Medical Malpractice and Physician Liability Under a Negligence Rule

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Abstract

A model of medical malpractice claims is developed to examine the effects of physicians being liable for actual damage under a negligence rule. This law provides weak incentives for physicians to spend the optimal amount of time on expertise and quality of service, and to treat the optimal number of patients. The incentive effects of physicians being liable for actual damage can be strengthened by the central provision of publicly available information that assists patients to accurately determine whether their health outcome was more likely the result of medical malpractice or just a poor outcome from the correct diagnosis and treatment.

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1. Introduction

Numerous empirical studies have found surprisingly large rates of medical malpractice. The Californian Medical Association (1977) using Californian hospital data found 1 in 125 patients suffered a negligent medical injury while Weiler et al. (1993) using New York hospital data found 1 in 100 patients suffered a negligent medical injury. These large rates occurred despite physicians being liable for damage under a negligence rule. In addition, they are inconsistent with the theoretical prediction of Shavell (1980) that under a negligence rule all physicians undertake “due care” and as a result there is no medical malpractice, Danzon (1991). The main innovation in this paper is the modeling of a patient’s medical malpractice claim decision which when coupled with physician liability for actual damage provides weak incentives for physicians to spend the optimal amount of time on expertise and quality of service, and to treat the optimal number of patients. These weak incentives result in too much medical malpractice.

In this paper, as in Arlen and MacLeod (2005), medical malpractice is defined as an incorrect diagnosis or treatment that occurs with some positive probability, where this probability depends on the expertise of the physician and the quality of the service provided. In turn, physician expertise and quality of service depend on the amount of time a physician spends on maintaining and developing expertise as well as on the amount of time a physician spends with each patient. An implication of this approach is that the optimal probability of medical malpractice occurring is non-zero. It is just too costly in terms of physician dis-utility of time to eliminate medical malpractice completely.

However, unlike Arlen and MacLeod, who implicitly assume that whenever an incorrect decision is made and damage occurs that a claim for med-
ical malpractice is instigated and is successful in court, this paper formally models the claim decision. It is assumed that patients know the probability distributions over health outcomes conditional on correct and incorrect physician decisions. On observing their health outcomes, patients use Bayes Rule to determine the probability that an incorrect decision was made. If this probability is greater than one half, patients make a medical malpractice claim.

It is shown in Section 5.2 that there exists a payment, for which the physician is liable when a successful medical malpractice claim is made, that results in physicians choosing the optimal amount of time to spend on expertise and quality of service, and treating the optimal number of patients. This payment is similar to that found in Arlen and MacLeod (2005). It is the difference between the monetary values of the expected health outcomes under the correct and incorrect decisions scaled up by the reciprocal of a probability. In this paper, this probability is the probability that a patient makes a claim, given an incorrect decision is made, and comes from a model of medical malpractice claims, while in Arlen and MacLeod it is the exogenous probability that actual damage occurred.¹

The problem with this payment is that it is paid whenever medical malpractice is demonstrated regardless of the amount of actual damage done. Tort law has two basic objectives, the first is to deter misconduct or errors and the second is to compensate victims for any damage inflicted. The payment above achieves the first objective, but not the second. In practice, courts compensate patients for actual damage as this is what is observed. In Section 5.3 it is shown that where actual damage is compensated, expected

¹In Polinsky and Shavell (1998) this probability is the probability of being found liable by a court.
actual damage is only calculated over a subset of the support of the distribution of outcomes given an incorrect decision (because claims are only made if the outcome is bad enough, that is, below some critical outcome) and so is less than the difference between the monetary values of the expected outcomes under the correct and incorrect decisions. Therefore, compensating actual damage does not provide strong enough incentives for physicians to spend the optimal amount of time on expertise and quality of service and to treat the optimal number of patients. This inefficiency is exacerbated if it is costly to make a claim, for then the critical outcome below which a claim is made is even lower as is the probability that a claim will be made. As expected, under a negligence rule, there is a tension between the two objectives of tort law. Either optimal incentives can be provided or actual damage is compensated, not both.

The model developed in this paper yields results that are consistent with several empirical findings summarised in Danzon (1991). (1) a relatively large rate of medical malpractice, (2) a small number of claims, (3) medical malpractice occurs, but no claim is made, (4) a claim is made, but no medical malpractice occurs, and (5) only the most valuable claims are made.

Compensating actual damage under a negligence rule results in too much medical malpractice because the probability of a patient making a claim is small. In Section 6.1 education subsidies and regulations aimed at improving physician expertise and quality of service are discussed. The model of medical malpractice claims developed in this paper suggests another policy option, namely, information provision. In Section 6.2 it is argued that the probability of making a claim is small when the probability distributions over health outcomes conditional on correct and incorrect physician decisions have the same support and both have weight in the tails, that is, they
are quite similar. In practice, the main source of patient information about these distributions is the physician providing the service and this physician has an incentive to inform patients that poor outcomes can occur even if correct decisions are made. The government, by providing publicly available information about these distributions on a central web-site allows patients to get a more accurate picture of the probability of a poor outcome given a correct decision. This increases the probability of patients making claims. As a result, physicians spend more time in total on developing expertise and with patients and this reduces the amount of medical malpractice.

2. Model Set-Up

A physician can make the correct diagnosis or implement the correct treatment, \( C \), with probability \( \Pi \) and make an incorrect diagnosis or implement an incorrect treatment, \( M \), with probability \( (1 - \Pi) \). \( M \) is interpreted as medical malpractice. If the correct decision is made, the benefit, \( b \), the patient receives from treatment is distributed with density \( f(b|C) \) and cumulative distribution \( F(b|C) \) over \( [\alpha_c, \beta_c] \). If an incorrect decision is made, then patient benefit is distributed according to \( f(b|M) \) and \( F(b|M) \) over \( [\alpha_m, \beta_m] \). It is assumed that \( \alpha_m \leq \alpha_c, \beta_m \leq \beta_c \), and that \( F(b|C) \) first-order stochastically dominates \( F(b|M) \). As a result, the expected benefit of the correct treatment, \( E_C \), is greater than the expected benefit of an incorrect treatment, \( E_M \), that is \( E_C > E_M \).

The probability of a physician making the correct decision depends on the expertise of the physician, \( x \), and the quality of the actual diagnosis and treatment, \( q \). In turn, physician expertise depends on the amount of time the physician spends on training and education, \( t_x \), and quality depends on the amount of time the physician spends with the patient, \( t_q \). There-
fore, $\Pi(x(t_x), q(t_q))$ or $\Pi(t_x, t_q)$. It is assumed that the latter function is a non-decreasing strictly quasi-concave function. The more time a physician spends on education and with the patient the less likely is a physician to make an incorrect decision.

