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Tortious Acts Affecting Markets

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Abstract

The present paper examines an injurer causing a temporary blackout to a firm as the primary victim but also affecting customers and competitors of the firm. Reflecting existing legal practice, the paper investigates efficiency properties of the negligence rule granting recovery of private losses but to the primary victim only. The regime is shown to provide efficient incentives for precaution provided that the primary loss exceeds the social loss from accidents. The main contribution of the paper consists of an explicit analysis of markets affected by a temporary blackout of one firm. The analysis reveals that the private loss exceeds the social loss indeed if the market is less than fully competitive. Moreover, the net social loss remains positive, no matter which market structure prevails.

JEL classification: K13, K12, D62

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1 Introduction

Tort law holds the promise of internalizing negative external effects, which otherwise would distort incentives for precaution. In fact, as I have shown elsewhere,[1] an extensive interpretation of the negligence rule would, in theory at least, allow to handle even complicated situations involving several parties and multilateral external effects. In practice, however, rather restrictive use is made of the instrument. Bussani and Palmer (2003) summarize the arguments in support of an exclusionary rule under the headline of "floodgates". Permitting extensive recovery of losses would overwhelm the courts. Widespread liability would place an excessive burden upon the defendant's human initiative and enterprise, enforcing a broad modern trend toward increasing tort liability.

To keep floodgates closed, some legal systems including the German one distinguish between damage to person or property from losses without antecedent harm to plaintiff's person or property. While such pure economic losses, as they are referred to, cannot be recovered, damage to property, including consequential loss, is granted recovery.

Bussani and Palmer present a bunch of case studies which aim at identifying a common core of principles governing tortious liability for pure economic loss in several European countries. Their cases cable I and cable II among others are of particular interest for the economic analysis of the present paper. Under cable II, the facts are constructed as follows. While operating his mechanical excavator, injurer A cuts the cable belonging to the public utility which delivers electricity to primary victim B. The unexpected blackout caused the temporary loss of production. B is claiming compensation from A for the damage caused by the loss of production. In the case of cable I, the only difference is that, in addition to loss of production, the blackout also caused damage to B's machinery.

Bussani and Palmer summarize the legal practice as follows. In Belgium, France, Greece, Italy, the Netherlands and Spain, lost production or lost profit will be compensated even in the absence of physical loss. These countries do not distinguish between damage to property and pure economic loss per se. In Austria, Sweden and Finland, the primary victim could recover

[1] See Schweizer (2005b).

damage to the machinery but would be denied recovery of lost production or profit. In Germany and Portugal finally, the primary victim would be granted recovery of both damage to the machinery and of lost production or profit under cable I, whereas it would be denied recovery under cable II. In other words, the rules governing such cases do not belong to the common core of European tort law.

The above cable cases involve externalities beyond the injurer and the primary victim. In fact, customers of B might also negatively be affected by accidents as B's shutdown or blackout may lead to temporary shortages on the market it serves. Party B's competitors, on the other side, may benefit from such an accident as they may face increased demand. To focus on the main issue at stake (and to keep floodgates closed), potential claims by secondary victims are ruled out. Moreover, parties enjoying windfall gains from accidents do not have to pay compensation for their benefits which is true under most if not all legal systems. Therefore, quite likely, a discrepancy between the private loss of the primary victim as compared to the social loss from accidents does arise which has been examined in the economic literature before.[2]

The main conclusions so far have been as follows. Under a regime of strict liability, to induce efficient precaution, the injurer should face damages equal to the social loss. Put differently, if just the primary victim can recover his private loss that is different from social loss, incentives would be distorted. More precisely, if private loss exceeds social loss there would be too much whereas, otherwise, there would be too little precaution.

Bishop (1982) argues that, in a range of cases, private economic loss caused by a tortious act is not a cost to society. His argument is widely accepted and used to justify legal practice which denies recovery of pure economic loss even to primary victims. Yet, as the present paper argues, that range of cases may be narrower than thought. As it turns out, if the primary victim operates in a fully competitive market then the social loss exceeds the primary victim's private loss such that granting recovery of private loss only, let alone denying recovery would induce too little precaution. The same holds obviously true if the primary victim serves its market as a monopolist.

[2]See, among others, Bishop (1982), Shavell (1987), Gilead (1997), Parisi (2003) and Dari Mattiacci (2003) for an extensive discussion of private versus social loss.

While the monopolist's customers may suffer as secondary victims from the temporary shutdown there is no party around who would benefit.

This leaves the more widespread case of imperfect competition in between. Here, as it turns out, the primary victim's private loss exceeds the social loss such that granting full recovery of private loss would induce, under a regime of strict liability, too much precaution indeed. Yet, as the social loss remains positive quite generally, imperfect competition does neither support Bishop's case of no cost to society. Denying recovery would induce too little precaution. Hence, under strict liability, there exist parameter constellations where granting recovery of private loss but to the primary victim only would outperform denying recovery and others where denying recovery would be socially preferable.

Yet, many tort cases are governed, instead of strict liability, by negligence rules. For becoming liable, the injurer must have violated a standard of conduct and his violation must have been the cause of the accident. Under such a negligence rule, the potential injurer has no incentives for precaution beyond the negligence standard. Therefore, if this standard is equal to efficient precaution the negligence rule provides incentives for efficient precaution provided that the injurer, if negligent, owes damages not below the social loss. Notice the case of no loss to society (if it occurs at all) would also qualify for efficient incentives under such a negligence rule.

The present paper identifies imperfect competition as the leading case where the primary victim's private loss exceeds the social loss. Since the bulk of cases will concern markets governed by such imperfect competition, on efficiency grounds, granting recovery of private loss but to the primary victim only without requiring the primary victim's competitors to compensate for windfall gains seems justified. Under the circumstances of cable II, this rule corresponds to legal practice in Belgium, France, Greece, Italy, the Netherlands and Spain. Under cable I, such a rule would also capture legal practice in Germany and Portugal. In any case, the rule is shown to provide efficient incentives for precaution provided that the private loss exceeds the social loss and that the negligence standard equals efficient precaution.[3] As a corollary, it follows that denying recovery of private loss to the primary victim, even if the loss is of pure economic nature, cannot be justified on

[3] For a closely related result, see also Dari Mattiacci (2003).

efficiency grounds, at least not if a blackout of a firm is at stake.

The main contribution of the present paper consists of pointing out that the discrepancy between the primary victim's private loss and the social loss depends on the structure of the affected market. While the extreme cases of monopoly and perfect competition are relatively easy to grasp, it is the case of imperfect competition in between that proves most challenging for intuition. Earlier findings on free entry under imperfect competition prove helpful in understanding the result.

Recall, if competition is less than perfect, free entry would lead to the range where social welfare is decreasing.[4] Therefore, social welfare under a blackout of the primary victim, net of the victim's fixed costs, exceeds social welfare without accident. Moreover, without the accident, the primary victim would earn revenues covering both fixed and variable costs. As a consequence, the primary victim's private loss is then easily seen to exceed the social loss.

