The Value of Waiting and the Incentives to Take Care under Different Negligence Rules

Laurent Bieri

Professor at the University of Lausanne

laurent.bieri@unil.ch

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Abstract

The value of waiting to take a precaution must be considered to set the due care level. This article presents a model to investigate the incentives of a potential injurer to take precautions, first under a negligence rule that takes into account the value of waiting, and then under a negligence rule that does not. Under the first rule, the incentives are socially optimal, while under the second this is not always the case.

1. INTRODUCTION

A precaution taken today may kill the option of not taking it later. For example, by installing a smoke scrubber this year, a firm may give up the option of not installing it next year if, based on new information available next year, this is then the best thing to do. And the loss of the value of that option is an implicit cost that should be taken into account to set the due care level. In other words, the value of waiting to take a precaution must be considered to determine if someone is negligent.

In this article, I present a two-period model to investigate the incentives of a potential injurer to take precautions, first under a negligence rule that takes into account the value of waiting, and then under a negligence rule that does not.

Under a negligence rule that takes into account the value of waiting to set the required level of precaution, the potential injurer will choose the socially optimal level of precaution in both periods. This result holds if the potential injurer is liable only for the harm caused by his negligence, but also if, when he is negligent, he is liable for any harm that arises, including the harm that would have happened even if he had not been negligent.

Under a negligence rule that does not take into account the value of waiting to set the required level of precaution, the potential injurer will also choose the socially optimal level of precaution in both periods provided, however, that he is liable only for the harm caused by his negligence. If, when he is negligent, he is liable for any harm that arises, he may be encouraged to take too much precautions in the first and in the second period.

It is worth mentioning that the occurrence of an accident may also kill an option (see especially Arrow and Fisher 1974, and Henry 1974). If this is the case, the value of that option should of course also be taken into account to set the required level of precaution[1]. But in order to focus on the lost option value of the precaution, it will be assumed throughout this article that this is not the case. For

[1] I thank ... for drawing my attention to the importance of that point.

the same reason, it will also be assumed that the precaution cannot create options, and that the expected harm in the second period, conditional on the occurrence of an accident in the second period, is the same whether or not an accident occurs in the first period.

This article follows a large literature extending the standard (one-period) model of tort law (Brown 1973 ; for a review of this literature, see Shavell 2007). The article most closely related to mine is Shavell (2008), which also presents a two-period model to investigate the incentives to take precautions under different regimes of liability. But Shavell's article focuses on the best way to set the required level of care in the second period, once the uncertainty has disappeared. Here, the emphasis is on the way to set the required level of precaution in the first period. Grady (1983) and Kahan (1989) emphasize the distinction between a liability regime in which a negligent party is liable only for the harm caused by his negligence and a liability regime in which he is liable for any harm that arises, but they focus on one-period models and therefore do not consider the distinction between a liability regime in which the value of waiting to take a precaution is taken into account and a liability regime in which it is not the case. My article also draws on the literature on investment under uncertainty (see especially Dixit and Pindyck 1994), and is related to the literature on the value of waiting in lawmaking (see Parisi, Fon, and Ghei, 2004, and Parisi and Ghei, 2005). To the best of my knowledge, however, none of the papers in this literature examines the incentives given by the different regimes of liability analyzed here.

After an illustration of the results with an example, the article presents a formal analysis of the different liability regimes and ends with a conclusion.

2. AN EXAMPLE

2.1. The Assumptions

There are two periods. At the beginning of period 1, a potential injurer can spend \$80 for a smoke scrubber that lowers the probability of harm in both periods from 30 percent to 20 percent. At the beginning of period 1, it is known that if an accident occurs in period 1, the harm amounts to \$100, but there is uncertainty about the harm in period 2, which could amount to \$1300 or \$500, with equal probability. The expected harm in period 2, conditional on the occurrence of an accident, therefore amounts to 50 percent x \$1300 + 50 percent x \$500 = \$900. At the beginning of period 2, it is known whether the conditional harm amounts to \$1300 or \$500. If the smoke scrubber has not been installed in period 1, the potential injurer may decide at the beginning of period 2 to spend \$80 to install the smoke scrubber. If the smoke scrubber has been installed in period 1, there is no decision to make in period 2. The parties are risk-neutral and the discount rate can be ignored.

2.2. The Socially Optimal Behavior

We assume that the social goal is to minimize the expected social costs. Consider first the socially optimal choice at the beginning of period 2 if the potential injurer has not installed the smoke scrubber in period 1. If the potential harm amounts to \$1300, the potential injurer should install the smoke scrubber because it costs \$80 and reduces the expected harm by (30 percent - 20 percent) x \$1300 = \$130. But if the potential harm amounts to \$500, the potential injurer should not install the smoke scrubber since it costs \$80 and reduces the expected harm by only (30 percent - 20 percent) x \$500 = \$50.