2.1. Patients

All patients are assumed identical and so have the same density and distribution functions over the benefits from treatment. The expected benefit a patient receives from treatment by a physician is given by

$$B(t_x, t_q) = \Pi(t_x, t_q) \cdot E_C + (1 - \Pi(t_x, t_q)) \cdot E_M. \quad (1)$$

It is assumed that patients are fully insured, either privately or publicly, and so do not directly pay for physician services. Physicians are paid by the private or public insurer. This insurance is not explicitly modeled.

2.2. Physicians

The number of physicians is fixed at $N$. All physicians are assumed to be risk neutral and only value income. The representative physician takes the price of physician services, $p$, as given and chooses the number of patients to treat, $n$, as well as $t_x$ and $t_q$ to maximise net payoff

$$U_P = p \cdot n - D(T), \quad (2)$$

where $T$ is the total time expended in treating $n$ patients by a physician with expertise $x$ and quality of service, $q$. That is, $T = t_x + t_q \cdot n$. $D(T)$ is the monetary value of the dis-utility of this time and it is assumed to be an increasing strictly convex function. To participate, the physician needs payoff, $\overline{U}_P = 0$, the outside option.
2.3. The Policy-Maker and the Social Optimum

The policy-maker is risk neutral and maximises the expected net benefit of \( n \) patients being treated by a given physician, subject to the constraint that the physician participates. That is

\[
\max B(t_x, t_q) \cdot n - p \cdot n \quad \text{s.t.} \quad U_P \geq 0.
\]  

(3)

3. Social Optimum

As a point of comparison it is useful to find the socially optimal values of \( t_x, t_q, \) and \( n \). This is done by assuming the policy-maker can choose \( t_x, t_q, \) and \( n \). The constraint in (3) binds and so the social optimum is found by solving

\[
\max_{t_x, t_q, n} W \equiv B(t_x, t_q) \cdot n - D(T).
\]  

(4)

It is useful to solve this problem in two stages. First, for a given \( T \) and \( n \), \( t_x \) and \( t_q \) are chosen to maximise the probability of a correct decision, and second, \( T \) and \( n \) are chosen to maximise social welfare, \( W \). The first stage problem is

\[
\max_{t_x, t_q} \Pi(t_x, t_q) \quad \text{s.t.} \quad T = t_x + t_q \cdot n.
\]  

(5)

The first-order conditions of the Lagrangian of this problem can be rearranged to yield

\[
\lambda = \frac{\partial \Pi}{\partial t_x} = \frac{\partial \Pi}{\partial t_q} / n,
\]  

(6)

where \( \lambda \) is the Lagrange multiplier. Therefore, \( T \) is allocated between \( t_x \) and \( t_q \) to satisfy

\[
\frac{\partial \Pi}{\partial t_q} \cdot \frac{\partial \Pi}{\partial t_x} = n.
\]  

(7)

The second order conditions for a unique maximum are satisfied because of the strict quasi-concavity of the objective function and the linearity of
the constraint. Let the solution to this problem be given by \( t_x(T, n) \) and \( t_q(T, n) \). Substituting these into the objective function yields the maximised probability of a correct decision, \( \Pi(T, n) \). By the envelope theorem

\[
\frac{\partial \Pi}{\partial T} = \lambda > 0 \quad \text{and} \quad \frac{\partial \Pi}{\partial n} = -\lambda \cdot t_q < 0 \tag{8}
\]

The second stage problem is

\[
\max_{T, n} W \equiv \left( \Pi(T, n)E_C + (1 - \Pi(T, n))E_M \right) \cdot n - D(T), \tag{9}
\]

where \( W \) is assumed to be quasi-concave in \( T \) and \( n \). Assuming a unique interior solution, the first-order conditions for a maximum are

\[
\frac{\partial W}{\partial T} = \frac{\partial \Pi}{\partial T} \cdot (E_C - E_M) \cdot n - \frac{dD}{dT} = 0 \tag{10}
\]

and

\[
\frac{\partial W}{\partial n} = \Pi(T, n)E_C + (1 - \Pi(T, n))E_M + \frac{\partial \Pi}{\partial n} \cdot (E_C - E_M) \cdot n = 0. \tag{11}
\]

The second-order conditions for a maximum are assumed to be satisfied.

Using (8), these first-order conditions can be rearranged and combined to yield

\[
\frac{\partial \Pi}{\partial T} \cdot (E_C - E_M) \cdot n = \frac{\Pi(T, n)E_C + (1 - \Pi(T, n))E_M}{t_q} = \frac{dD}{dT} \tag{12}
\]

Let the solution to the first-order conditions be given by \( T^* \) and \( n^* \). Given this solution \( t_x^* \) and \( t_q^* \) are obtained from (7). At the solution, the marginal social benefit of a physician devoting more time in total to expertise, quality of service, or on the number of patients treated equals the physician’s marginal cost of this time. It should be noted that at the social optimum there is a positive probability that medical malpractice occurs, \( 1 - \)

\footnote{It is assumed that the total number of patients seeking treatment is greater than \( n^* \cdot N \). Treating all potential patients this period is too costly in terms of physician dis-utility of time.}
\[ \Pi(t_x^*, t_q^*) \]. That is, even if the physician spends the socially optimal amount of time on expertise, \( t_x^* \), and spends the socially optimal amount of time with each patient, \( t_q^* \), the physician can make an incorrect decision.

4. Decentralised Solution

The decentralised solution involves the physician choosing \( t_x, t_q \) and \( n \) to maximise \( U_P \), given \( p \). Since \( D(T) \) is increasing in both \( t_x \) and \( t_q \), this is achieved by setting each to its minimum value, \( t_x^0 \) and \( t_q^0 \), respectively. These minimum values are determined by the minimum standards of practice required by licensing and registration boards. Given \( t_x^0 \) and \( t_q^0 \), the physician chooses \( n \) to satisfy

\[
\frac{\partial U_P}{\partial n} = p - \frac{dD}{dT} \cdot t_q^0 = 0. \tag{13}
\]

Let the solution be given by \( n^0(p) \).