The paper is organized as follows. Section 2 introduces the general setting. It examines the negligence rule with a standard of conduct where the injurer owes damages if his violation of the standard has caused the accident. If the standard equals efficient precaution and if damages are not lower than the social loss keeping the standard is an optimal strategy of the injurer. Moreover, if there are multiple optimal strategies all of them turn out to be efficient. This robust efficiency result turns out to hold quite generally. More restrictive assumptions are needed to show that other negligence rules, be it that they are relying on inefficient standards or be it that the injurer owes damages below the social loss, fail to provide efficient incentives.

Section 3 models the market affected by a blackout of the primary victim explicitly. A first subsection deals with monopoly and perfect competition. While the monopoly case is obvious, it is shown that, under perfect competition, the social loss exceeds the private loss of the primary victim provided that marginal costs are strictly increasing. The case of constant marginal costs is trivial as firms would earn zero profits and the accident would cause neither a private nor a social loss. The second subsection deals with the linear specification of the Cournot model. Unless the primary victim has marginal

[4] Weizsäcker (1980) has pointed out this result for the linear specification of Cournot quantity competition. Mankiw and Whinston (1986) have extended it to more general settings of imperfect competition.

costs low enough relative to his competitors to approach the position of a monopolist, his private loss is shown to exceed the social loss. Nevertheless, the social loss remains positive in general such that Bishop's range of cases where private loss is not a cost to society does not cover the linear specification of the Cournot model. The third subsection examines more general market structures to confirm the findings of the previous subsection beyond the linear specification of Cournot.

Section 4 takes up the view that entry choice may depend on the negligence rule in place. It is shown that entry choice would be distorted downwards even if the market were governed by perfect competition and if the negligence rule were perfect in the sense that it induces the injurer to take socially optimal precaution.

Section 5 investigates capacity choice. While entry choice is modelled as a binary decision, capacity choice faces a continuous range of alternatives. The market, again, is assumed to be governed by perfect competition. Capacity choice is shown to be distorted in the same direction as entry choice. However, for continuous capacity choice, the distortion arises even in the complete absence of accidents whereas for mere entry choice, distortions only arise if accidents are expected to occur. These findings hint at the fact that the blame for distortion of entry or capacity choice should not prematurely be put on the negligence rule as such.

Rather, the obligations involved are of a multilateral nature and, to restore full efficiency, would have to be handled as such. In fact, an extensive interpretation of the negligence rule which takes the multilateral nature into account would provide efficient incentives both for precaution and capacity choice. Section 6 concludes. Rigorous proofs of some of the propositions are relegated to the appendix.

2 The general setting

The primary victim is assumed to be a firm supplying output to a given market and possibly facing competing firms. On the other side of the market, there are customers. In the absence of an accident, let W^0 denote social welfare, i.e. the sum of customers' and producers' surplus and G^0 the primary victim's profit. Moreover, let ΔS and ΔP denote the social loss and the primary victim's private loss, respectively, from an accident.

The potential injurer decides on precaution $r \in R = [0, \infty)$. The probability of an accident depends on precaution and is denoted $\varepsilon(r)$. Let

$$R^* = \arg\max_{r \in R} [1 - \varepsilon(r)] \cdot W^0 + \varepsilon(r) \cdot \left[W^0 - \Delta S\right] - r$$

denote the set of efficient precautions. Equivalently, it holds that

$$R^* = \arg\min_{r \in R} r + \varepsilon(r) \cdot \Delta S.$$

Notice, without further restrictions, this set may contain more than one element.

In the following, negligence rules with a standard of conduct r_S are examined. Let $d(r, r_S)$ denote expected damages owed by the injurer. The rational injurer takes precaution from the set

$$R_I = \arg\min_{r \in R} r + d(r, r_S).$$

No damages are due if the injurer keeps the standard, i.e., $d(r_S, r_S) = 0$. To ensure efficient incentives, it turns out to be sufficient if expected damages $d(r, r_S)$ are never lower than the difference $[\varepsilon(r) - \varepsilon(r_S)] \cdot \Delta S$ of expected social losses under actual precaution and standard of conduct, no matter which deviation $r \neq r_S$ from the standard has occurred. Under this assumption, the following proposition establishes that, at an efficient standard, keeping the standard is an optimal decision for the injurer and, if multiple decisions exist that are optimal, they all must be efficient.

Proposition 1 *If $d(r, r_S) \geq [\varepsilon(r) - \varepsilon(r_S)] \cdot \Delta S$ holds for any deviation $r \neq r_S$ from the standard of conduct and if this standard is efficient, i.e. $r_S \in R^*$ then $r_S \in R_I \subset R^*$.*

Proof. Under the assumption of the proposition,

$$r + d(r, r_S) \geq r + [\varepsilon(r) - \varepsilon(r_S)] \cdot \Delta S \geq r_S + d(r_S, r_S)$$

must hold for all r because r_S minimizes total costs $r + \varepsilon(r) \cdot \Delta S$ and, hence, r_S also minimizes the injurer's total costs $r + d(r, r_S)$ such that $r_S \in R_I$ must hold indeed. As a consequence, for any other decision $r \in R_I$, it holds that

$$r_S = r + d(r, r_S) \geq r + \varepsilon(r) \cdot \Delta S - \varepsilon(r_S) \cdot \Delta S$$

and, hence, that

$$r_S + \varepsilon(r_S) \cdot \Delta S \geq r + \varepsilon(r) \cdot \Delta S$$

must also hold. Yet, since r_S minimizes total costs, the above inequality cannot be strict and, for that reason, r must be a cost minimizing decision as well. It follows that $R_I \subset R^*$ as was to be shown. ■

The proof can also be captured on more intuitive grounds. No matter, which decision is taken by the injurer, the rest of society will be at least as well of as if the injurer had kept the standard and since keeping the standard minimizes total costs, it will also be in the injurer's interest to meet the standard.

The following two rules, among others, would meet the assumption of the above proposition. First, suppose the injurer owes damages $\Delta H \geq \Delta S$ not below the social loss if he spends less than the due standard r_S on precaution. Then the expected damages amount to $d^B r, r_S) = \lambda^B(r, r_s) \cdot \Delta H$ where

$$\lambda^B(r, r_S) = \begin{cases} 0 & \text{if} \quad r \geq r_S \\ 1 & \text{if} \quad r < r_S \end{cases}$$

defines liability, well in line with the traditional negligence rule as pioneered by Brown (1973). Second, following Kahan (1989), suppose expected damages are equal to $d^K(r, r_S) = \lambda^K(r, r_s) \cdot \Delta H$ where

$$\lambda^K(r, r_S) = \begin{cases} 0 & \text{if} \quad r \geq r_S \\ \varepsilon(r) - \varepsilon(r_S) & \text{if} \quad r < r_S \end{cases}$$

and where, again, $\Delta H \geq \Delta S$ is assumed to hold. Both Brown's and Kahan's versions of the negligence rule are easily seen to satisfy the assumption of the above proposition and, hence, both rules provide efficient incentives for precaution if the standard of conduct is equal to efficient precaution and damages owed by the injurer if ruled liable are not lower than the social loss.