Consider now the socially optimal choice in period 1. The smoke scrubber should not be installed in period 1, because the cost of the smoke scrubber is equal to \$80, whereas the benefit of the smoke scrubber amounts only to (30 percent - 20 percent) x \$100 + 50 percent x \$80 + 50 percent x (30 percent - 20 percent) x \$500 = \$75. Another way of seeing that the smoke scrubber should not be installed in period 1 is to note that if the smoke scrubber is installed in period 1, the expected social costs amount to \$80 + 20 percent x \$100 + 50 percent x 20 percent x \$1300 + 50 percent x 20 percent x \$500 = \$280, whereas if it is not installed in period 1, the expected social costs amount to 30 percent x \$100 + 50 percent x (\$80 + 20 percent x \$1300) + 50 percent x 30 percent x \$500 = \$275.

2.3. The Negligence Rule that Takes into Account the Value of Waiting

Under the negligence rule that takes into account the value of waiting, the required level of precaution in period 1 is the socially optimal level of precaution in that period and the required level of precaution in period 2 is the socially optimal level of precaution in that period, assuming that the optimal level of precaution was taken in period 1. This means that he potential injurer is not required to take the precaution in period 1, and is required to take it in period 2 if and only if it is then known that the harm would amount to \$1300. If the potential injurer is liable only for the harm caused by his negligence, his behavior will be socially optimal.

To see that, consider first his choice in period 2 if the smoke scrubber has not been installed in period 1. If the potential harm amounts to \$1300, the potential injurer will install the smoke scrubber, because he will pay \$80 for the installation and will not be liable, while if he does not install the smoke scrubber he will be liable and the expected damages will amount to 30 percent x \$1300 - 20 percent x \$1300 = \$130. But if the potential harm amounts to \$500, the potential injurer will not install the smoke scrubber since he escapes all liability even if it does not install it. And in period 1, the potential injurer will therefore not install the smoke scrubber, for if he installs it his expected cost amounts to \$80, while if he does not install it, his expected cost amounts to 50 percent x \$80 = \$40.

But under the negligence rule that takes into account the value of waiting to set the required level of precaution in period 1, the potential injurer will also choose the socially optimal level of precaution in both periods if, when he is negligent, he is liable for any harm that arises, including the harm that would have happened even if he had taken due care.

Consider first his choice in period 2 if the smoke scrubber has not been installed in period 1. If the potential harm amounts to \$1300, the potential injurer will install the smoke scrubber, because he will pay \$80 for the installation and will not be liable, while if he does not install the smoke scrubber he will be liable and the expected damages will amount to 30 percent x \$1300 = \$390. And if the potential harm amounts to \$500, the potential injurer will not install the smoke scrubber since he escapes all liability even if he does not install it. In period 1, the potential injurer will therefore not install the smoke scrubber, for if he installs it his expected cost amounts to \$80, while if he does not install it, his expected cost amounts to 50 percent x \$80 = \$40.

2.4. The Negligence Rule that does not Take into Account the Value of Waiting

Under the negligence rule that does not take into account the value of waiting, the required level of precaution in period 1 is set as if it were not possible to increase the level of precaution in period 2. The lost option value of waiting is therefore not taken into account, which means that the required level of precaution is greater than the socially optimal level of precaution. This means that the potential injurer is required to install the smoke scrubber in period 1 because, if the smoke scrubber could not be installed in period 2, the cost of the smoke scrubber would be equal to \$80, whereas the benefit of the smoke scrubber would be equal to (30 percent - 20 percent) x \$100 + 50 percent x (30 percent - 20 percent) x \$1300 + 50 percent x (30 percent - 20 percent) x \$500 = \$100. Another way of seeing that with this liability regime the potential injurer is not required to install the smoke scrubber in period 1 is to note that if the smoke scrubber could not be installed in period 2, the expected social costs if the smoke scrubber were installed in period 1 would amount to \$80 + 20 percent x \$100 + 50 percent x 20 percent x \$1300 + 50 percent x 20 percent x \$500 = \$280, whereas if the smoke scrubber were not installed in period 1, the expected social costs would amount to 30 percent x \$100 + 50 percent x 30 percent x \$1300 + 50 percent x 30 percent x \$500 = \$300. Nevertheless, assuming that the potential injurer is liable only for the harm caused by his negligence, his behavior will be socially optimal.

To see that, consider first his choice in period 2 if the smoke scrubber has not been installed in period 1. If the potential harm amounts to \$1300, the potential injurer will install the smoke scrubber, because he will pay \$80 for the installation and will not be liable, while if he does not install the smoke scrubber he will be liable and the expected damages will amount to 30 percent x \$1300 - 20 percent x \$1300 = \$130. And if the potential harm amounts to \$500, the potential injurer will not install the smoke scrubber, because if he installs the smoke scrubber, he will pay \$80 for the smoke scrubber and will not be liable, while if he does not install the smoke scrubber he will be liable (because the firm should have installed the smoke scrubber in period 1) and the expected damages will amount to 30 percent x \$500 - 20 percent x \$500 = \$50. In period 1, the potential injurer will therefore not install the smoke scrubber, for if he installs it his expected cost amounts to \$80, while if he does not install it his expected cost amounts to 30 percent x \$100 - 20 percent x \$100 + 50 percent x \$80 + 50 percent x (30 percent x \$500 - 20 percent x \$500) = \$75.