Given \( t_x^0, t_q^0 \) and \( n^0(p) \), the policy-maker then chooses \( p \) to solve (3) above. The social optimum is assumed to involve an interior solution, where the benefits patients derive from physician expertise and quality of service are explicitly considered. Therefore, \( t_x^0 < t_x^* \) and \( t_q^0 < t_q^* \), and the probability of medical malpractice in the decentralised solution is greater than in the social optimum, \( (1 - \Pi(t_x^0, t_q^0)) > (1 - \Pi(t_x^*, t_q^*)) \).

If \( t_x \) and \( t_q \) as well as \( n \) are observable by the policy maker, then there are per-unit subsidies, \( s_x \) and \( s_q \), for time spent developing and maintaining expertise as well as for time spent with patients and a price that reproduce the social optimum, \( t_x^*, t_q^* \), and \( n^* \). These are obtained by examining

\[ ^3 \text{This is the most interesting case and the most relevant given the role of liability law is to increase the probability of correct decisions.} \]
conditions (6), (8), (10) and (11) and are given by

\[ s_x = \frac{\partial \Pi}{\partial t_x} \cdot (E_C - E_M) \cdot n^* \]

\[ s_q = \frac{\partial \Pi}{\partial t_q} \cdot (E_C - E_M) \cdot n^* \]

\[ p = B(t^*_x, t^*_q). \quad (14) \]

all evaluated at \( t^*_x, t^*_q, \) and \( n^* \). Note that this solution involves the physician extracting all the social surplus through price. This is needed to obtain the efficient activity level, \( n^* \), and is an artefact of the expected benefit of physician services being equivalent for all patients. The problem with this solution is that the policy-maker can not observe \( t_x \) and \( t_q \). What the policy-maker can observe is the outcome or patient benefit from the services (or at least this can be determined by a court of law). So instead of using subsidies to reproduce the social optimum, other authors, Shavell (1980) and Arlen and MacLeod (2005), have demonstrated that making physicians liable for medical malpractice damage can achieve the same result.

5. Physician Liability for Medical Malpractice

A tort occurs when one person’s actions result in injury or harm to another person and this injury can be redressed through the law by awarding damages. Medical malpractice is a negligent tort. For a medical malpractice claim to be successful, the patient must prove that an injury occurred, that the physician caused the injury by action or in-action, and that the action or in-action represents a failure by the physician to exercise due care which is defined as the standard care of a reasonable medical practitioner, Danzon (1991), Sloan (2008), and Weiler et al (1993). In a medical context, the two main goals of tort law are (i) to deter medical malpractice and (ii) to compensate patients for their injuries, Sloan (2008) and Weiler et al (1993).
5.1. A Model of Malpractice Claims under a Negligence Rule

It is assumed that patients can not observe whether a correct or incorrect diagnosis or treatment occurred. What they do observe is the outcome of treatment, $b$. How can they infer from $b$ whether or not they have a claim for medical malpractice against a physician? Even if $b < E_M$, there can be some positive probability that the physician treated the patient correctly.

Assume patients have knowledge of the distribution of benefits under correct treatment. This was communicated to them by the physician before treatment began. Suppose the patient received a “poor” outcome, worse than expected, $b < E_C$. In this case, it is assumed the patient seeks an opinion from a medical malpractice lawyer concerning the likelihood of them being subject to medical malpractice. As a result of experience, it is assumed the lawyer has knowledge of both $F(b|C)$ and $F(b|M)$ as well as the historic proportions of correct and incorrect treatments, $P_C$ and $P_M = 1 - P_C$. The patient and the lawyer are in a position to use Bayes Rule to determine the probability of medical malpractice given the outcome.

In fact, the probability of medical malpractice given outcome $b$ is given by

$$P(M|b) = \frac{f(b|M)P_M}{f(b|M)P_M + f(b|C)P_C}. \tag{15}$$

It is assumed that the probability distributions are such that there is a $b_c$, where for all $b < b_c$, $P(M|b_c) > .5$ and for all $b > b_c$, $P(M|b_c) < .5$. For interior solutions, $b_c$ satisfies

$$\frac{f(b_c|M)P_M}{f(b_c|M)P_M + f(b_c|C)P_C} = .5, \quad \text{or} \quad \frac{f(b_c|M)}{f(b_c|C)} = \frac{P_C}{P_M}. \tag{16}$$

When $b < b_c$, it is assumed the patient makes a claim for medical malpractice because the balance of probabilities is used to determine guilt in civil cases.
5.2. The Physician’s Problem under Medical Malpractice Liability

Assume that the level of medical malpractice liability, \( L \), is set by the policymaker and is paid by the physician when the physician is found guilty of medical malpractice. It is also assumed that the courts can decide on the evidence presented to them whether the physician made an incorrect decision. The expected liability payout of the physician per-patient is then

\[
EL = (1 - \Pi(T, n)) \cdot F(b_c|M) \cdot L.
\]

This is the probability of medical malpractice occurring multiplied by the probability that the actual outcome is less than \( b_c \) multiplied by \( L \).

The physician’s problem is given by

\[
\max_{t_x, t_q, n} U_P \equiv p \cdot n - D(T) - EL \cdot n.
\]  

Once again it is useful to solve this problem in two stages. In the first stage, for a given \( T \) and \( n \) the physician allocates time between \( t_x \) and \( t_q \) to maximise the probability of a correct decision. This is the same problem the social planner faced in Section 3 above and has the same solution, that is, allocate time between \( t_x \) and \( t_q \) to satisfy (7).

In the second stage, the physician chooses \( T \) and \( n \) to maximise expected net payout. The physician’s problem is

\[
\max_{T, n} U_P \equiv p \cdot n - D(T) - (1 - \Pi(T, n)) \cdot F(b_c|M) \cdot L \cdot n
\]  

Assuming a unique interior solution, the first-order conditions for a maximum are

\[
\frac{\partial U_P}{\partial T} = \frac{\partial \Pi}{\partial T} \cdot L \cdot F(b_c|M) \cdot n - \frac{dD}{dT} = 0,
\]

and

\[
\frac{\partial U_P}{\partial n} = p + \frac{\partial \Pi}{\partial n} \cdot F(b_c|M) \cdot L \cdot n - (1 - \Pi(T, n)) \cdot F(b_c|M) \cdot L = 0.
\]
The second-order conditions for a maximum are assumed to be satisfied.