Kahan refers to the legal doctrine, according to which injurers are held liable if they have acted negligently and their negligence has caused the accident. Notice the injurer still owes full damages ΔH but only in those states of nature where the accident has actually occurred but would have been avoided if the injurer had kept the standard. Therefore, from the ex ante perspective when the precaution decision must be taken, damages owed by the injurer amount to $[\varepsilon(r) - \varepsilon(r_S)] \cdot \Delta H$ in expected terms.

Kahan's rule takes the above legal doctrine into account while the more traditional rule does not. For that reason, the present paper rather sides with Kahan's rule. However, changes of results that would follow under the more traditional negligence rule will also be hinted at.

For Proposition 1, which provides a sufficient condition on the negligence rule for inducing efficient precaution, the exact specification of the negligence rule does not matter. Characterizing necessary conditions, however, turns out to be more subtle. To derive such conditions, for simplicity, the probability of an accident $\varepsilon(r)$ is assumed to be a differentiable, decreasing and convex function of precaution, i.e. $\varepsilon_r(r) < 0$ and $\varepsilon_{rr}(r) > 0$. Notice, none of these assumptions was needed to establish Proposition 1. Obviously, it follows from these assumptions that efficient precaution r^* and precautions

$$r^B \in \arg\min r + d^B(r, r_S) \text{ and } r^K \in \arg\min r + d^K(r, r_S)$$

as induced by the above two damage rules are all unique. The following proposition also refers to the precaution

$$r_H = \arg\min_r r + \varepsilon(r) \cdot \Delta H$$

that would result from strict liability, which is also unique under the assumptions made. The proposition establishes that the injurer chooses precaution among the standard of conduct and the precaution that would result from strict liability, whichever happens to be lower.

Proposition 2 *Suppose the probability of an accident is a decreasing and convex function of precaution. Then, under the damage rule as proposed by Kahan, the injurer would choose precaution* $r^K = \min[r_H, r_S]$.

The proof of Proposition 2 is standard. Under strict liability, total costs of the injurer amount to $r + \varepsilon(r) \cdot \Delta H$ which attain their minimum at precaution r_H. Under Kahan's rule and in the range $r \leq r_S$, the injurer's total costs are equal to $r + [\varepsilon(r) - \varepsilon(r_S)] \cdot \Delta H$ which attain their minimum also at r_H provided r_H is in this range. Otherwise, the injurer just keeps the standard in order to minimize total costs as follows from the convex shape of total costs.

Under Kahan's rule, efficient incentives beyond the cases of Proposition 1 would only result if damages owed were equal to the social loss, i.e. $\Delta H = \Delta S$

and the standard were excessive in the sense of $r_S > r^*$. In all other cases, incentives of the injurer are distorted. In particular, if damages owed were lower than social loss, i.e. $\Delta H < \Delta S$ then $r_H < r^*$ and, hence, insufficient incentives result from Kahan's rule as follows directly from Proposition 2.

Under the more traditional negligence rule proposed by Brown, the injurer would decide as follows:

$$r^B = \begin{cases} r_S & \text{if} \quad r_S \leq r_H \\ \in \{r_H, r_S\} & \text{if} \quad r_H < r_S \end{cases} .$$

In fact, under Brown's rule and in the open range $r < r_S$, total costs of the injurer amount to $r + \varepsilon(r) \cdot \Delta H$. If $r_S \leq r_H$, then these costs are decreasing in the open range such that the infimum is not attained in this range. Rather, the injurer meets the standard to escape liability. However, if $r_H < r_S$, then the injurer's total costs attain a minimum in the open range at r_H which must then be compared with precaution costs r_S where the injurer's total costs attain their minimum in the closed range $r_S \leq r$. Under Brown's rule, the injurer chooses among the minima from the two ranges. Such ambiguity arises from the discontinuous jump of the expected damages at the standard of conduct. As a consequence, even if damages owed are lower than the social loss, i.e. $\Delta H < \Delta S$, efficient incentives may still result from Brown's version of the negligence rule provided that the standard is equal to efficient precaution.

To sum up, if damages owed by the injurer are not lower than the social loss and if the standard of conduct is equal to efficient precaution then the injurer has efficient incentives for precaution quite generally. If damages owed by the injurer are lower than the social loss then the injurer will have insufficient incentives for precaution under Kahan's version of the negligence rule whereas, under Brown's version of the negligence rule, efficient incentives may still prevail though not necessarily so.

3 The affected market

In this section, the market affected by a tortious act is modelled explicitly. The primary victim is assumed to be a firm supplying output to a given market. Firm $i \in M = \{1, ..., m\}$ has cost function $K_i(x_i) = k_i(x_i) + \phi_i$ where

ϕ_i denotes fixed costs of firm i. Marginal costs are positive and increasing ($dk_i(x_i)/dx_i > 0$ and $d^2k_i(x_i)/dx_i^2 > 0$). On the other side of the market, there are customers. The inverse demand function of the customers is denoted by $f(X)$ and is equal to the price at which demand would clear market supply X. The law of demand is assumed to hold, i.e. the inverse demand function is downwards sloping ($df(X)/dX < 0$). No matter whether markets are perfectly or imperfectly competitive, let x_i^0 and $X^0 = \sum_{i \in M} x_i^0$ denote output of firm i and aggregate output, respectively, if there is no accident. Then the profit of firm i amounts to

$$G_i^0 = g_i^0 - \phi_i = f(X^0) \cdot x_i^0 - K_i(x_i^0)$$

and customers' surplus amounts to

$$c^0 = \int_0^{X^0} f(X)dX - f(X^0) \cdot X^0$$

whereas social welfare amounts to

$$W^0 = w^0 - \sum_{i \in M} \phi_i = c^0 + \sum_{i \in M} g_i^0 - \sum_{i \in M} \phi_i = \int_0^{X(m)} f(X)dX - \sum_{i \in M} K_i(x_i^0).$$

If there is an accident, the blackout causes a temporary loss of production to the primary victim $v \in M$. The victim must bear the fixed costs with and without accident and, for that reason, fixed costs do not affect the victim's private loss arising from the accident. Rather, the victim's private loss amounts to revenues minus variable costs, i.e.

$$\Delta P = g_v^0 = f(X^0) \cdot x_v^0 - k_v(x_v^0).$$

Depending on the shape of marginal costs, the other firms may be able to offset, in part at least, the victim's lost production. After the accident, the output of firm $i \neq v$ is x_i^{-v} and total output is $X^{-v} = \sum_{i \neq v} x_i^{-v}$. The profit of firm $i \neq v$ amounts to $g_i^{-v} = f(X^{-v}) \cdot x_i^{-v} - k_i(x_i^{-v})$ and customers' surplus to $c^{-v} = \int_0^{X^{-v}} f(X)dX - f(X^{-v}) \cdot X^{-v}$. The social welfare during the blackout of the primary victim net of fixed costs amounts to $w^{-v} = c^{-v} + \sum_{i \neq v} g_i^{-v}$. The social loss from an accident amounts to $\Delta S = w^0 - w^{-v}$ such that the discrepancy between private and social loss is

$$\Delta P - \Delta S = g_v^0 + w^{-v} - w^0. \tag{1}$$

Recall, it is the sign of (1) which matters if the efficiency of the negligence rule granting recovery of private losses but to the primary victim only is at stake. This sign turns out to depend on the market structure as I now want to show.

