{-\left(r+\sum_{j=1}^n h_j\right)\partial A/\partial h_i} > 0 \qquad (9)$$

where $k \neq i$, and both the first-order condition (7) and the assumption of positive expected profits in equilibrium have been applied.

Now, the market equilibrium (10) can be determined. With symmetric firms and rationale expectations formed by consumers, $h = \overline{h} = h_i$ applies, which yields

$$A^E := (v - x(h)d)(r+(n-1)h) - h\gamma x'(h)d(r+nh) - c(h)\left[\frac{c'(h)}{c(h)}(r+nh)-1\right] = 0 \qquad (10)$$

Stability of the equilibrium requires that $\partial A^E/\partial h < 0$, which we assume to be fulfilled.[1] Given this additional condition it is easy to show that the equilibrium hazard rate h increases with the number of firms taking part in the innovation race and decreases with the damages firms are liable for, i.e., the damages factor γ. More intensive competition forces firms to increase innovation costs and to reduce the expected time-to-market, because of the threat that another firm might serve the market earlier. On the other hand, tougher liability rules dampen

[1] Indeed, in the second-best equilibrium, in which the policy maker chooses the optimal damages factor γ, the condition is fulfilled with certainty.

a firm's incentive to launch innovations early, making it more advantageous to invest a greater amount of time in research and thereby reduce product risks.

In the next step, we will address the question of what level of research a social planner maximizing a utilitarian welfare function would choose. In other words, what is the socially optimal amount of time that a firm should spend on research? In order to determine this optimum level of research, the social planner maximizes the expected present value of the sum of producer and consumer welfare. Due to the simplifying assumptions with respect to the market structure, the consumer surplus is equal to zero in equilibrium. Thus, it is sufficient to look at the firms' expected present value of profits. Expected social welfare is then given by

$$ESW = \int_0^\infty e^{-rt}\left[e^{-\sum_{j=1}^{n} h_j t}\left(\sum_{k=1}^{n}\left[h_k(v - x(h_k)d) - c(h_k)\right]\right)\right]dt = \frac{\sum_{k=1}^{n}\left[h_k(v - x(h_k)d) - c(h_k)\right]}{r + \sum_{j=1}^{n} h_j}$$

Acknowledging the symmetric structure of the equilibrium, we can restate social welfare as

$$ESW = \frac{nh(v - x(h)d) - nc(h)}{r + nh} \tag{11}$$

The first-best hazard rate h^* results from the first-order condition

$$\frac{\partial ESW}{\partial h} = \frac{n(v - x(h^*)d)r - nh^* x'(h^*)d(r + nh^*) - nc(h^*)\left[\frac{c'(h^*)}{c(h^*)}(r + nh^*) - n\right]}{(r + nh^*)^2} = 0$$

implying that

$$B := (v - x(h^*)d)r - h^* x'(h^*)d(r + nh^*) - c(h^*)\left[\frac{c'(h^*)}{c(h^*)}(r + nh^*) - n\right] = 0 \tag{12}$$

A comparison between the market equilibrium, equation (10), and equation (12) reveals that the social planner values the monopoly profits *(v-x(h)d)* to a lesser extent, since he/she notices that innovation on the part of one firm implies that no other firms will participate in the monopoly rent. In contrast, the social planner sees a benefit in the saving of total costs *nc(h)* after an innovation has been introduced, in contrast to a single firm, which takes account only of its own cost savings.

Furthermore, the change in the accident probability is taken into account with a factor of one by the social planner, whereas firms apply the damages factor γ. With the second-order condition for a welfare maximum being fulfilled, $\partial B / \partial h < 0$, equation (12) indicates that the optimal hazard rate h^* is a decreasing function of the number of market participants n, $\partial h^* / \partial n < 0$. The intuition for this result is that a growing number of firms leads to increasing negative externalities between the firms' research efforts on the sum of the expected present value of profits.

Yet the question is how the policy maker can urge firms to adjust innovation efforts to the socially optimal level. For this goal the policy maker has the damages factor γ at his/her disposal, whereby γd equals the liability imposed on the firms.