Comparing these first order condition to those of the social optimum, (10) and (11), reveals that if the policy maker chooses $L$ and $p$ so that

$$L = \frac{E_C - E_M}{F(b_c|M)} \quad \text{and} \quad p = B(T^*, n^*) + (E_C - E_M) \cdot (1 - \Pi(T^*, n^*)) = E_C,$$  

(21)

then the physician chooses the socially optimal values, $T^*$ and $n^*$ with $t_x^*$ and $t_q^*$ obtained from (7).

For the choice of $L$, this result is similar to results found in Polinsky and Shavell (1998) and Arlen and Macleod (2005), where damage and expected damage, respectively, are scaled-up by the reciprocal of the probability that the physician be found liable for damage when medical malpractice has occurred.\textsuperscript{4} It should be noted that the physician now gets all the social surplus plus an additional amount to provide the correct incentives for the physician to choose $n^*$.\textsuperscript{5} Discussion about the socially optimal activity level, $n^*$, is missing from the analysis of Arlen and Macleod (2005) as there is only one patient. In Shavell (1980), competition and free entry (zero profit) ensure the socially optimal activity level occurs under negligent liability. In Shavell, the set-up is quite different to that of this paper as there is a level of due care that if achieved means the injurer is non-negligent. Also, the injured party has a demand curve not unit demands. Nevertheless, if competition rather than a policy-maker determined price in this paper, similar arguments to those of Shavell establish that competition leads to the same price as that chosen by the policy-maker.

\textsuperscript{4} Polinsky and Shavell (1998) refer to the difference between expected damages and these scaled-up damages as punitive damages.

\textsuperscript{5} If instead of the physician only valuing income the physician also valued patient utility, it turns out that the optimal $L$ and $p$ are the same as in (21) above. Therefore, having more than two types of physicians does not alter the analysis unless the total number of patients is less than the total number of patients the physicians would like to service.
As discussed above, in a medical context, the two main goals of tort law are (i) to deter medical malpractice and (ii) to compensate patients for their injuries. Clearly, the $L$ obtained in (21) above yields the social optimum in terms of physician expertise, quality of service and the number of patients treated and so is an optimal deterrent to medical malpractice. However, it fails to compensate patients for damage they actually suffer. A patient who has successfully claimed medical malpractice is paid $L$, given in (21). This is independent of the amount of damage actually incurred. This is true of Arlen and MacCleod (2005) and Shavell (1980) as well.

In practice, physician’s are liable for the actual damage inflicted on patients. The object of compensatory damages is to make the patient as well off as if the correct decision was made, Sloan (2008 p.108), or what amounts to the same thing, to provide relief for the damages incurred, Cornell University Law School (2008). Polinsky and Shavell (1998) demonstrate that paying actual damage (or in some cases punitive damage based on actual damage) is socially optimal. However, in that paper damage is a certain amount. In the framework of this paper, actual damage is not a certain amount. Therefore, the effects of physicians being liable for actual damage need to be discussed.

5.3. The Physician’s Problem Under Liability for Actual Damage

To begin, actual damage needs to be defined. This is complicated by the fact that the patient outcome might be poor even if the physician made a correct decision. In this paper, actual damage is defined as the difference between the benefit a patient expects to receive, given the physician made the correct decision, and the actually benefit the patient receives, given the
physician made an incorrect decision. That is, the physician is liable for actual damage, $AD = E_C - b$, when the patient makes a successful medical malpractice claim.

From the point of view of the physician, expected actual damage is

$$EAD = (1 - \Pi(T, n)) \cdot \int_{\alpha_m}^{b_c} (E_C - b) f(b|M) db.$$  \hfill (22)

This is the expectations of $E_C - b$ over all $b < b_c$, given medical malpractice has occurred, multiplied by the probability of medical malpractice occurring. Remember, a claim is made if $b < b_c$ and it is successful if $M$ occurred. This happens with probability $(1 - \Pi(T, n))$.

The physician’s problem is given by

$$\max_{T, n} U_P \equiv p \cdot n - D(T) - EAD \cdot n.$$  \hfill (23)

Assuming a unique interior solution, the first-order conditions for a maximum are

$$\frac{\partial U_P}{\partial T} = \frac{\partial I}{\partial T} \cdot n \cdot \int_{\alpha_m}^{b_c} (E_C - b) f(b|M) db - \frac{dD}{dT} = 0,$$  \hfill (24)

and

$$\frac{\partial U_P}{\partial n} = p - EAD + \frac{\partial I}{\partial n} \cdot n \cdot \int_{\alpha_m}^{b_c} (E_C - b) f(b|M) db = 0.$$  \hfill (25)

The second-order conditions for a maximum are assumed to be satisfied.

Using (8), the first-order conditions can be rearranged and combined to yield

$$\frac{\partial I}{\partial T} \int_{\alpha_m}^{b_c} (E_C - b) f(b|M) db \cdot n = \frac{p - EAD}{t_q} = \frac{dD}{dT}$$  \hfill (26)

Let the solution to the first-order conditions be given by $T(p)$ and $n(p)$. At the solution, the physician’s marginal benefit of devoting more time in total to expertise, quality of service, or on the number of patients treated equals the physician’s marginal cost of this time.
Expected actual damage is an expected transfer from physicians to patients. If it is assumed that the policy-maker can use a lump-sum transfer to ensure that the physician’s participation constraint binds, then the policy-maker’s problem can be written as

\[
\max_p W \equiv B(T(p), n(p)) \cdot n(p) - D(T(p)).
\]  

(27)

That is, the policy-maker maximises expected total surplus. Assuming a unique interior solution, this problem has first-order condition

\[
\frac{dW}{dp} = \left( \frac{\partial \Pi}{\partial T} \cdot (E_C - E_M) \cdot n(p) - \frac{dD}{dT} \right) \cdot \frac{dT}{dp} + (B(T(p), n(p)) + \frac{\partial \Pi}{\partial n} \cdot (E_C - E_M) \cdot n(p)) \cdot \frac{dn}{dp} = 0.
\]  

(28)

It is assumed that the second-order condition for a maximum is satisfied.

This first-order condition is solved for \( \hat{p} \) and in turn \( \hat{T} = T(\hat{p}) \), \( \hat{n} = n(\hat{p}) \), \( \hat{t}_x = t_x(\hat{p}) \), and \( \hat{t}_q = t_q(\hat{p}) \).

Before a comparison of the solution under liability for actual damage is made with the social optimum a number of additional results are derived.

**Lemma 1:** \( \frac{dn}{dp} > 0 \) and if \( \frac{\partial^2 \Pi}{\partial n \partial T} \cdot n + \frac{\partial \Pi}{\partial T} > 0 \), then \( \frac{dT}{dp} > 0 \).