3.1 Monopoly and perfect competition

The simplest case is that of a primary victim serving the market as a monopolist. Since, by definition of a monopoly, there are no competitors that could benefit from the primary victim's blackout and since the customers loose their surplus, the social loss, not only, must be positive but must even exceed the private loss of the primary victim. In fact, the monopolist's loss is less than social loss by the amount of customers' surplus.

A similar result holds true if the primary victim serves a market governed by perfect (short-run) competition where firms do not perceive any market power. Due to competitive pressure, prices equal marginal costs (but may still be higher than average costs):

$$\frac{dk_i(x_i^0)}{dx_i} = f(X^0) \text{ and } \frac{dk_i(x_i^{-v})}{dx_i} = f(X^{-v})$$

In this case, too, it can be shown that $\Delta S > \Delta P$ must hold.

In case of an accident, the other firms will make up for part of the reduction in supply but the price will raise. Figure 1 provides a standard demand and supply diagram from which the result can easily be visualized. Notice, that

$$-k_v(x_v^0) = \sum_{i \neq v} k_i(x_i^0) - \sum_{i \in M} k_i(x_i^0)$$

must hold and recall that total costs net of fixed costs are equal to the area under the appropriate supply curve. Since social surplus is equal to the area between demand and supply curves, the discrepancy $\Delta S - \Delta P$ must be equal to the area 123 in figure 1 and, hence, must be positive as claimed.

[Figure 1 here approximately]

Surprisingly enough, monopoly and perfect competition both lead to a situation where the social loss, not only, remains positive but even exceeds the private loss of the primary victim. Therefore, if the primary victim serves his market as a monopolist the negligence rule granting recovery but to the primary victim only induces too little precaution. Yet the rule still outperforms the rule that denies recovery. Moreover, neither monopoly nor perfect competition at increasing marginal costs support Bishop's range of cases involving no loss to society.

3.2 Linear specification of the Cournot model

Under the Cournot model, accidents will cause positive social losses even if marginal costs are constant. In fact, though lost output may be provided by others at the same costs, due to lessened competition, prices will raise if one of the suppliers suffers from a temporary blackout. Since there are countervailing forces at work, the overall effect remains difficult to grasp. To obtain first insights, the linear specification of the Cournot model is investigated, which allows to calculate private and social losses explicitly. Later, more general market structures are examined and some intuition will be provided.

Let us assume that marginal costs c_i of firm i are constant such that total costs at output x_i amount to $K_i(x_i) = c_i x_i + \phi_i$. Inverse demand of customers is assumed linear $f(X) = A - X$. In the following, the findings of some tedious but straightforward calculations are listed. Under quantity competition in the sense of Cournot, firm i maximizes profit

$$x_i^0 \in \arg\max_{x_i}(A - c_i - x_i - \sum_{j \neq i} x_j^0) \cdot x_i.$$

It follows from first order conditions that total supply and supply of firm i amount to

$$X^0 = \frac{m}{m-1} \cdot (A - c^a) \text{ and } x_i^0 = \frac{A - c^a + (m+1) \cdot (c^a - c_i)}{m+1},$$

respectively, where $c^a = \sum_{i \in M} c_i / m$ denotes average marginal costs. The solution is tacitly assumed to be interior such that all firms supply some positive quantity.

In the absence of an accident, the profit of firm i net of fixed costs amounts to

$$g_i^0 = (x_i^0)^2 = \frac{(A - c^a)^2}{(m+1)^2} + \frac{2(A - c^a) \cdot (c^a - c_i)}{m+1} + (c^a - c_i)^2$$

and the customers' surplus to

$$c^0 = \frac{1}{2} \cdot (X^0)^2 = \frac{m^2 (A - c^a)^2}{2(m+1)^2}.$$

Hence, social welfare net of fixed costs amounts to

$$w^0 = c^0 + \sum_{i \in M} g_i^0 = \frac{(m^2 + 2m) \cdot (A - c^a)^2}{2(m+1)^2} + \sum_{i \in M} (c^a - c_i)^2.$$

If there is an accident leading to a blackout of the primary victim $v \in M$, social welfare net of fixed costs amounts to

$$w^{-v} = c^{-v} + \sum_{i \neq v} g_i^{-v} = \frac{(m^2 - 1) \cdot (A - c^{-v})^2}{2m^2} + \sum_{i \neq v} (c^{-v} - c_i)^2$$

where $c^{-v} = \sum_{i \neq v} c_i/(m-1)$ denotes average marginal costs after the accident. The discrepancy between private and social loss amounts to

$$\begin{aligned} & \Delta P - \Delta S \qquad (2) \\ = \ & w^{-v} + g_v^0 - w^0 = \\ = \ & \frac{2m^2 - 2m - 1}{2m^2(m+1)^2} \cdot (A - c^a)^2 + \\ & + \frac{m^2 - 2m - 1}{m^2(m+1)} \cdot (A - c^a) \cdot (c^a - c_v) - \frac{2m+1}{2m^2} \cdot (c^a - c_v)^2 \end{aligned}$$

and the social loss to

$$\begin{aligned} \Delta S \ = \ & \frac{2m+1}{2m^2(m+1)^2} \cdot (A - c^a)^2 + \\ & + \frac{m^2 + 2m + 1}{m^2(m+1)} \cdot (A - c^a) \cdot (c^a - c_v) + \frac{2m^2 + 2m + 1}{2m^2} \cdot (c^a - c_v)^2. \end{aligned}$$

While it seems difficult to provide general intuition for the above terms, several limiting cases are more easy to grasp.

First, obviously it must hold that

$$\lim_{m \to \infty} \Delta P - \Delta S = 0.$$

In fact, for $m \to \infty$, Cournot competition under the linear specification is approaching the case of perfect competition. Under perfect competition and at constant marginal costs, firms would earn zero profit and a blackout would cause neither a private nor a social loss. Therefore, the discrepancy would vanish, well in line with the above limiting case under Cournot competition.

Second, suppose the primary victim produces very little even in the absence of a blackout ($x_v^0 \approx 0$). Then, the private as well as the social loss from a blackout would be negligible ($\Delta P \approx \Delta S \approx 0$, hence $\Delta P - \Delta S \approx 0$), in line with (2).

Third, suppose all competitors of the primary victim produce negligible quantities ($x_i^0 \approx 0$ for $i \neq v$) then the case is approaching that of a monopolist suffering from the blackout. For this case, the discrepancy has been shown, in the previous subsection, to be negative, again in line with the corresponding property as derived from (2).