We can solve for the optimal damages factor by equating the expressions in equations (10) and (12), while stipulating that $h = h^*$. This yields

$$\gamma^* - 1 = \frac{n-1}{h^* x'(h^*) d} \frac{h^*(v - x(h^*)d) - c(h^*)}{r + nh^*} = \frac{n-1}{\varepsilon_{x,h}(h^*)} \frac{E\pi^*}{x(h^*)d} \geq 0 \tag{13}$$

where $\varepsilon_{x,h}(h^*) = h^* x'(h^*) / x(h^*)$. The optimal damages factor depends on (i) the number of firms in the market, (ii) the relationship between the expected accident probability and the hazard rate described by the respective elasticity $\varepsilon_{x,h}(h^*)$, and (iii) a firm's value in equilibrium in relation to expected harm. As long as there is competition between firms, $n > 1$, the optimal damages factor exceeds one and increases in expected profits. This means that it is not enough that firms compensate actual harm in order to obtain the optimal level of innovative activity. There have to be extra fines, exceeding the value of actual harm. This is equivalent to the requirement of *punitive damages*. Only if competition is absent, $n = 1$, do we find an optimal damages factor equal to one and no punitive damages required.

The intuition for this result can be summarized as follows. A damages factor equal to one makes the firm internalize all the effects of its decision regarding the innovation hazard rate on the value of the product as perceived by the consumers. This result confirms the findings in the standard models of liability in market settings (see, for example, Shavell 2004). Note that in our setup no consumer surplus exists, which implies that a monopoly is not necessarily welfare-reducing; hence, we obtain the first-best outcome for a monopoly and full liability. However, as outlined above, with competition, firms' incentives with respect to the innovation hazard rate deviate from the social optimum. Firms do not account for the lower expected profits of competitors when accelerating their research efforts, while, on the contrary, a greater number of firms in the market even increases the incentives for launching innovations onto the market early. However, by setting the damages factor above one, the policy maker tackles the exaggerated incentives for marketing innovations too early by punishing firms whose products induce harm to consumers.

Finally, we can show that the damages factor is indeed a monotonous function of the number of competitors, i.e., the degree of competition in the market. Differentiating equation (13) with respect to the number of firms and noticing that the optimal hazard rate depends on the number of firms, we obtain

$$\begin{aligned}\frac{d\gamma^*}{dn} = & \frac{h^*(v - x(h^*)d) - c(h^*)}{(r+nh^*)^2}\frac{(r+h^*)}{h^*x'(h^*)d} \\ & - \frac{h^*(v-x(h^*)d)-c(h^*)}{r+nh^*}\frac{(n-1)[x'(h^*)d + h^*x''(h^*)d]}{(h^*x'(h^*)d)^2}\frac{\partial h^*}{\partial n} > 0\end{aligned} \tag{14}$$

The optimal damages factor increases due to two effects. First, it increases when the number of firms increases, since the externalities that are due to competition become more prevalent. Second, it increases because the first-best innovation hazard rate decreases with the number of firms, whereas private incentives for early innovation increase in the number of firms. This means that more fierce competition makes firms more eager to launch innovations (too) early, which then has to be counteracted by making even more intensive use of punitive damages.

4 Discussion

The general aim of this contribution is to provide an extended framework for the analysis of optimal tort law regimes. In our setup, we combine an innovation contest (with a variable number of firms) with the idea of product risks and the subsequent liability of tortfeasors. This setup allows us to highlight the impact of the fierceness of competition on incentives for innovation and its subsequent results for product safety. We are also able to deduce the implications for the optimal damages factor in tort law. As a result of this, we can specify which factors should be accounted for when the responsible body determines punitive damage awards. It emerges that the main factors in this calculation should be: 1) the degree of competition in the market, i.e., the number of firms in the relevant sector, as this determines the incentive for marketing innovations too early; 2) the extent to which a lengthened development period reduces product risks, since this determines how tort law can affect a firm's decision to launch an innovation; and 3) expected profits, which have been shown to indeed explain the level of punitive damages applied, at least to some extent (see, for example, Karpoff/Lott 1999). Given these features the model is rich in its predictive content, especially given its rather simple structure.

The simple structure naturally comes at a price. First, in our model we concentrate on a firm's liability as the sole mean for the policy maker to influence research decisions. When considering innovations, another approach taken instead of the ex post instrument of liability may be ex ante regulation (for a comparison of different approaches see, for example, Shavell 1987, chapter 12). This method of government intervention is prominent in the pharmaceutical industry, for instance, where the selling of a new drug most often necessitates the approval by a state agency like the 'Food and Drug Administration' in the USA. If allowing for such an approach of government intervention in addition to firms' liability, the relevance of a high damages factor applied to firms is likely to be the less pronounced the more effective direct regulation is. However, given information asymmetry between the regulator and firms, the sole use of the instrument of requiring official product approval might not result in a first-best allocation. We have extended our model to allow for imperfect ex ante regulation in this respect in order to illustrate this line of argument. The formal calculations can be retraced in the Appendix. Indeed, high damages become less important if regulation is more effective. However, firm liability may still be part of the optimal policy package.[2]