The proof of Lemma 1 is in the Appendix. The intuition for the increase in \( n \) is clear. An increase in price directly increases the marginal benefit of treating more patients and so more patients are treated. This increase in the number of patients treated, directly increases the marginal benefit of \( T \), but indirectly decreases the marginal benefit of \( T \) as time is reallocated away from quality of service and towards expertise. By assumption, the first affect dominates causing the increase in \( p \) to increase \( T \). Lemma 1 ensures that the locus \( g(n, T) = (n(p), T(p)) \) is positively sloped. This locus is the set of points available to the policy-maker through its choice of \( p \).

Let the gradient vector of welfare, (9), be given by \( \nabla W = (\frac{\partial W}{\partial n}, \frac{\partial W}{\partial T}) \) and let the gradient vector of \( g(n(p), T(p)) \) be given by \( \nabla g = (\frac{\partial n}{\partial p}, \frac{\partial T}{\partial p}) \), then (28)
can be written as

\[ \nabla W \cdot \nabla g = 0 \quad (29) \]

That is, at the solution to problem (27), the slopes of the contours of \( W(n, T) \) and \( g(n, T) \) are equal.

**Assumption 1:** The distributions of \( f(b|C) \) and \( f(b|M) \) are such that \( \beta_m < E_C \). That is, the best outcome possible given the incorrect decision is made is worse than the expected outcome given the correct decision is made.

Given \( b_c \leq \beta_m \), this assumption ensures that all the \( E_C - b \) terms in \( \int_{\alpha_m}^{b_c} (E_C-b) f(b|M) db \) are positive. If \( b_c = \beta_m \), then \( \int_{\alpha_m}^{b_c} (E_C-b) f(b|M) db = E_C - E_M \). If \( b_c < \beta_m \), then \( \int_{\alpha_m}^{b_c} (E_C-b) f(b|M) db < E_C - E_M \) as less positive terms are involved in the integral. This leads to Lemma 2.

**Lemma 2:** Given Assumption 1, \( \int_{\alpha_m}^{b_c} (E_C-b) f(b|M) db < E_C - E_M \).

A more general discussion of the relationship between \( \int_{\alpha_m}^{b_c} (E_C-b) f(b|M) db \) and \( E_C - E_M \) can be found in the Appendix, where the distributions \( f(b|C) \) and \( f(b|M) \) are assumed to have the same support. A condition is given for \( \int_{\alpha_m}^{b_c} (E_C-b) f(b|M) db < E_C - E_M \).

**Lemma 3:** Assume price is fixed at \( p^* \). If the direct effects of \( \int_{\alpha_m}^{b_c} (E_C-b) f(b|M) db \) being less than \( E_C - E_M \) on \( n \) and \( T \) are greater than the indirect effects, then \( T(p^*) < T^* \) and \( n(p^*) > n^* \).

The proof of Lemma 3 is in the Appendix. The intuition is clear. The expected physician payout, given an incorrect decision, is lower under liability for actual damage than expected damage, \( \int_{\alpha_m}^{b_c} (E_C-b) f(b|M) db < E_C - E_M \). This reduces the incentive the physician has to spend time on expertise and quality of service and also makes treating additional patients less costly. Therefore, \( T(p^*) < T^* \) and \( n(p^*) > n^* \).
Consider Figure 1. The quasi-concavity of welfare implies its upper level sets are convex. The constraint, \( g(n(p), T(p)) \), is positively sloped by Lemma 1. By Lemma 3, if \( p = p^* \), then the solution to the physicians problem is represented by a point like \( a \). By Lemma 2, \( \int_{\alpha m}^{b e} (E_C - b) f(b|M) db < E_C - E_M \), so at \( \hat{p} \) by (24), \( \frac{\partial W}{\partial T} > 0 \). As a result, \( \frac{\partial W}{\partial n} < 0 \) from (29). Therefore, the solution of (28) is characterized by a point like \( b \).

**Figure 1**

Solution to Policy-Maker’s Problem

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**Proposition 1:** If \( \int_{\alpha m}^{b e} (E_C - b) f(b|M) db < E_C - E_M \) and the conditions of Lemmas 1 and 3 are satisfied, then the policy maker can not achieve the social optimum through its choice of price.

**Proof:** By Lemma 1, \( g(\cdot) \) is positively sloped. By Lemma 3 \((n(p^*), T(p^*))\) is to the south-east of \((n^*, T^*)\). Therefore, \((n^*, T^*)\) is not attainable.

This proposition is expected because under liability for actual damage
the policy-maker has only one instrument, $p$, but two variables to control, $n$ and $T$.

As Figure 1 is drawn, $\hat{n} > n^*$, $\hat{T} < T^*$ and $\hat{p} < p^*$. It is optimal for the policy-maker to reduce price below $p^*$ because at $p^*$ the slope of $g(\cdot)$ is less than the slope of the contour of $W$. If at $p^*$ the slope of $g(\cdot)$ was greater than the slope of the contour of $W$, then $\hat{p} > p^*$ and $\hat{n} > n(p^*)$ and $\hat{T} > T(p^*)$. As long as at $T^*$ ($n > n^*$) the slope of $g(\cdot)$ is less than the slope of the contour of $W$, then $\hat{T} < T^*$. This discussion is summarized in the following Proposition.

**Proposition 2:** If $\int_{\alpha_m}^{b_c} (E_C - b)f(b|M)db < E_C - E_M$, the conditions of Lemmas 1 and 3 are satisfied, and at $T^*$ ($n > n^*$) $g(\cdot)$ is relatively flat compared to the slope of the contours of $W$, then $\hat{T} < T^*$. Physicians spend too little time in total on expertise and quality of service relative to the social optimum. The relationship between $\hat{n}$ and $n^*$ is ambiguous.

The intuition is clear. The expected payout of the physician under liability for actual damage is less than $E_C - E_M$. Therefore, at $p^*$, under liability for actual damage, the physician has less incentive to spend time on expertise and quality of service. The policy-maker can increase the physician’s incentive to spend time on expertise and quality of service by increasing price above $p^*$, but this is costly in terms of further increasing the number of patients treated. If the number of patients treated is very responsive to changes in price, but $T$ is not, then price will not rise much above $p^*$ and may even fall. This results in $\hat{T}$ being less than $T^*$, while the effect on $n$ depends on whether $\hat{p} > or < p^*$ and by how much.