Fourth, if the primary victim has average marginal costs ($c_v = c^a$) and if there exists at least one competitor ($m \geq 2$) then the discrepancy must be positive ($\Delta P - \Delta S > 0$) as follows from (2). In this case, the formula coincides with the one where all firms have equal marginal costs and which is less messy to calculate.

Fifth, ceteris paribus, the discrepancy is a concave, the social loss a convex function of c_v. Therefore, a cutoff value $c^{\#} < c^a$ must exist such that the discrepancy $\Delta P - \Delta S > 0$ remains positive if and only if the marginal costs of the primary victim exceed this cutoff. In other words, unless the primary victim has relatively low marginal costs as compared to its competitors the private loss of the victim exceeds the social loss. The social loss is positive if the victim has average marginal costs. The social loss vanishes if the marginal costs of the victim are so high that his output becomes negligible. It then follows from convexity that the social loss is positive as long as the primary victim would remain active in the absence of an accident. In other words, the linear specification of Cournot does not confirm Bishop's case of zero social loss. However, it supports the use of the negligence rule granting recovery but to the primary victim only. The following proposition summarizes these findings.

Proposition 3 *Under the linear specification of the Cournot model, the primary victim's private loss exceeds the social loss if and only if the primary victim's marginal costs are not too small relative to the rivals' marginal costs. In particular, this condition would be met if all firms had the same marginal costs. Moreover, the social loss always remains positive.*

So far, these claims have been established for the linear specification of Cournot. They hold far beyond as I now want to show.

3.3 More general market structures

In this section, more general market structures are examined. Yet, for simplicity, firms are assumed to be symmetric. Inverse demand is assumed to obey the law of demand but need not be restrained otherwise. The cost function of each firm is $K(x) = k(x) + \phi$ where ϕ denotes fixed costs. Marginal costs are assumed to be positive and to be strictly increasing, i.e. $dk(x)/dx > 0$ and $d^2k(x)/dx^2 > 0$. For a given market structure, let $x(m)$ and $X(m) = m \cdot x(m)$ denote output per firm and market supply, respectively, if m firms are active. It is assumed that output per firm decreases whereas market supply increases as more firms are brought in, i.e.

$$\frac{dx(m)}{dm} < 0 \text{ and } \frac{dX(m)}{dm} > 0. \tag{3}$$

Finally, since the case of (short-run) perfect competition has already been dealt with, prices are assumed to exceed marginal costs, i.e.

$$f(X(m)) - \frac{dk(x(m))}{dx} > 0$$

holds for all m. For such a setting, the following proposition can be established.

Proposition 4 *Under imperfect competition, the social loss from an accident remains positive. Moreover, under free entry at least, the primary victim's private loss exceeds the social loss.*

Therefore, under the assumptions of this proposition, the negligence rule granting recovery of private losses but to primary victims only provides efficient incentives for precaution. Denying recovery even to the primary victim, however, would typically provide insufficient incentives for precaution.

A rigorous proof of this proposition can be found in the appendix. The following intuition may be of help in grasping the claim. Since fixed costs arise with and without accident, the social loss does not depend on the level of fixed costs. Moreover, while fixed costs may affect the entry decision of firms, they are not relevant for quantity choice. Therefore, the social loss from a blackout of one of the suppliers in a setting with fixed costs would be the same as in the absence of fixed costs. Yet, in the absence of fixed costs, the blackout will lead to higher prices as competition is lessened. Since higher prices mean a lower sum of producers' and customers' surplus, the social loss will be positive indeed.

To understand the second claim of the proposition, a little algebra may be of help. Let $W(m)$ denote the sum of customers' and producers' surplus net of fixed costs and $G(m)$ the profit per firm also net of fixed costs if m firms are present. Suppose m^0 firms are present before the accident. Due to an accident, one of the firms suffers from a temporary blackout. Since the victim must bear its fixed costs with and without the accident, its private loss amounts to $\Delta P = G(m^0) + \phi$. The social loss from the accident amounts to $\Delta S = W(m^0) - W(m^0 - 1) + \phi$. Indeed, since the first term contains the fixed costs of m^0 firms, the second term of $m^0 - 1$ firms and since the social loss does neither depend on fixed costs, fixed costs must be added once to arrive at the social loss from the accident. The discrepancy between private and social losses then amounts to $\Delta P - \Delta S = G(m^0) + W(m^0 - 1) - W(m^0)$.

Under the linear specification of the Cournot model, this discrepancy turned out to be positive for any number of firms. For the above proposition, the number m^0 is assumed to result from free entry. At free entry, profits net of fixed cost will be zero and, hence, the discrepancy is equal to $\Delta P - \Delta S = W(m^0 - 1) - W(m^0)$ which is positive for the following reason. Under less than perfect competition, firms may survive even if they have higher costs than some of their competitors. For similar reasons, under less than perfect competition, more firms can survive with non-negative profits than what would be optimal (second best given the price distortion). In other words, the sum of customers' and producers' surplus net of fixed costs with $m^0 - 1$ firms would be higher than with m^0 firms and, hence, private loss ΔP would exceed social loss ΔS as was to be shown.

Notice the second claim of the proposition is derived under the implicit assumption that firms when deciding about entry do not anticipate that they may possibly be affected by a blackout caused by a tortious act. If they would anticipate such accidents the negligence rule in place may influence the entry decision as will be investigated in the next section.

4 Anticipating accidents under perfect negligence rules

So far, firms took the entry decision without anticipating that they might possibly be disrupted from power supply by a cable accident. In the present section, the strategic interaction between the entry decision and the negligence rule in place is explored. It will turn out that the entry decision may well be distorted. But the main message will be that the blame for such distortions should not be put on the negligence rule a such.

To arrive at such conclusion, imagine the following timing of events. After firms have decided to enter the market, with some probability, the injurer starts operating in the neighborhood of one of the competing firms. The socially optimal level of precaution by the injurer depends on the number of firms that are potentially affected by a temporary blackout. If the negligence rule in place provides incentives for socially optimal precaution and if the injurer escapes liability by choosing efficient precaution, for obvious reasons, the negligence rule may justly be called perfect.

To focus on potential distortions at the entry stage, let us assume that the negligence rule is perfect and that the market supplied by the firms operates under perfect competition as well. Still, too few firms will enter for the following reason.

Since the injurer will meet the standard of conduct, the firm suffering from a blackout cannot recover its private loss. Its competitors will enjoy a windfall gain due to the blackout for which they must not pay any compensation. In this way, a firm's entry decision may give rise to a positive externality for the benefit of its competitors. It is this positive externality, which stops entry before the optimal number of firms is reached in spite of the fact that the negligence rule is assumed to provide perfectly efficient incentives for precaution. The following proposition, whose rigorous proof can be fund in the appendix, summarizes these findings.