Second, we neglect the fact that granting a monopoly in product markets may itself entail inefficiencies. Given downward-sloping demand curves, firms will restrict output and charge higher prices. This may also affect the decision to launch innovations as lower output might imply reduced incentives to invest in avoiding harmful accidents. As Baumann and Friehe (2011) show, this may be another reason for awarding punitive damages, in order to stimulate the search for less harmful technologies. Third, an argument broadly discussed in the economic literature is one of positive research externalities associated with innovations, which may be the base for alleged insufficient innovative activity in the market. By contributing to the stock of knowledge in an economy, a generation of innovations may result

[2] The argument for applying liability in addition to regulation might even be strengthened if one considers different levels of transaction costs which are associated with ex ante regulation and liability as well.

in spillover effects by, for example, reducing the costs of further technological progress. Abstracting from the arguments brought forth here, whether or not incentives for innovation in markets with imperfect competition are too low or too high cannot be stated a priori (see, for example, Aghion/Howitt 1992), and empirical studies are skeptical about the importance of such spillover effects (see, for example, Bottazzi/Peri 2003). However, should such spillover effects be present, this may argue for lower damages in line with the theory of second best (Lipsey/Lancaster 1956).

Finally, the 'hazard rate' model employed here (Kamien/Schwartz 1972) might be replaced by a more comprehensive one, as for example proposed by Kamien and Schwartz (1980), in order to embrace the innovation process of firms more thoroughly. Also, a more refined game theoretical treatment might reveal additional insights into the interaction of competing firms facing the possibility of being sued in a tort case. The inclusion of more refined models would allow a firm's innovative behavior under certain circumstances to be investigated in more detail. However, we think that the basic relation between competition, innovation and tort law, as outlined in this article, remains intact.

5 Policy implications

With regard to the design of tort law, the policy implications of our findings are straightforward. With the exception of the case in which competition is absent, optimal investment behavior on the part of innovative firms is induced only if there are punitive damages.

Our findings suggest that countries which do not yet have punitive damages at their legal disposal should introduce this legal instrument. This holds in general for most European countries, where punitive damages are regarded critically. In most European countries it is argued that punitive damages are in conflict with the *ordre public*, which means that a clear distinction has to be made between the aim of tort law of compensating victims and the purpose of punishing a perpetrator of harm in a criminal court (see, for example, Licari 2011). In a criminal court the procedural yardstick for determining liability is much higher than in a private law court (Cooter/Ulen 2008, pp. 489); also, in a criminal court the punitive award will not usually be awarded to the victim but to the public. From a consequentialist point of view, the legal arguments against punitive damages do not make so much sense when a legal system is aimed at providing incentives for agents to behave efficiently in the sense that society minimizes social costs.

Yet tort law would have to undergo a reform in the US as well. The point is that today punitive damages are awarded more or less arbitrarily (see, for example, Viscusi 1998), although in recent years in some US states caps on punitive damages have been introduced or requirements have been established that more evidence be provided before punitive damages are awarded (Rubin/Shepherd 2007). However, our findings suggest that in the case of innovations, punitive damages ought to be employed on a regular basis in a tort case along the parameters outlined above. As part of this, the option might be considered of awarding the punitive damages to the public instead of to the victim and the related lawyers, in order to prevent perverse incentives to sue.

However, we are not pleading for unrestricted use of punitive damages. First, our analysis is concerned with punitive damages related to innovative activity and competition; in the case that there is no innovative activity on the part of firms, other arguments pro and contra punitive damages may play a role. For example, Daughety and Reinganum (1997) provide an analysis in which competition and punitive damages are both means of setting incentives for firms to reveal the true quality of a (non-innovative) product. Second, our findings suggest that the optimal amount of punitive damages depends on the intensity of competition within an industry to bring forth innovation. That is, the level of competitive pressure plays a decisive role in determining the optimal amount of punitive damages to be awarded. As a consequence, the level of punitive damages cannot be decided subjectively by a jury or a judge, but must be derived as a result of equilibrating different economic forces. Thus, our argument is very much in line with Viscusi's plea for a more economics-oriented tort law system (Viscusi 1998), even though we do not share his opinion that punitive damages are superfluous.