Assume that $\hat{n} > n^*$, from (7) the allocation of a given $T$ between $t_q$ and $t_x$ shifts towards $t_x$ and away from $t_q$. Now $\hat{T} < T^*$ so $\hat{t}_q < t^*_q$, but the relationship between $\hat{t}_x$ and $t^*_x$ is ambiguous. The greater number of
patients being treated means it is expensive to maintain quality of service and so time is reallocated towards expertise which is spread over all patients. If ˆ\( n < n^* \), then ˆ\( t_x < t_x^* \), but the relationship between ˆ\( t_q \) and ˆ\( t_q^* \) is ambiguous.

Proposition 1 was derived assuming an interior solution to the physician’s problem. If the distributions \( f(b|C) \) and \( f(b|M) \) are not too different, then, as discussed in Section 6 below, the probability a patient makes a medical malpractice claim is zero. In this case, the physician chooses the minimum level of expertise and quality of service, namely, \( t_x^0 < t_x^* \) and \( t_q^0 < t_q^* \). This is summarised in Proposition 3.

**Proposition 3:** If the distributions \( f(b|C) \) and \( f(b|M) \) are not too different, then ˆ\( t_x = t_x^0 \) and ˆ\( t_q = t_q^0 \), and physicians put too little time into expertise and quality of service relative to the social optimum.

As physicians spend too little time in total on expertise and quality of service relative to the social optimum, physicians make too many incorrect decisions relative to the social optimum. The optimal liability in (21) provided the right incentives for total time spent on expertise and quality of service and for the number of patients treated, but did not compensate actual damage. Perhaps it is not surprising that compensating actual damage does not provide the right incentives.

5.3.1. Costly Claims

To date, it has been implicitly assumed that it is costless to file a claim for medical malpractice. It is now assumed that it cost \( k \) to file a claim and that this cost is independent of actual damage. It is also assumed that \( b_c < E_C \). As before, a claim is filed only if the probability of winning the claim is greater than .5, that is, \( b < b_c \). In addition, a claim is filed only if the damage is greater than the cost of the claim, that is, \( E_C - b > k \), or
$b < E_C - k$. So a claim is filed only if $b < \min\{b_c, E_C - k\}$. If $k$ is large, so that $E_C - k$ is small, a claim is filed only if the outcome, $b$, is very poor.

From the point of view of the physician expected actual damage is

$$EAD_k = (1 - \Pi(t_x, t_q)) \cdot \int_{b_m}^{\min\{b_c, E_C - k\}} (E_C - b)f(b|M)db. \quad (30)$$

By definition, $EAD_k \leq EAD$. Therefore, costly claims weaken the incentive physicians have to devote time to expertise and quality of service even further. As a result, the probability of medical malpractice increases in the presence of costly claims.\(^6\)

### 5.4. The Model and the Data

The model developed above demonstrates that there is an optimal amount of time in total that physicians should spend on expertise and quality of service. Even if this optimal amount of time is spent, physicians can make an incorrect decision. With physicians liable for actual damage under a negligence rule Proposition 2 establishes that $\hat{T} < T^\ast$. As a result, the model predicts too many negligent medical injuries will occur relative to the social optimum. Weiler et.al. (1993) examined medical injuries in New York hospitals in 1984 and found that 1% of all patients suffered a negligent medical injury (p. 143). An earlier study, (Californian Medical Association 1977), used Californian hospital data from 1974 and found that 1 in 125 patients suffered a negligent medical injury. A later study, Wilson et.al. (1995), used Australian hospital data and found an even higher rate of medical malpractice with 1 in 12 hospital patients suffering a preventable

\(^6\)If instead of the patient paying a fixed cost of $k$ to make a claim, the patient only receives a proportion $K$ of actual damage and the lawyer takes the rest, then the patient makes a claim whenever $b < b_c$, the size of $K$ is irrelevant.
adverse event. Although, there is no way of determining the socially optimal rate of medical malpractice from these empirical studies, it is clear that substantial medical malpractice occurred. This is in sharp contrasts with the prediction of Shavell (1980), where under a negligence rule all physicians undertake ‘due care’ and there is no medical malpractice or medical malpractice claims. However, it is consistent with the prediction of this paper that medical malpractice occurs even at the social optimum and in practice at a rate in excess of the social optimum.

Another prediction of the model is that patients only make a claim for medical malpractice after observing a poor outcome, \( b < b_c \). Therefore, an incorrect decision can be made and yet no claim is made because the outcome is not poor enough. Weiler et.al. (1993) found that only 1 claim for negligence was lodged for every 7 negligent injuries, (p. 69), while the Californian study, Californian Medical Association (1977), found that only one claim for negligence was lodged for every 10 negligent injuries. On the other hand, the model also predicts that a correct decision can be made and yet a claim is made because the outcome is poor. Weiler et al. found that most claims were ill-founded and that only 1 out of 2 tort claims were actually paid, (p. 139). Weiler et.al. also found that when tort claims were matched against independent appraisal of injury only 1 in 6 claims were found to involve medical negligence.\(^8\)

If there is a fixed cost of making a claim, the model predicts patients

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7 This Australian study used a more lax definition of an adverse event than the two US studies referred to above.

8 Presumably the courts had access to more information than the appraisers, so that 1 in 6 became 1 in 2.
only make a claim for medical malpractice if \( b < \min\{b_c, E_C - k\} \). For large 
\( k \), this means claims will only be filed when damage, \( E_C - b \), is large. Once again this is consistent with the finding of Weiler et al, (p. 70-71) who found that nearly 80% of the patients who suffered a negligent injury, but did not lodge a tort claim, were either fully recovered from the injury within 6 months or were over 70 years of age and so their lost earnings were small. It is also consistent with Danzon (1985) who found that the ratio of claims to injuries tended to be lower for minor relative to major injuries.

6. Implications

Under liability for actual damage it was seen above that physicians did not have strong enough incentives to spend the optimal amount of time in total on expertise and quality of service. This was because \( \int_{b_c}^{b_c} (E_C - b) f(b|M) db < E_C - E_M \). It is useful to rearrange this inequality yielding

\[
\int_{a_m}^{b_c} (E_C - b) f(b|M) db = F(b_c|M) \cdot (E_C - E[b \mid b < b_c, M]) < E_C - E_M,
\]

where \( E[b \mid b < b_c, M] \) is the expected value of \( b \), given \( b < b_c \) and an incorrect decision is made. Although \( E_C - E[b \mid b < b_c, M] > E_C - E_M \), because the expectation in \( E[b \mid b < b_c, M] \) is only taken over relatively poor outcomes, the left hand side of (31) is less than the right hand side because \( F(b_c|M) \) is small. That is, because the probability that a patient makes a claim, even when an incorrect decision is made, is small.