Proposition 5 *Suppose the market is governed by perfect competition and liability is governed by a perfect negligence rule. Then entry choice would be distorted downwards.*

While the present section looks at distortions of the mere entry decision, the next section explores potential distortions of capacity choice of a more general type. Capacity choice affects the cost structure of a firm. Extra capacity may also be held as a backup against blackouts. Both aspects of capacity choice will be investigated.

5 Capacity choice

To begin with, the situation is explored where capacity choice only concerns the cost structure of firms. At high capacity, fixed costs are high but marginal costs are low and, vice versa, at low capacity. The next proposition shows that even if the output market is governed by perfect competition and in the complete absence of any accidents leading to blackouts, capacity choice will be distorted. Therefore, if such accidents are anticipated possibly to occur then, no matter how perfect the negligence rule will be, it should not be expected to cure the fundamental distortion underlying capacity choice.

Proposition 6 *Even if output markets were governed by perfect competition and in the absence of any accidents, capacity choice would be distorted downwards.*

A rigorous proof of this proposition is given in the appendix. The following intuition captures the essence of the arguments. Imagine that firm i is extending its capacity. As a consequence, firm i will enjoy lower marginal costs and, hence, will increase its supply to the market while its competitors will decrease their supply as their relative cost situation has worsened. Nonetheless, total output will be higher if one of the firms increases its capacity and, hence, prices will be lower. Customers are benefitting while competitors are suffering from an increase in firm i's capacity. Overall, as it turns out, the discrepancy between social and private benefits from increasing the capacity remains positive. Due to this positive external effect, capacity choice will be distorted downwards as claimed by the above proposition.

The remaining part of this section is devoted to extra capacity, which is held, not to reduce marginal costs, but rather as a backup against blackouts caused by accidents. I shall argue that this gives rise to a setting of multilateral obligations. In fact, by holding extra capacity at an excessive level, the competitors are deprived of potential windfall gains arising with a temporary blackout of the firm holding such capacity. It is shown that if the competitors could recover losses from excessive extra capacities, efficient incentives for capacity choice of the firm would be restored.

The simplest setting illustrating this claim is as follows. The injurer decides on precaution $r \in R = [0, \infty)$. There are just two firms, the potential victim v and its only competitor c. If an accident occurs the victim suffers from a private loss $\Delta P > 0$ whereas its competitor enjoys a windfall gain $\Delta Q > 0$. Following some of the earlier literature, for simplicity, the customers' loss is neglected such that the net social loss amounts to $\Delta S = \Delta P - \Delta Q$ and exceeds the victim's private loss by the windfall gain of its competitor.

If capacities are hold as a backup against accidents capacity choice affects the probability of a private loss arising from an accident. Let $\kappa \in [0, \infty)$ denote the victim's capacity choice. Then the victim's private loss ΔP and his competitor's windfall gain ΔQ arises with probability $\varepsilon(r, \kappa)$. The efficient precaution and capacity (first best) solves

$$(r^*, \kappa^*) \in \arg\min r + \kappa + \varepsilon(r, \kappa) \cdot \Delta S. \tag{4}$$

The following analysis concentrates on Kahan's version of the negligence rule. Under a unilateral rule with efficient standard of conduct and granting recovery of private losses to the victim, the injurer owes damages to the victim amounting to

$$d_i(r, \kappa) = \max\left[\varepsilon(r, \kappa) - \varepsilon(r^*, \kappa), 0\right] \cdot \Delta P$$

in expected terms. It follows from the proof of the next proposition that, under such a unilateral negligence rule, the best response of the injurer to the efficient capacity choice would be efficient precaution, well in line with the findings of section 3. Yet, the victim's best response to efficient precaution would consist of excessive capacity. Nonetheless, the blame for distorted capacity choice should not be put on the negligence rule as such but rather on its unilateral nature.

Strictly speaking, by holding excessive capacity, the victim inflicts harm on his competitor. To reflect this fact, suppose the victim would owe damages amounting to

$$d_v(r, \kappa) = \max\left[\varepsilon(r, \kappa^*) - \varepsilon(r, \kappa), 0\right] \cdot \Delta Q$$

in expected terms to his competitor accordingly. This rule takes into account that excessive capacities impose a negative externality on the competitor as the probability of his enjoying a windfall gain would be diminished. In any case, the above multilateral negligence scheme where injurer and primary victim both owe damages would restore full efficiency as the following proposition establishes.

Proposition 7 *Efficient precaution and efficient capacities are a Nash equilibrium under the above multilateral negligence scheme.*

Proof. Suppose, first, that the victim has chosen efficient capacity $\kappa = \kappa^*$. Then the injurer bears total expected costs

$$r + d_i(r, \kappa^*) \geq r + [\varepsilon(r, \kappa^*) - \varepsilon(r^*, \kappa^*), 0] \cdot \Delta S \geq r^* = r^* + d_i(r^*, \kappa^*)$$

that attain their minimum at efficient precaution. Hence, efficient precaution r^* is the injurer's best response to efficient capacity κ^* of the victim.

Suppose, second, that the injurer has chosen efficient precaution r^* and, hence, escapes liability. Then the victim bears total expected costs

$$\begin{aligned} & \kappa + \varepsilon(r^*, \kappa) \cdot \Delta P + d_v(r^*, \kappa) \\ \geq \ & \kappa + \varepsilon(r^*, \kappa) \cdot (\Delta P - \Delta Q) + \varepsilon(r^*, \kappa^*) \cdot \Delta Q \geq \\ \geq \ & \kappa^* + \varepsilon(r^*, \kappa^*) \cdot \Delta P = \kappa^* + \varepsilon(r^*, \kappa^*) \cdot \Delta P + d_v(r^*, \kappa^*) \end{aligned}$$

that attain their minimum at efficient capacity. Hence, efficient capacity κ^* is the victim's best response to efficient precaution r^* as well. This establishes the proposition. ■

The intuition behind the above proof is exactly the same as for Proposition 1. The present proposition shows that an extensive interpretation of the negligence rule would restore full efficiency with respect to both precaution and capacity choice.[5] However, to keep the floodgates closed, existing legal systems would probably hesitate to rely on such an extensive interpretation of the negligence rule.

[5] See Schweizer (2005c) for another setting where a multilateral version of the negligence rule restores full efficiency.

6 Concluding remarks

The present paper examines an injurer who directly affects a primary victim but also indirectly affects the victim's customers and competitors. In fear of floodgates, existing legal systems are reluctant to grant recovery of losses to secondary victims. Arguments in favor of such exclusionary practice hint at the other fact that beneficiaries enjoying windfall gains from accidents do neither have to pay compensation. While it is not explicitly claimed that benefits and losses balance exactly, the arguments implicitly allude to a discrepancy between the private loss to the primary victim and the social loss from accidents. The argument is used to justify the restrictive use of granting recovery to indirectly affected parties and, at times, even to the primary victim.

While a discrepancy between private and social loss distorts incentives for precaution under a regime of strict liability, this need not be the case under a negligence rule. In fact, if precaution generates a negative externality to third parties then granting recovery of private losses to primary victims in excess of social losses does not provide excessive incentives as liability would be waved at and beyond efficient precaution.