Finally, under a negligence rule that does not take into account the value of waiting to set the optimal level of precaution in period 1, the potential injurer will not always choose the socially optimal level of precaution if, when he is negligent, he is liable for any harm that arises, including harm that would have happened even if he had taken due care.

Consider first his choice in period 2 if the smoke scrubber has not been installed in period 1. If the potential harm amounts to \$1300, the potential injurer will install the smoke scrubber, because he will pay \$80 for the installation and will not be liable, while if it does not install the smoke scrubber he will be liable and the expected damages will amount to 30 percent x \$1300 = \$390. But if the potential harm amounts to \$500, the potential injurer will also install the smoke scrubber, because if he installs it, he will pay \$80 for the installation and will not be liable, while if he does not install the smoke scrubber he will be liable and the expected damages will amount to 30 percent x \$500 = \$150. In period 1, the potential injurer will therefore install the smoke scrubber, for if he installs it his expected cost amounts to \$80, while if he does not install it his expected cost amounts to 30 percent x \$100 + 100 percent x \$80 = \$110.

But the potential injurer would act optimally with this liability regime if the example were slightly modified. Let us assume that the example is exactly the same, except that the smoke scrubber lowers the probability of harm in both periods from 10 percent to zero percent rather than from 30 percent to 20 percent. Since in both cases the smoke scrubber lowers the probability of harm by 10 percent, it is clear that, as before, the smoke scrubber should not be installed in period 1 and should be installed in period 2 if and only if the potential harm then amounts to \$1300. In that case, assuming that the smoke scrubber has not been installed in period 1, the potential injurer will install it in period 2 if and only if the potential harm amounts to \$1300, which is socially optimal. If the potential harm amounts to \$1300, the potential injurer will install the smoke scrubber because he will pay \$80 for the installation and will not be liable, while if he does not install the smoke scrubber he will be liable and the expected damages will amount to 10 percent x \$1300 = \$130. And if the potential harm amounts to \$500, the potential injurer will not install the smoke scrubber, because if he installs it, he will pay \$80 for the installation and will not be liable, while if he does not install the smoke scrubber he will be liable and the expected damages will amount to 10 percent x \$500 = \$50. In period 1, the potential injurer will therefore not install the smoke scrubber, for if he installs it his expected cost amounts to \$80, while if he does not install it his expected cost amounts to 10 percent x \$100 + 50 percent x \$80 + 50 percent x 10 percent x \$500 = \$75.

3. THE MODEL

3.1. The Assumptions

Consider a situation in which a potential injurer engages in a potentially harmful activity during two periods. At the beginning of period 1, it is known that if an accident occurs in period 1, the harm to the victim amounts to h_1, but the magnitude of the harm if an accident occurs in period 2 is unknown. The magnitude of the possible harm in period 2, denoted h_2, is known only at the beginning of period 2. At the beginning of period 1, the probability density of h_2 is given by $f(h_2)$.

The potential injurer must choose the level of precaution, denoted x_1, at the beginning of period 1, and can take additional precautions, denoted x_2, at the beginning of period 2. The probability of an accident amounts to $p(x_1)$ in period 1, and to $p(x_1 + x_2)$ in period 2, with $p'(x) < 0$, $p'(x) \to -\infty$ as $x \to 0$, and $p''(x) > 0$. The investment in the precautions taken in period 1 is irreversible, which means that it cannot be recovered in period 2. The parties are risk-neutral and the discount rate can be ignored.

3.2. The Socially Optimal Behavior

We assume that the social goal is to minimize the expected social costs, and for convenience we define $x^*(h)$, the x that minimizes $x + p(x)h$, and $h^*(x)$, the h for which $x^*(h) = x$.

Consider first the socially optimal x_2 conditional on x_1. If $h_2 \leq h^*(x_1)$, $x_1 \geq x^*(h_2)$, and it is therefore optimal that $x_2 = 0$. If $h_2 > h^*(x_1)$, $x_1 < x^*(h_2)$, and it is optimal that $x_2 = x^*(h_2) - x_1$.

The expected social costs as a function of x_1 are then given by

$$\begin{aligned} S(x_1) =& x_1 + p(x_1)h_1 + \int_0^{h^*(x_1)} p(x_1)h_2 f(h_2)dh_2 \\ &+ \int_{h^*(x_1)}^{\infty} [x^*(h_2) - x_1 + p(x^*(h_2))h_2] f(h_2)dh_2, \end{aligned} \tag{1}$$

where the first term on the right is the cost of the precautions in period 1, the second term is the expected harm in period 1, the third term is the expected harm in period 2 if $h_2 \leq h^*(x_1)$, and the fourth term is the expected harm in period 2 if $h_2 > h^*(x_1)$.