Another, more indirect policy implication is that punitive damages may avoid innovative products being introduced too early due to a patent race in general. Thus, while punitive damages cannot avoid the duplication of innovation costs in a patent race, they make the time-cost trade-off of innovative activity less severe by setting an incentive for firms to slow down the pace of innovation. Society as a whole benefits from this effect, since fewer resources are employed in order to accelerate innovation processes. In other words, the 'common pool' problem of patent races becomes mitigated by punitive damages. The positive effect on social welfare resulting from the mitigation of the 'common pool' problem will, of course, differ between countries, depending on the size of a country's R&D sector. However, the welfare gain might be considerable and may be understood as a second social dividend besides the social gain from reducing accidents.

Even though the model applied here is rather simple, it captures the basic features of the interaction between competition, innovation and the tort law regime. Moreover, the model gives rise to the policy conclusion that punitive damages are an important means of calibrating the pace of innovation to an optimal level. At the very least, the conclusion may be drawn that without punitive damages the innovation process becomes less efficient. However, we are aware that the simplicity and clarity of the model comes at a price. While the model may be suitable for deriving a general statement in favor of punitive damages, in a specific tort case more factors may have to be taken into account before one can decide on the efficiency of punitive damages. Insofar the model proposed here constitutes rather the beginning of a discussion than the end.

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Appendix

Extending the model by the requirement of official product approval

In order to scrutinize the use of damages in the case that the policy maker has access to the instrument of directly regulating a firm's market entry (e.g., a government agency has to approve the product before it can be sold in the market), we extent the model described in Section 3 in the following way. To take into account that direct regulation is likely to be imperfect as well, we assume that the probability that a firm *i*'s product finds approval by the agency is a function of the hazard rate h_i, where the probability is denoted by $q(h_i)$ and $q'(h_i) < 0 < q''(h_i)$ holds. That is, the regulator may have the idea that a certain hazard rate should be chosen. However, due to asymmetric information between the better informed firm and the regulator, product approval might be granted also for higher values of the hazard rate or even be denied for lower rates. Accordingly, we assume that the probability of the product being approved is an increasing function of the expected time until an innovation is made ($1/h_i$), as the product is more likely to meet given standards. Taking this additional aspect into account, we can state expected profits of a firm as

$$E\pi_i = \int_0^{\infty} e^{-(r+\sum_{j=1}^{n} q(h_j)h_j)t}\left[q(h_i)h_i\pi^I(h_i) - c(h_i)\right]dt = \frac{q(h_i)h_i\pi^I(h_i) - c(h_i)}{r+\sum_{j=1}^{n} h_j} \tag{5'}$$

which might be compared to equation (5), while profits after successful approval of the product are still given by equation (3). After determining the first-order condition for a profit maximum and using the fact of a symmetric equilibrium, we can restate the condition determining the chosen hazard rate in the market equilibrium as

$$\begin{aligned} A^E &:= q(h)[1+\varepsilon_{qh}(h)](v - x(h)d)(r+(n-1)h) - h\gamma x'(h)d(r+nh) \\ &\quad - c(h)\left[\frac{c'(h)}{c(h)}(r+nh) - q(h)[1+\varepsilon_{qh}(h)]\right] = 0 \end{aligned} \tag{10'}$$

where $\varepsilon_{qh}(h) = q'(h)h/q(h)$ is the elasticity of the approval probability with respect to the chosen hazard rate. This elasticity is negative and should be absolutely higher for a more effective regulation system, that is, the easier it is for the regulation agency to determine the appropriateness of firms' research efforts. Given the probability of approval $q(h)$, the expected social welfare reads

$$ESW = \frac{nq(h)h(v - x(h)d) - nc(h)}{r + nh} \tag{11'}$$

and maximization of expected social welfare results in the optimal hazard rate being described by

$$\begin{aligned} B := {} & q(h^*)[1+\varepsilon_{qh}(h^*)](v - x(h^*)d)r - h^* x'(h^*)d(r + nh^*) \\ & - c(h^*)\left[\frac{c'(h^*)}{c(h^*)}(r + nh^*) - nq(h^*)[1+\varepsilon_{qh}(h^*)]\right] = 0 \end{aligned} \tag{12'}$$