The present paper explicitly examines the market which may be affected by the tortious act of the injurer. While under both monopoly and perfect competition, the social loss exceeds the primary victim's private loss, the more likely case of imperfect competition in between turns out to enhance the performance of the above negligence rule.

The dividing line under actual legal systems such as the German one is the nature of loss. While damage to person or property can be recovered, pure economic losses cannot. In cases such as cable I and II, this practice is likely to deny recovery of losses to parties that are only indirectly affected by accidents. The analysis of this paper justifies such an exclusionary rule on economic grounds. Yet it fails to justify that even the primary victim may be denied recovery if the harm suffered from an accident classifies as pure economic loss. In fact, since cases such a cable I and II seem to be isomorphic from the economic perspective, an exclusionary rule with respect to the primary victim remains difficult to explain.

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8 Appendix

Proof of Proposition 4:

The profit per firm amounts to

$$G(m) = g(m) - \phi = f(X(m)) \cdot x(m) - k(x(m)) - \phi.$$

Social welfare amounts to

$$W(m) = w(m) - m \cdot \phi = \int_0^{X(m)} f(X)dX - m \cdot k(x(m)) - m \cdot \phi$$

and marginal welfare from adding a marginal firm amounts to

$$\frac{dW(m)}{dm} = G(m) + m \cdot \left[f(X(m)) - \frac{dk(x(m))}{dx} \right] \cdot \frac{dx(m)}{dm} < G(m)$$

and is strictly less than the profit per firm. Without entry barriers, firms enter until economic profits vanish, i.e. $G(m^0) = 0$. Therefore, at free entry, marginal social welfare $dW(m^0)/dm < G(m^0) = 0$ is negative. Due to imperfect competition, the market would sustain more firms than what would be second best.[6] Hence, under imperfect competition and free entry, social welfare with a blackout but net of the victim's fixed costs $W(m^0 - 1)$ exceeds social welfare $W(m^0)$ without accident. It follows that he discrepancy between private and social loss from the accident

$$\Delta P - \Delta S = W(m^0 - 1) - W(m^0) + G(m^0) = W(m^0 - 1) - W(m^0) > 0$$

would be positive indeed.

Since fixed costs must be borne, with and without accident, the social loss amounts to

$$\Delta S = w(m) - w(m - 1).$$

In the absence of fixed costs, any plausible market theory predicts that a higher number of firms would increase both competition and social welfare such that the social loss ΔS would remain positive quite generally. As a

[6] This result is due to Mankiw and Whinston (1986).

consequence, the case of imperfect competition does neither support Bishop's case of zero social loss. ■

Proof of Proposition 5:

Suppose, at the first stage, m firms have decided to enter the market. At the second stage, with probability α, the injurer starts operating in the neighborhood of one of the competing firms. For simplicity, a symmetric setting is imposed such that, from the ex ante view, each firm expects the injurer starting its operation next to its own site with probability α/m. At the third stage, the injurer, after having started his activity in the neighborhood of one of the competing firms, chooses precaution $r \in R = [0, \infty)$. The expected social welfare amounts to

$$Y(m, r) = w(m) - m \cdot \phi - \alpha \cdot [r + \varepsilon(r) \cdot (w(m) - w(m-1))]$$

where $w(m)$ denotes the sum of customers' and producers' surplus net of fixed costs as a function of the number m of active firms.

Under a *perfect negligence rule*, the injurer is given incentives to choose socially optimal precaution

$$r^* = r^*(m) \in \arg\min_{r \in R} r + \varepsilon(r) \cdot [w(m) - w(m-1)]$$

and, by doing so, he avoids liability for accidents. Socially optimal precaution depends on the number of active firms.

Anticipating such behavior, a firm's expected profit from the perspective of the first stage amounts to

$$\Gamma(m, r) = g(m) - \phi + \alpha \cdot \frac{m-1}{m} \cdot \varepsilon(r) \cdot [g(m-1) - g(m)] - \frac{\alpha}{m} \cdot \varepsilon(r) \cdot g(m)$$

where $g(m)$ denotes the profit per firm net of fixed costs and in the absence of an accident. Notice, from the first stage's view, a firm does not know, if at all, whether it will benefit from a competitor being hit by an accident or whether it will end up as the primary victim itself.

Since the injurer is expected, by choosing socially efficient precaution, to escape liability, the number of firms m^0 entering under the present setting follows from $\Gamma(m^0, r^*(m^0)) = 0$. Even if the market is governed by perfect competition, the level of entry turns out to be insufficient as I now want to show.

Under (short-run) perfect competition, the marginal surplus from adding a marginal firm is equal to the profit per firm, i.e. $dw(m)/dm = g(m)$. It follows that

$$\frac{\partial Y(m,r)}{\partial m} = g(m) - \phi - \alpha \cdot \varepsilon(r) \cdot [g(m) - g(m-1)]$$

must hold. Furthermore, under socially optimal precaution,

$$\frac{dY(m,r^*(m))}{dm} = \frac{\partial Y(m,r^*(m))}{\partial m}$$

must also hold. Since, finally,

$$\frac{\partial Y(m,r)}{\partial m} - \Gamma(m,r) = \frac{\alpha}{m} \cdot \varepsilon(r) \cdot g(m-1) > 0$$

it follows that, at free entry while anticipating accidents,

$$\frac{dY(m^0,r^*(m^0))}{dm} > 0$$

must hold such that entry would stop in the range indeed where social surplus is still increasing. Therefore, free entry while anticipating accidents would remain insufficient as was to be shown. ■

Proof of Proposition 6:

Capacity choice is modelled as a game in extensive form. At he first stage, m firms decide about their capacities. At the second stage, the market is governed by perfect competition such that prices equal marginal costs. Even if accidents can be ruled out entirely, capacity choice suffers from distortion as I now want to show.

Capacity affects the cost structure of firms. At high capacity, fixed costs are high but marginal costs are low. Formally, if firm j operates at capacity κ_j and produces x units of output, its costs amount to $K(x,\kappa_j) = k(x,\kappa_j) + \phi(\kappa_j)$. The cost function is assumed to exhibit the following properties:

$$\frac{\partial k(x,\kappa_j)}{\partial x} > 0, \quad \frac{\partial^2 k(x,\kappa_j)}{\partial x^2} > 0, \quad \frac{\partial^2 k(x,\kappa_j)}{\partial x \partial \kappa_j} < 0 \text{ and } \frac{d\phi(\kappa_j)}{d\kappa_j} > 0.$$

Moreover, let $\kappa = (\kappa_1, ..., \kappa_m)$ denote the capacity profile chosen at the first stage.