The socially optimal x_1, denoted x_1^*, is given by the first order condition[2]

$$\frac{dS(x_1^*)}{dx_1} = 1 + p'(x_1^*)h_1 + p'(x_1^*) \int_0^{h^*(x_1^*)} h_2 f(h_2)dh_2 - \int_{h^*(x_1^*)}^{\infty} f(h_2)dh_2 = 0. \tag{2}$$

3.3. The Negligence Rule that Takes into Account the Value of Waiting

Under the negligence rule that takes into account the value of waiting to set the required level of precaution in period 1, the due care level in period 1 is equal to x_1^*, and the due care level in period 2 is equal to x_1^* if $h_2 \leq h^*(x_1^*)$ and to $x^*(h_2)$ if $h_2 > h^*(x_1^*)$. Assuming that the potential injurer is liable only for the harm caused by his negligence, he will choose the socially optimal x_1 and the socially

[2] Using Leibniz's formula and noticing that $p(x_1^*)h^*(x_1^*)f(h^*(x_1^*))h^{*'}(x_1^*) - [x^*(h^*(x_1^*) - x_1^* + p(x^*(h^*(x_1^*))h^*(x_1^*)]f(h^*(x_1^*))h^{*'}(x_1^*) = 0$.

optimal x_2.

To see that, consider first his choice of x_2 conditional on x_1. If $h_2 \leq h^*(x_1^*)$ and $x_1 \geq x_1^*$, he will not choose $x_2 > 0$, for he will escape liability by choosing $x_2 = 0$. If $h_2 \leq h^*(x_1^*)$, but $x_1 < x_1^*$, and $x_1 < x^*(h_2)$, he chooses $x_2 = x^*(h_2) - x_1$; the reason is that as long as $x_2 < x^*(h_2) - x_1$, it is worth increasing the level of precaution because $x^*(h_2) - (x_1 + x_2) < p(x_1 + x_2)h_2 - p(x^*(h_2))h_2$, but if $x_2 > x^*(h_2) - x_1$, it is not worth increasing the level of precaution because as long as $x_1 + x_2 < x_1^*$, $x_1 + x_2 - x^*(h_2) > p(x^*(h_2))h_2 - p(x_1 + x_2)h_2$, and as soon as $x_1 + x_2 \geq x_1^*$, it is not necessary to increase the level of precaution to escape liability. If $h_2 \leq h^*(x_1^*)$, $x_1 < x_1^*$, and $x_1 \geq x^*(h_2)$, he chooses $x_2 = 0$, because as long as $x_1 + x_2 < x_1^*$, $x_2 > p(x_1)h_2 - p(x_1 + x_2)h_2$, and as soon as $x_1 + x_2 \geq x_1^*$, it is not necessary to increase the level of precaution to escape liability. If $h_2 > h^*(x_1^*)$, and $x_1 \leq x^*(h_2)$, the potential injurer will choose x_2 so that $x_2 = x^*(h_2) - x_1$. The potential injurer will not choose $x_2 > x^*(h_2) - x_1$, for he will escape liability by choosing $x_2 = x^*(h_2) - x_1$. And he will not choose $x_2 < x^*(h_2) - x_1$, for he would be liable and his expected costs in period 2 would be $x_2 + p(x_1 + x_2)h_2 - p(x^*(h_2))h_2$, which is greater than $x^*(h_2) - x_1 + p(x_1 + x^*(h_2) - x_1)h_2 - p(x^*(h_2))h_2$, which is equal to $x^*(h_2) - x_1$. And if $h_2 > h^*(x_1^*)$, but $x_1 > x^*(h_2)$, the potential injurer will not choose $x_2 > 0$, for he will escape liability by choosing $x_2 = 0$.

Consider now the potential injurer's choice of x_1. The potential injurer will choose x_1^* and his expected cost will be

$$C(x_1^*) = x_1^* + \int_{h^*(x_1^*)}^{\infty} [x^*(h_2) - x_1^*] f(h_2) dh_2. \tag{3}$$

The reason is that he will not choose $x_1 > x_1^*$, for his expected costs would be

$$C(x_1) = x_1 + \int_{h^*(x_1)}^{\infty} [x^*(h_2) - x_1] f(h_2) dh_2, \tag{4}$$

which exceeds his expected costs if he chooses x_1^*, because he would be sure to pay $x_1 - x_1^*$ more in period 1, and would have only a chance to pay at best $x_1 - x_1^*$ less in period 2. More precisely, in period 2, he would have nothing less to pay if $h_2 \leq h^*(x_1^*)$, he would have only $x^*(h_2) - x_1^*$ less to pay if $h^*(x_1^*) < h_2 \leq h^*(x_1)$, and he would have exactly $x_1 - x_1^*$ less to pay if $h_2 > h^*(x_1)$. And he will not choose $x_1 < x_1^*$ either, for his expected costs would be