6.1. Subsidies and Regulation

Given the lack of incentives provided by tort law under a negligence rule for safe medical practice, perhaps subsidies and regulation should be considered.
It was seen in Section 4 that if the time spent by physicians on education and training and with patients was observable, then the social optimum could be obtained with appropriate per-unit subsidies. The difficulty is that this time is not observable. However, education and training is observable to some extent. Refresher courses and new training could be subsidised. Or, to maintain expertise, physicians could be required to pass competency exams on a regular basis, especially given evidence from the US that current physician licensing arrangements guarantee nothing more than minimum physician expertise, Cooper and Aiken (2001), and little physician learning post-medical school, Gawande (2002).

Although the quantity of time spent with patients in taking histories, examination, diagnosis, and treatment is not observable its quality could be more heavily regulated. For example, physicians like airline pilots could be subject to deregistration if found with alcohol or other drugs in their system at the time they are diagnosing or treating patients. Or the length of a physician’s working day or continuous time at work might be regulated like airline pilots to ensure they are no tired and prone to error. Given evidence that self-regulation fails to respond to patient complaints Sage (2002), and that review boards rarely impose serious disciplinary sanctions, Gawande (2002), Public Citizen (2008), and Sloan (1989), regulations of this type would need to be independently enforced. One would expect the political opposition to this by physicians to be large.

6.2. Patient Information

A possible alternative to subsidies and regulations as a means to reduce medical malpractice can be found through an understanding of why \( F(b_c|M) \) is low. Weiler et.al. (1993) found that medical malpractice occurred once
in every 100 patients. Therefore, it will be assumed that

**Assumption 2:** $P_M << P_C$.

Consider Figure 2 below, $f(b|C)$ and $f(b|M)$ have the same support and are quite similar. Given Assumption 2, the likelihood ratio $\frac{f(b|M)}{f(b|C)} < \frac{P_C}{P_M}$ for all outcomes $b$. Therefore $P(M|b) < .5$ for all $b$ and the patient never makes a claim for medical malpractice.

![Figure 2](image)

Figure 2

$f(b|C)$ and $f(b|M)$ have the same support and are quite similar

\[ \frac{P_C}{P_M} > \frac{f(b|M)}{f(b|C)} \] for all $b$. Therefore $P(M|b) < .5$ for all $b$.

Now consider Figure 3 below. The two densities have different supports and are very different. Given Assumption 2, a $b_c > a_m$ exists and $F(b_c|M)$ is quite large. In this case, if the physician makes an incorrect decision, then the probability is very high that a claim for medical malpractice will be made by the patient.

In reality, few claims are made, therefore the two densities $f(b|C)$ and $f(b|M)$ must be quite similar. More specifically, the likelihood ratio must be less than $\frac{P_M}{P_C}$ for most outcomes. What can a policy maker do to make them less similar and more like those of Figure 3?
The main source of information for $f(b|C)$ is from the physician who is providing the service. The physician has an incentive to advise that the support is wide and that there is weight in the tails because if the physician makes an incorrect decision, it is hard for the patient to determine if the poor outcome was due to an incorrect decision or just due to a bad draw from $f(b|C)$. The relevant figure is Figure 2. The patient is stuck with a wide support and weight in the tails for $f(b|C)$ and minimal information about $f(b|M)$ (the physician would not usually discuss $f(b|M)$).

What the policy maker needs to do is provide information about $f(b|C)$ and $f(b|M)$ for all physician services. It might be that $F(b_c|M)$ is small for some services while for other services $F(b_c|M)$ might be quite large as in Figure 3. In this latter case, there are very strong incentives for physicians to spend close to the optimal amount of time on expertise and quality of service because if an error is made, there is a high probability that the patient will make a successful claim. Note also that if the distributions are as given in
Figure 3, then \( \int_{b}^{c} \alpha_m (E_C - b)f(b|M)db \) and \( \frac{E_C - E_M}{f(b|M)} \) differ by only a small amount. Therefore, liability for actual damage comes close to yielding the social optimum.

Much information about \( f(b|C) \) is already available in the pharmaceutical and medical literature, but is hard for patients to locate. The policy-maker would just need to make it centrally available in an accessible form and make its existence widely known. Information about \( f(b|M) \) is more problematic, especially in practice, because many different types of incorrect decisions can be made. Information concerning this can probably only be obtained from experienced malpractice lawyers or experienced physicians who are familiar with the mistakes made and the outcomes that result. Patients can use \( f(b|C) \) as a first screen to alert themselves to possible malpractice and then consult malpractice lawyers for the Bayesian calculation.

The idea behind providing patients with information about \( f(b|C) \) is so the number of poor health outcomes that result in a claim of medical malpractice increases.\(^9\) In turn, this makes having physicians liable for actual damage under a negligence rule more effective in providing physicians with incentives to spend more time on developing and maintaining expertise and spending more time with patients.

\(^9\)To increase the number of claims, Baker (2005) also argues for more information provision. However, his approach is to make the reporting to patients of possible incidents of medical malpractice mandatory by any medical staff involved in provision of the particular service, including nursing staff. To provide medical staff with the incentive to make such reports he suggests that if a patient makes a successful claim for medical malpractice, then all staff who did not make a report, even if they were not negligent in providing the service, be liable for any damage. A problem with this approach is that medical staff have an incentive to err on the side of caution and make excessive reports to avoid liability. The system would be overrun with reports.
7. Insurance for Medical Malpractice Liability

To date, as in Arlen and MacLeod (2005), it has been assumed that physicians are risk neutral. If they are risk averse, then making them liable for actual damage exposes them to risk and makes their participation more costly for the policy-maker. Providing physicians with medical malpractice liability insurance reduces the cost of their participation but also reduces their incentive to spend time on expertise and quality of service. This is a classic moral hazard problem and the policy-maker optimally trades-off incentives and insurance, Shavell (1982) and Shavell (2000). Therefore, although malpractice insurance reduces the total time spent on expertise and quality of service and so increases the probability of an incorrect decision its availability is optimal as it makes physician participation less costly.