Comparing equations (10') and (12') yields the result that the optimal damages factor γ^* can be found from

$$\gamma^* - 1 = [1+\varepsilon_{qh}(h^*)]\frac{n-1}{h^* x'(h^*)d}\frac{h^*(v - x(h^*)d) - c(h^*)}{r + nh^*} = [1+\varepsilon_{qh}(h^*)]\frac{n-1}{\varepsilon_{x,h}(h^*)}\frac{E\pi^*}{x(h^*)d} \geq 0 \tag{13'}$$

which corresponds to the respective condition in the main model, equation (13), except for the additional factor $[1+\varepsilon_{qh}(h^*)]$. To summarize, in addition to the conditions outlined in the main text, the optimal damages factor now depends on the effectiveness of the ex ante regulation of product approval. Given this additional instrument, the optimal damages factor is lower than in the main analysis, which reflects the substitutability between the different means, regulation and firms' liability. Punitive damages remain part of the optimal liability system as long as the approach of regulation is relatively ineffective, which translates into $\varepsilon_{qh}(h^*) > -1$. For a more effective system of regulation, optimal damages are lower. This might be likened to a change in the liability system in the direction of a negligence rule. For example, in the realm of products liability, liability is often incurred if the firm's product is judged as defective, which includes an element of negligence into the otherwise applicable liability rule of strict liability.

Additional Appendix

In this appendix, we describe in more detail some of the more tedious calculations performed to obtain the mathematical results in the paper.

Derivation of equation (9)

From equation (7), we obtain

$$\frac{\partial A}{\partial h_k} = \pi^I(h_i) - h_i \gamma x'(h_i) d - c'(h_i)$$

We make use of the transformed first-order condition, equation (7), to replace the last two terms in the above equation and arrive at

$$\frac{\partial A}{\partial h_k} = \pi^I(h_i) - \pi^I(h_i) \frac{r + \sum_{j \neq i} h_j}{r + \sum_{j=1}^{n} h_j} - \frac{c(h_i)}{r + \sum_{j=1}^{n} h_j} = \frac{h_i \pi^I(h_i) - c(h_i)}{r + \sum_{j=1}^{n} h_j}$$

This result is used to obtain equation (9).

Stability requirement for the symmetric equilibrium

In the manuscript, footnote 1, we claim that in the second-best equilibrium with $\gamma = \gamma^*$, the stability requirement of $\partial A^E / \partial h < 0$ is fulfilled. Here, we describe the corresponding calculations.

Differentiation of equation (10) with respect to h yields

$$\begin{aligned}\frac{\partial A^E}{\partial h} &= -x'(h)d(r + (n-1)h) + (v - x(h)d)(n-1) - \gamma x'(h)d(r + nh) - h\gamma x''(h)d(r + nh) - h\gamma x'(h)dn \\ &\quad - c''(h)(r + nh) - c'(h)n + c'(h) \\ &= (v - x(h)d)(n-1) - c'(h)(n-1) - x'(h)d\left[r + (n-1)h + \gamma(r + 2nh)\right] \\ &\quad - h\gamma x''(h)d(r + nh) - c''(h)(r + nh)\end{aligned}$$

Using the damages factor displayed in equation (13) to (partly) substitute for γ in the above expression, we are able to unambiguously sign the derivative, with all terms in the second row negative to begin with.

$$\frac{\partial A^E}{\partial h} = (v - x(h)d)(n-1) - c'(h)(n-1) - x'(h)d\left[r + (n-1)h + \left(\frac{n-1}{hx'(h)d}E\pi + 1\right)(r+2nh)\right]$$
$$- h\gamma x''(h)d(r+nh) - c''(h)(r+nh)$$
$$= (v - x(h)d)(n-1) - c'(h)(n-1) - (n-1)\frac{h(v - x(d)) - c(h)}{h(r+nh)}(r+2nh)$$
$$- x'(h)d(2r + (3n-1)h) - h\gamma x''(h)d(r+nh) - c''(h)(r+nh)$$
$$= -\frac{n(n-1)[h(v - x(h)d) - c(h)]}{r+nh} + (n-1)\frac{c(h)}{h}\left[1 - \frac{hc'(h)}{c(h)}\right]$$
$$- x'(h)d(2r + (3nn-1)h) - h\gamma x''(h)d(r+nh) - c''(h)(r+nh) < 0$$

With a positive expected value of profits and the characteristic of the cost function given in equation (1), all terms in the above equation are negative.