$$\begin{aligned} C(x_1) =& x_1 + p(x_1)h_1 - p(x_1^*)h_1 \\ &+ \int_0^{h^*(x_1)} [p(x_1)h_2 - p(x_1^*)h_2] f(h_2) dh_2 \\ &+ \int_{h^*(x_1)}^{h^*(x_1^*)} [x^*(h_2) - x_1 + p(x^*(h_2))h_2 - p(x_1^*)h_2] f(h_2) dh_2 \\ &+ \int_{h^*(x_1^*)}^{\infty} [x^*(h_2) - x_1] f(h_2) dh_2, \end{aligned} \tag{5}$$

which is also more than his expected costs if he chooses x_1^*, because x_1^* is the socially optimal level of precaution in period 1 and he would bear the entire increase in expected social costs due to the fact that he has taken less than x_1^* in that period. More precisely, in period 1 his expected costs would rise by $p(x_1)h_1 - p(x_1^*)h_1$, and in period 2, his expected cost would rise by $p(x_1)h_2 - p(x_1^*)h_2$ when $0 < h_2 < h^*(x_1)$, by $x^*(h_2) - x_1 + p(x^*(h_2) - p(x_1^*)h_2$ when $h^*(x_1) < h_2 < h^*(x_1^*)$, and by $x_1^* - x_1$ when $h_2 > h^*(x_1^*)$.

But under a negligence rule that takes into account the value of waiting to set the optimal level of precaution in period 1, the potential injurer will also choose the socially optimal level of precaution in both periods if, when he is negligent, he is liable for any harm that arises, including the harm that would have happened even if he had taken due care.

To see that, consider first his choice of x_2 conditional on x_1. If $h_2 \leq h^*(x_1^*)$ and $x_1 \geq x_1^*$, he will not choose $x_2 > 0$, for he will escape liability by choosing $x_2 = 0$. If $h_2 \leq h^*(x_1^*)$, but $x_1 < x_1^*$, and $x_1 < x^*(h_2)$, then either $x_1^* - x_1 \leq x^*(h_2) - x_1 + p(x^*(h_2))h_2$, and he chooses $x_2 = x_1^* - x_1$, or $x_1^* - x_1 > x^*(h_2) - x_1 + p(x^*(h_2))h_2$, and he chooses $x_2 = x^*(h_2) - x_1$. And if $h_2 \leq h^*(x_1^*)$, $x_1 < x_1^*$, but $x_1 \geq x^*(h_2)$, either $x_1^* - x_1 \leq p(x_1)h_2$, and he chooses $x_2 = x_1^* - x_1$, or $x_1^* - x_1 > p(x_1)h_2$, and he chooses $x_2 = 0$. If $h_2 > h^*(x_1^*)$, and $x_1 \leq x^*(h_2)$, the potential injurer will choose x_2 so that $x_2 = x^*(h_2) - x_1$. The potential injurer will not choose $x_2 > x^*(h_2) - x_1$, for he will escape liability by choosing $x_2 = x^*(h_2) - x_1$. And he will not choose $x_2 < x^*(h_2) - x_1$, for he would be liable and his expected costs in period 2 would be $x_2 + p(x_1 + x_2)h_2$, which is greater than $x^*(h_2) - x_1 + p(x_1 + x^*(h_2) - x_1)h_2$, which is greater than $x^*(h_2) - x_1$. And if $h_2 > h^*(x_1^*)$, but $x_1 > x^*(h_2)$, the potential injurer chooses $x_2 = 0$, for it is sufficient to escape liability.

Consider now the potential injurer's choice of x_1. The potential injurer will choose x_1^* and his expected cost will be

$$C(x_1^*) = x_1^* + \int_{h^*(x_1^*)}^{\infty} [x^*(h_2) - x_1^*] f(h_2) dh_2. \tag{6}$$

The reason is that he will not choose $x_1 > x_1^*$ in period 1, for his expected costs would be

$$C(x_1) = x_1 + \int_{h^*(x_1)}^{\infty} [x^*(h_2) - x_1] f(h_2) dh_2, \tag{7}$$

which exceeds his expected costs if he chooses x_1^*, because he would be sure to pay $x_1 - x_1^*$ more in period 1, and would have only a chance to pay at best $x_1 - x_1^*$ less in period 2. More precisely, in period 2, he would have nothing less to pay if $h_2 \leq h^*(x_1^*)$, he would have only $x^*(h_2) - x_1$ less to pay if $h^*(x_1^*) < h_2 \leq h^*(x_1)$, and he would have exactly $x_1 - x_1^*$ less to pay if $h_2 > h^*(x_1)$. And he will not choose $x_1 < x_1^*$ either, for his expected costs would be

$$\begin{aligned} C(x_1) =& x_1 + p(x_1)h_1 \\ &+ \int_0^{h^*(x_1)} [min(x_1^* - x_1, p(x_1)h_2)] f(h_2) dh_2 \\ &+ \int_{h^*(x_1)}^{h^*(x_1^*)} [min(x_1^* - x_1, x^*(h_2) - x_1 + p(x^*(h_2))h_2)] f(h_2) dh_2 \\ &+ \int_{h^*(x_1^*)}^{\infty} [x^*(h_2) - x_1] f(h_2) dh_2, \end{aligned} \tag{8}$$