Let $x_j = x_j(\kappa)$ and $X = X(\kappa) = \sum_j x_j(\kappa)$ denote output of firm j and total output, respectively, as functions of the capacity profile. Due to perfect competition, prices are equal to marginal costs, i.e.

$$f(X) = \frac{\partial k(x_j,\kappa_j)}{\partial x_j}$$

must hold for $j = 1, ..., m$. Differentiating these equations with respect to firm i's capacity leads to

$$\frac{df(X)}{dX} \cdot \frac{\partial X}{\partial \kappa_i} = \frac{\partial^2 k(x_j, \kappa_j)}{\partial x_j^2} \cdot \frac{\partial x_j}{\partial \kappa_i} + \delta_{ij} \cdot \frac{\partial^2 k(x_j, \kappa_j)}{\partial x_j \partial \kappa_i}$$

where δ_{ij} denotes Kronecker's symbol ($\delta_{ii} = 1$ and $\delta_{ij} = 0$ for $i \neq j$). It follows that positive values $\mu > 0$ and $\mu_j > 0$ exist such that

$$\frac{\partial x_j}{\partial \kappa_i} = -\mu_j \cdot \frac{\partial X}{\partial \kappa_i} + \delta_{ij} \cdot \mu$$

and, hence,

$$\left(1 + \sum_{j=1}^{m} \mu_j\right) \cdot \frac{\partial X}{\partial \kappa_i} = \mu > 0$$

must hold. As a consequence, total output increases, i.e. $\partial X / \partial \kappa_i > 0$, the output of all competitors decreases, i.e. $\partial x_j / \partial \kappa_i < 0$ for $j \neq i$, whereas the output of firm i increases, i.e. $\partial x_i / \partial \kappa_i > 0$ if firm i has increased its capacity.

The profit of firm j amounts to

$$G_j = G_j(\kappa) = g_j - \phi(\kappa_j) = g_j(\kappa) - \phi(\kappa_j) = f(X) \cdot x_j - K(x_j, \kappa_j)$$

whereas social welfare net of fixed costs amounts to

$$w = w(\kappa) = \int_0^{X(\kappa)} f(X) dX - \sum_j k(x_j, \kappa_j).$$

Therefore, the marginal increase of social welfare from increasing the capacity of firm i amounts to

$$\begin{aligned} \frac{\partial w}{\partial \kappa_i} &= f(X(\kappa)) \cdot \frac{\partial X}{\partial \kappa_i} - \sum_j \frac{\partial k(x_j, \kappa_j)}{\partial x_j} \cdot \frac{\partial x_j}{\partial \kappa_i} - \frac{\partial k(x_i, \kappa_i)}{\partial \kappa_i} \\ &= \sum_j \left[f(X(\kappa)) - \frac{\partial k(x_j, \kappa_j)}{\partial x_j} \right] \cdot \frac{\partial x_j}{\partial \kappa_i} - \frac{\partial k(x_i, \kappa_i)}{\partial \kappa_i}. \end{aligned}$$

Similarly, the marginal increase of firm i's profit from increasing its capacity amounts to

$$\frac{\partial g_i}{\partial \kappa_i} = f(X(\kappa)) \cdot \frac{\partial x_i}{\partial \kappa_i} - \frac{\partial k(x_i, \kappa_i)}{\partial x_i} \cdot \frac{\partial x_i}{\partial \kappa_i} + \frac{df(X(\kappa))}{dX} \cdot \frac{\partial X}{\partial \kappa_i} - \frac{\partial k(x_i, \kappa_i)}{\partial \kappa_i}$$

and, hence, the discrepancy between social and private benefit from increasing firm i's capacity remains positive, more precisely

$$\frac{\partial w}{\partial \kappa_i} - \frac{\partial g_i}{\partial \kappa_i} = -\frac{df(X(\kappa))}{dX} \cdot \frac{\partial X}{\partial \kappa_i} > 0.$$

In other words, expanding capacity under fully competitive pressure gives rise to a positive externality such that non-cooperative behavior will lead to capacities that are distorted downwards even in the complete absence of accidents. ■

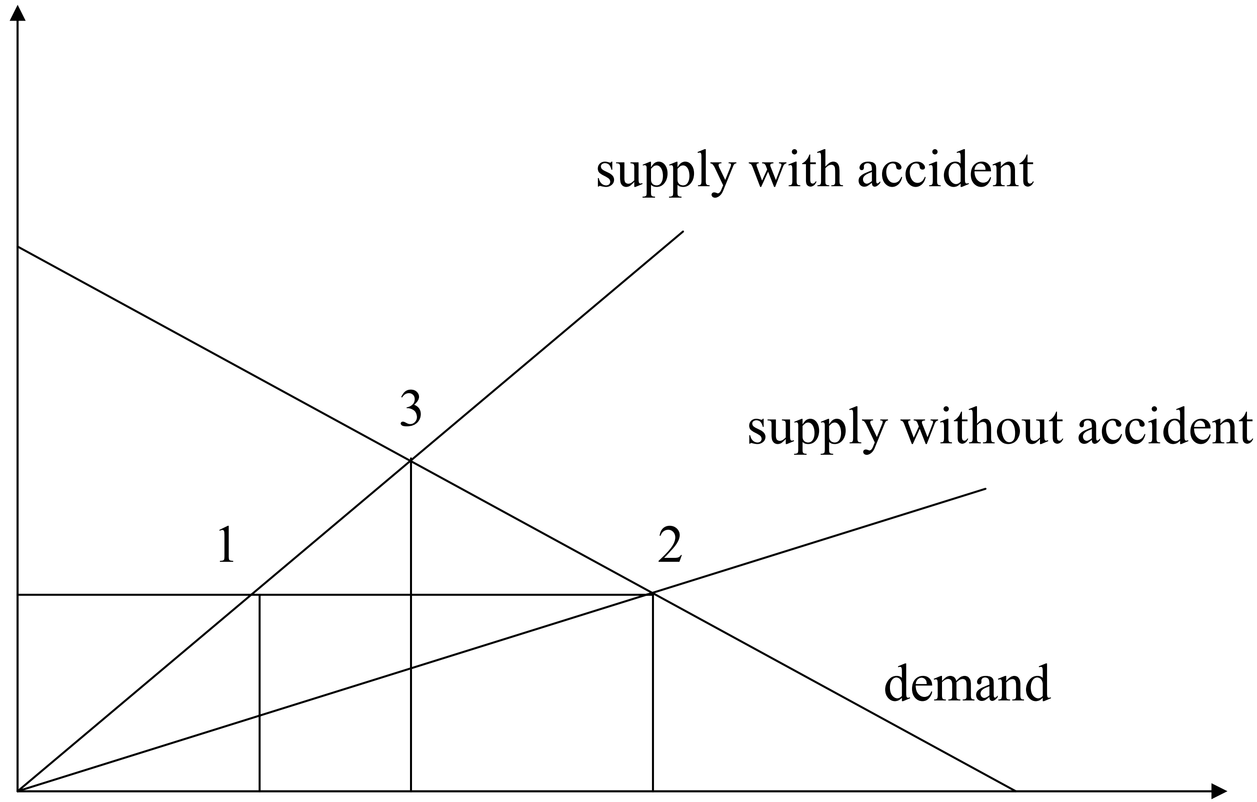

Figure 1: discrepancy between private and social loss