<u>Properties of the hazard rate *h* in equilibrium</u>

On pages 10-11 it is stated that for $\partial A^E / \partial h < 0$, "the equilibrium hazard rate *h* increases with the number of firms taking part in the innovation race and decreases with the damages firms are liable for, i.e., the damages factor γ." The corresponding calculations are stated here.

$$\frac{\partial h}{\partial n} = -\frac{\partial A^E / \partial n}{\partial A^E / \partial h} = \frac{(v - x(h)d)h - h^2\gamma x'(h)d - c'(h)h}{-\partial A^E / \partial h}$$

Applying equation (10) to substitute for the last two terms in the nominator, we obtain

$$\frac{\partial h}{\partial n} = \frac{h}{-\partial A^E / \partial h}\left[(v - x(h)d)\left(1 - \frac{r + (n-1)h}{r+nh}\right) - c(h)\frac{1}{r+nh}\right] = \frac{h}{-\partial A^E / \partial h(r+nh)}\left[h(v - x(h)d) - c(h)\right] > 0$$

which is larger than zero for a positive expected present value of profits. In addition,

$$\frac{\partial h}{\partial \gamma} = -\frac{\partial A^E / \partial \gamma}{\partial A^E / \partial h} = \frac{-hx'(h)d(r+nh)}{-\partial A^E / \partial h} < 0$$

holds.

Properties of the optimal hazard rate h^*

On page 12 we claim that: "With the second-order condition for a welfare maximum being fulfilled, $\partial B / \partial h < 0$, equation (12) indicates that the optimal hazard rate h^* is a decreasing function of the number of market participants n, $\partial h^* / \partial n < 0$." The corresponding calculations are displayed here.

$$\begin{aligned}\frac{\partial B}{\partial h} &= -x'(h^*)d[r + r + nh^* + nh^*] - h^* x''(h^*)d(r + nh^*) - c''(h^*)(r + nh^*) - c'(h^*)(n - n) \\ &= -2x'(h^*)d(r + nh^*) - h^* x''(h^*)d(r + nh^*) - c''(h^*)(r + nh^*) < 0\end{aligned}$$

$$\frac{\partial h^*}{\partial n} = -\frac{\partial B / \partial n}{\partial B / \partial h} = \frac{-h^{*2}\, x'(h^*)d - c'(h^*)h^* + c(h^*)}{-\partial B / \partial h} = \frac{-h^{*2}\, x'(h^*)d - c(h)\left[\dfrac{c'(h^*)h^*}{c(h^*)} - 1\right]}{-\partial B / \partial h} < 0$$

Again, the characteristic of the cost function described in equation (1) has been used.

Derivation of equation (14)

Differentiating equation (13) with respect to the number of firms n yields

$$\begin{aligned}\frac{d\gamma^*}{dn} &= \frac{1}{h^* x'(h^*)d} \frac{h^*(v - x(h^*)d) - c(h^*)}{r + nh^*} - \frac{n-1}{h^* x'(h^*)d} \frac{h^{*2}\,(v - x(h^*)d) - h^* c(h^*)}{(r + nh^*)^2} \\ &\quad + \Bigg[-\frac{(n-1)[x'(h^*)d + h^* x''(h^*)d]}{(h^* x'(h^*)d)^2} \frac{h^*(v - x(h^*)d) - c(h^*)}{r + nh^*} \\ &\quad + \underbrace{\frac{[(v - x(h^*)d) - h^* x'(h^*)d - c'(h^*)](r + nh^*) - nh^*(v - x(h^*)d) + nc(h^*)}{(r + nh^*)^2}}_{= B/(r+nh^*)^2 = 0} \frac{n-1}{h^* x'(h^*)d} \Bigg] \frac{\partial h^*}{\partial n} \\ &= \frac{1}{h^* x'(h^*)d} \frac{h^*(v - x(h^*)d) - c(h^*)}{(r + nh^*)^2} (r + nh^* - (n-1)h^*) \\ &\quad - \frac{(n-1)[x'(h^*)d + h^* x''(h^*)d]}{(h^* x'(h^*)d)^2} \frac{h^*(v - x(h^*)d) - c(h^*)}{r + nh^*} \frac{\partial h^*}{\partial n} \\ &= \frac{r + h^*}{h^* x'(h^*)d} \frac{h^*(v - x(h^*)d) - c(h^*)}{(r + nh^*)^2} \\ &\quad - \frac{(n-1)[x'(h^*)d + h^* x''(h^*)d]}{(h^* x'(h^*)d)^2} \frac{h^*(v - x(h^*)d) - c(h^*)}{r + nh^*} \frac{\partial h^*}{\partial n} > 0\end{aligned}$$