which is also more than his expected costs if he chooses x_1^*, because x_1^* is the socially optimal level of precaution in period 1 and he would bear more than the entire increase in expected social cost due to the fact that he has taken less than x_1^*. More precisely, in period 1, the cost of the precautions would be reduced by $x_1^* - x_1$ and the expected damages would rise by $p(x_1)h_1$, and in period 2, his expected cost would rise by $x_1^* - x_1$ or $p(x_1)h_2$ when $0 < h_2 < h^*(x_1)$, by $x_1^* - x_1$ or $x^*(h_2) - x_1 + p(x^*(h_2))$ when $h^*(x_1) < h_2 < h^*(x_1^*)$, and by $x_1^* - x_1$ when $h_2 > h^*(x_1^*)$.

3.4. The Negligence Rule that does not Take into Account the Value of Waiting

Under the negligence rule that does not take into account the value of waiting to set the optimal level of precaution in period 1, the required level of precaution in period 1 is set as if it were not possible to increase the level of precaution at the beginning of period 2, and is therefore equal to the x_1 that minimizes

$$W(x_1) = x_1 + p(x_1)h_1 + p(x_1)\int_0^{\infty} h_2 f(h_2)dh_2, \tag{9}$$

where the first term on the right would be the cost of the precaution in period 1, the second term would be the expected harm in period 1, and the third term would be the expected harm in period 2. The required level of precaution in period 1, denoted x_1^{**}, is given by the first order condition

$$\frac{dW(x_1^{**})}{dx_1} = 1 + p'(x_1^{**})h_1 + p'(x_1^{**})\int_0^{\infty} h_2 f(h_2)dh_2 = 0. \tag{10}$$

The due care level in period 2 is equal to x_1^{**} if $h_2 \leq h^*(x_1^{**})$ and to $x^*(h_2)$ if $h_2 > h^*(x_1^{**})$.

It is worth mentioning that $x_1^{**} > x_1^*$, because to set x_1^{**}, the lost option value of waiting is not taken into account. More formally, this can be seen by comparing equation (2) and equation (10) and noting that between $h^*(x_1)$ and ∞, $h_2 > h^*(x_1)$, which means that

$$-\int_{h^*(x_1)}^{\infty} f(h_2)dh_2 > p'(x_1)\int_{h^*(x_1)}^{\infty} h_2 f(h_2)dh_2. \tag{11}$$

Under a negligence rule that does not take into account the value of waiting to set the optimal level of precaution in period 1, the potential injurer will choose the optimal level of precaution in both periods if he is liable only for the harm caused by his negligence.

Consider first his choice of x_2 conditional on x_1. If $h_2 \leq h^*(x_1^{**})$ and $x_1 \geq x_1^{**}$, he will not choose $x_2 > 0$, for he will escape liability by choosing $x_2 = 0$. If $h_2 \leq h^*(x_1^{**})$, but $x_1 < x_1^{**}$, and $x_1 < x^*(h_2)$, he chooses $x_2 = x^*(h_2) - x_1$; the reason is that as long as $x_2 < x^*(h_2) - x_1$, it is worth increasing the level of precaution because $x^*(h_2) - (x_1 + x_2) < p(x_1 + x_2)h_2 - p(x^*(h_2))h_2$, but if $x_2 > x^*(h_2) - x_1$, it is not worth increasing the level of precaution because as long as $x_1 + x_2 < x_1^{**}$, $(x_1 + x_2) - x^*(h_2) > p(x^*(h_2))h_2 - p(x_1 + x_2)h_2$, and as soon as $x_1 + x_2 \geq x_1^{**}$, it is not necessary to increase the level of precaution to escape liability. If $h_2 \leq h^*(x_1^{**})$, $x_1 < x_1^{**}$, and $x_1 \geq x^*(h_2)$, he chooses $x_2 = 0$, because as long as $x_1 + x_2 < x{*}{*}_1$, $x_2 > p(x_1)h_2 - p(x_1 + x_2)h_2$, and as soon as $x_1 + x_2 \geq x_1^{**}$, it is not necessary to increase the level of precaution to escape liability. If $h_2 > h^*(x_1^{**})$, and $x_1 \leq x^*(h_2)$, the potential injurer will choose x_2 so that $x_2 = x^*(h_2) - x_1$. The potential injurer will not choose $x_2 > x^*(h_2) - x_1$, for he will escape liability by choosing $x_2 = x^*(h_2) - x_1$. And he will not choose $x_2 < x^*(h_2) - x_1$, for he would be liable and his expected costs in period 2 would be $x_2 + p(x_1 + x_2)h_2 - p(x^*(h_2))h_2$, which is greater than $x^*(h_2) - x_1 + p(x_1 + x^*(h_2) - x_1)h_2 - p(x^*(h_2))h_2$, which is equal to $x^*(h_2) - x_1$. And if $h_2 > h^*(x_1^{**})$, but $x_1 > x^*(h_2)$, the potential injurer will not choose $x_2 > 0$, for he will escape liability by choosing $x_2 = 0$.