The policy recommendation in Section 6.2 above is designed to increase the probability that a malpractice claim will be made when a physician makes an incorrect decision. This exposes the physician to additional risk and malpractice insurance will dampen its incentive effect. However, once again the availability of insurance is optimal. The policy recommendation still has force because even if insurance dampens its effect on physician incentives it still increases the probability of a successful claim and so increases the probability that injured patients will be compensated for damage.

8. Conclusion

In this paper, tort law under a negligence rule, where actual damage is compensated, is found to provide weak incentives for physicians to spend the socially optimal amount of time on expertise and quality of service. As a result, too much medical malpractice occurs. Education subsidies and regular
competency testing can maintain or increase expertise while regulations concerning the length of a physicians working day or continuous time at work can increase the quality of service. However, the model of medical malpractice claims developed in this paper suggests another policy alternative, namely, the central provision of publicly available information concerning the probability distributions of health outcomes under correct and incorrect treatments. This information can assist patients to more accurately determine whether their outcome was more likely the result of medical malpractice rather than just a poor outcome from a correct decision. In turn, this increases the probability of a medical malpractice claim and strengthens the incentive effects of tort law under a negligence rule.

Rather than using negligent liability to provide incentives, Weiler et.al. (1993) argue for the use of strict liability, where any damage is compensated regardless of whether it is the result of negligence or not. They stress that this would increase the number of claims and provide strong incentives for physicians to maintain and develop expertise and quality of service. However, under strict liability it still has to be established that any damage was the result of medical care and not a result of a patient’s medical condition. Patients are still faced with the decision of when to make a claim and need information about the probability distributions of health outcomes, given correct treatment and given no treatment, so they can apply Bayes Rule and claim when there is more than a 50% chance that the damage was caused by medical care. The rule of strict liability has the same general problem as the rule of negligent liability. In either case, patients need information about conditional probability distributions over health outcomes and there is a role for the policy-maker to centrally provide it.
9. Appendix

**Lemma 1 - Proof:** Totally differentiating first-order conditions (24) and (25) and applying Cramer’s Rule yields

\[
\frac{dn}{dp} = -\frac{\frac{\partial^2 \Pi}{\partial T^2} \cdot n \cdot \int_{\alpha_m}^{b_c} (E_C - b) f(b|M) db + \frac{\partial^2 D}{\partial T^2}}{\Delta} > 0, \tag{32}
\]

where the numerator is greater than zero by one of the second-order conditions for a maximum and \( \Delta > 0 \) is the other second-order condition for a maximum, and

\[
\frac{dT}{dp} = \frac{\int_{\alpha_m}^{b_c} (E_C - b) f(b|M) db \cdot \left( \frac{\partial^2 \Pi}{\partial n \partial T} \cdot n + \frac{\partial \Pi}{\partial T} \right)}{\Delta} > 0, \tag{33}
\]

because the direct affect of \( T \) on \( \Pi \) is assumed greater than the indirect effect of \( T \) on \( \frac{\partial \Pi}{\partial n} \cdot n \).

**The relationship between** \( \int_{\alpha_m}^{b_c} (E_C - b) f(b|M) db \) **and** \( E_C - E_M \). In the text, the distributions \( f(b|C) \) and \( f(b|M) \) were assumed to have different supports to generate the result that \( \int_{\alpha_m}^{b_c} (E_C - b) f(b|M) db < E_C - E_M \). A condition is now derived under which \( \int_{\alpha_m}^{b_c} (E_C - b) f(b|M) db < E_C - E_M \) even if \( f(b|C) \) and \( f(b|M) \) have the same supports. Assume \( b_c < E_C \).

\[
\int_{\alpha_m}^{\beta_m} (E_C - b) f(b|M) db = \int_{\alpha_m}^{b_c} (E_C - b) f(b|M) db + \int_{b_c}^{E_C} (E_C - b) f(b|M) db + \int_{E_C}^{\beta_m} (E_C - b) f(b|M) db = E_C - E_M \tag{34}
\]

The second term in the sum in (34) is positive and the last term is negative. If \( \int_{b_c}^{E_C} (E_C - b) f(b|M) db + \int_{E_C}^{\beta_m} (E_C - b) f(b|M) db > 0 \), then \( \int_{\alpha_m}^{b_c} (E_C - b) f(b|M) db < E_C - E_M \).
Lemma 3 - Proof: The physician’s problem can be rewritten as

$$\max_{T,n} U_P \equiv p \cdot n - D(T) - (1 - \Pi(T,n)) \cdot X \cdot n,$$  \hspace{1cm} (35)$$

where $X$ is the expected liability payout if a mistake is made. Totally differentiating the first order conditions for a maximum and applying Cramer’s rule yields

$$\frac{\partial T}{\partial X} = \text{sign} \left[ -\frac{\partial \Pi}{\partial T} \cdot n \cdot \frac{\partial^2 U_P}{\partial n^2} - \left( -\frac{\partial \Pi}{\partial n} \cdot n + (1 - \Pi) \right) \cdot \frac{\partial^2 U_P}{\partial T \partial n} \right]$$ \hspace{1cm} (36)$$

and

$$\frac{\partial n}{\partial X} = \text{sign} \left[ \frac{\partial^2 U_P}{\partial T^2} \cdot \left( -\frac{\partial \Pi}{\partial n} \cdot n + (1 - \Pi) \right) + \frac{\partial \Pi}{\partial T} \cdot n \cdot \frac{\partial^2 U_P}{\partial T \partial n} \right].$$ \hspace{1cm} (37)$$

The first term on the right-hand-side of (36) is the direct effect of $X$ on $T$ and the second term is the indirect effect of $X$ on $T$ as a result of the change in $n$. By (8) and one of the second-order conditions for a maximum the first term is positive. Assuming the direct effect is greater than the indirect effect implies $\frac{\partial T}{\partial X} > 0$.

The first term on the right-hand-side of (37) is the direct effect of $X$ on $n$ and the second term is the indirect effect of $X$ on $n$ as a result of the change in $T$. By (8) and one of the second-order conditions for a maximum the first term is negative. Assuming the direct effect is greater than the indirect effect implies $\frac{\partial n}{\partial X} < 0$.

From (18) and (21), at the social optimum $X = E_C - E_M$. Under liability for actual damage $X = \int_{\alpha_m}^{b_c} (E_C - b) f(b|M) db$. As $E_C - E_M > \int_{\alpha_m}^{b_c} (E_C - b) f(b|M) db$, $T(p^*) < T^*$ and $n(p^*) > n^*$. 

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10. References