Consider now the potential injurer's choice of x_1. If the potential injurer chooses $x_1 < x_1^{**}$, his expected costs will be

$$
\begin{aligned}
C(x_1) =& x_1 + p(x_1)h_1 - p(x_1^{**})h_1 \\
&+ \int_0^{h^*(x_1)} [p(x_1)h_2 - p(x_1^{**})h_2] f(h_2) dh_2 \\
&+ \int_{h^*(x_1)}^{h^*(x_1^{**})} [x^*(h_2) - x_1 + p(x^*(h_2))h_2 - p(x_1^{**})h_2] f(h_2) dh_2 \\
&+ \int_{h^*(x_1^{**})}^{\infty} [x^*(h_2) - x_1] f(h_2) dh_2,
\end{aligned} \tag{12}
$$

which is minimized if he chooses $x_1 = x_1^*$. The reason is that x_1^* is socially optimal and if he takes $x_1 < x_1^{**}$, but $x_1 \neq x_1^*$, he will bear the entire increase in social cost due to the fact that he has not taken x_1^*. More precisely, if he takes $x_1 < x_1^*$, in period 1, the cost of the precautions would be reduced by $x_1^* - x_1$ and the expected damages will rise by $p(x_1)h_1 - p(x_1^*)h_1$, and in period 2, his expected costs would rise by the entire social cost if $h_2 < h^*(x_1^{**})$, because he is always liable if an accident occurs, and by $x_1^* - x_1$ if $h_2 \geq h^*(x_1^{**})$. And if he chooses $x_1 > x_1^*$, in period 1, the cost of the precautions would increase by $x_1 - x_1^*$ and the expected damages would decrease by $p(x_1^*)h_1 - p(x_1)h_1$, and in period 2, his expected costs would decrease by the entire social cost if $h_2 < h^*(x_1^{**})$, because he is always liable if an accident occurs, and by $x_1 - x_1^*$ if $h_2 \geq h^*(x_1^{**})$. And if the potential injurer chooses $x_1 \geq x_1^{**}$, his expected costs will amount to

$$
C(x_1) = x_1 + \int_{h^*(x_1)}^{\infty} [x^*(h_2) - x_1] f(h_2) dh_2, \tag{13}
$$

which is minimized if he chooses $x_1 = x_1^{**}$, because if he chooses $x_1 > x_1^{**}$, in period 1, he would pay $x_1 - x_1^{**}$ more, and in period 2, he would have only a chance to pay at best $x_1 - x_1^{**}$ less. More precisely, he would have nothing less to pay if

$h_2 < h^*(x_1^{**})$, he would have $x^*(h_2) - x_1^{**}$ less to pay if $h^*(x_1) > h_2 \geq h^*(x_1^{**})$, and he would have $x_1 - x_1^{**}$ less to pay if $h_2 \geq h^*(x_1)$. And the potential injurer will not choose x_1^{**} rather than x_1^* in period 1, because he would bear the entire increase in social cost due to the fact that he has not taken the socially optimal level of precaution. More precisely, in period 1, the costs of the precautions will rise by $x_1^{**} - x_1^*$ and the expected damages will decrease by $p(x_1^*)h_1 - p(x_1^{**})h_1$, and in period 2, his expected costs would decrease by the entire social cost if $h_2 < h^*(x_1^{**})$, and by $x_1^{**} - x_1^*$ if $h_2 \geq h^*(x_1^{**})$. The potential injurer will therefore choose $x_1 = x_1^*$ in period 1.

Finally, under a negligence rule that does not take into account the value of waiting to set the optimal level of precaution in period 1, the potential injurer will not always choose the socially optimal level of precaution in both periods if, when he is negligent, he is liable for any harm that arises, including the harm that would have happened even if he had taken due care.

Consider first his choice of x_2 conditional on x_1. If $h_2 \leq h^*(x_1^{**})$ and $x_1 \geq x_1^{**}$, he will not choose $x_2 > 0$, for he will escape liability by choosing $x_2 = 0$. If $h_2 \leq h^*(x_1^{**})$, but $x_1 < x_1^{**}$, and $x_1 < x^*(h_2)$, then either $x_1^{**} - x_1 \leq x^*(h_2) - x_1 + p(x^*(h_2))h_2$, and he chooses $x_2 = x_1^{**} - x_1$, or $x_1^{**} - x_1 > x^*(h_2) - x_1 + p(x^*(h_2))h_2$, and he chooses $x_2 = x^*(h_2) - x_1$. And if $h_2 \leq h^*(x_1^{**})$, $x_1 < x_1^{**}$, but $x_1 \geq x^*(h_2)$, either $x_1^{**} - x_1 \leq p(x_1)h_2$, and he chooses $x_2 = x_1^{**} - x_1$, or $x_1^{**} - x_1 > p(x_1)h_2$, and he chooses $x_2 = 0$. If $h_2 > h^*(x_1^{**})$, and $x_1 \leq x^*(h_2)$, the potential injurer will choose x_2 so that $x_2 = x^*(h_2) - x_1$. The potential injurer will not choose $x_2 > x^*(h_2) - x_1$, for he will escape liability by choosing $x_2 = x^*(h_2) - x_1$. And he will not choose $x_2 < x^*(h_2) - x_1$, for he would be liable and his expected costs in period 2 would be $x_2 + p(x_1 + x_2)h_2$, which is greater than $x^*(h_2) - x_1 + p(x_1 + x^*(h_2) - x_1)h_2$, which is greater than $x^*(h_2) - x_1$. And if $h_2 > h^*(x_1^{**})$, but $x_1 > x^*(h_2)$, the potential injurer chooses $x_2 = 0$, for it is sufficient to escape liability.

Consider now the potential injurer's choice of x_1. If he chooses $x_1 < x_1^{**}$, his expected amounts to

$$\begin{aligned} C(x_1) =& x_1 + p(x_1)h_1 \\ &+ \int_0^{h^*(x_1)} [min(x_1^{**} - x_1, p(x_1)h_2)] f(h_2) dh_2 \\ &+ \int_{h^*(x_1)}^{h^*(x_1^{**})} [min(x_1^{**} - x_1, x^*(h_2) - x_1 + p(x^*(h_2))h_2)] f(h_2) dh_2 \\ &+ \int_{h^*(x_1^{**})}^{\infty} [x^*(h_2) - x_1] f(h_2) dh_2, \end{aligned} \tag{14}$$

which is minimized if he chooses x_1^*. The reason is that x_1^* is socially optimal and if he takes $x_1 < x_1^{**}$, but $x_1 \neq x_1^*$, he will bear at least the entire increase in social cost due to the fact that he has not taken x_1^*. More precisely, if he takes $x_1 < x_1^*$, in period 1, the cost of the precautions would be reduced by $x_1^* - x_1$ and the expected damages would rise by $p(x_1)h_1 - p(x_1^*)h_1$, and in period 2, his expected cost would rise either by $x_1^* - x_1$ or by at least the entire increase in social costs when $h_2 < h^*(x_1^{**})$, and by $x_1^* - x_1$ when $h_2 > h^*(x_1^{**})$. And if he chooses $x_1 > x_1^*$, in period 1, the cost of the precautions would increase by $x_1 - x_1^*$ and the expected damages would decrease by $p(x_1^*)h_1 - p(x_1)h_1$, and in period 2, his expected costs would decrease by either $x_1 - x_1^*$ or by at most the entire social cost if $h_2 < h^*(x_1^{**})$, and by $x_1 - x_1^*$ if $h_2 \geq h^*(x_1^{**})$. And if he chooses $x_1 \geq x_1^{**}$, his expected cost amounts to

$$C(x_1) = x_1 + \int_{h^*(x_1)}^{\infty} [x^*(h_2) - x_1] f(h_2) dh_2, \tag{15}$$

which is minimized if he chooses $x_1 = x_1^{**}$, because if he chooses $x_1 > x_1^{**}$, in period 1, he would pay $x_1 - x_1^{**}$ more, and in period 2, he would have only a chance to pay at best $x_1 - x_1^{**}$ less. More precisely, he would have nothing less to pay if $h_2 < h^*(x_1^{**})$, he would have $x^*(h_2) - x_1^{**}$ less to pay if $h^*(x_1) > h_2 \geq h^*(x_1^{**})$, and he would have $x_1 - x_1^{**}$ less to pay if $h_2 \geq h^*(x_1)$.

But if the potential injurer chooses x_1^{**} rather than x_1^* in period 1, his expected cost will not necessarily be greater. If $p(x_1^{**})$ is sufficiently close to zero, than $p(x_1^{**})h_1$ and $p(x_1^{**})h_2$ are negligible, and it does not matter that, when he is negligent, the potential injurer is liable for any harm that arises, including the harm that would have happened even if he had taken due care (because the harm that would have happened if he had taken due car would be approximately zero). In that case, the potential injurer will take x_1^*. But if $p(x_1^{**})$ is sufficiently close to one, the potential injurer will choose x_1^{**}. The reason is that if he chose x_1^* in period 1, he would choose to take $x_1^{**} - x_1^*$ in period 2 if $h_2 < h^*(x_1^{**})$. This means that there is no point in not already taking x_1^* in period 1, since it would reduce the expected damages in that period.

4. CONCLUSION

When there is uncertainty, it may be socially optimal to wait to take a precaution. The main point of this article is that the value of waiting to take a precaution should be taken into account to set the required level of precaution. If it is not the case, a potential injurer will act optimally if he is liable only for the harm caused by his negligence. But, if he is liable for any harm that arises, including the harm that would have happened even if he had taken due care, he might be encouraged to take too much precaution. This result was demonstrated in a simple two-period model, but the value of waiting to take a precaution must of course be taken into account each time a required level precaution must be set.

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