Comparisons of the Incentive for Insolvency under Different Legal Regimes

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Abstract

This paper investigates the effects of potential insolvency on decisions for waste production under several only (independent) and joint and several (shared) liability within the context of Superfund. Our main result is that increased potential liability causes firms to decrease asset exposure, but may also lead firms to create less waste. First, we find that both several only and joint and several liability induces firms to go bankrupt more often and create more waste than would be the social optimum. Then we find that, for a given level of wealth, joint and several liability induces firms to go bankrupt more often and create more waste than several only liability. This implies that society will be responsible for a larger share of cleanup under joint and several liability than under several only liability. Finally, we show that firms with potentially higher liabilities for cleanup will raise less funds in the capital markets, creating "smaller" firms, and thus, the possibility of less waste generated overall.

1 Introduction

In response to the public outcry over Love Canal in 1978, Congress passed the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), commonly know as Superfund.[1] The Superfund legislation created a system for assessing the liability of firms that generate toxic waste. This comprehensive liability scheme provides some of the most powerful incentives for firms to prevent release of hazardous substances. Two related problems of

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[1]U.S. Code - Title 42, Chapter 103.

insolvency arise under this statutory regime, however. Some firms held liable for waste disposal may not be able to pay all of their assessed liability; and firms may "disappear" between the time of waste disposal and the time of liability assessment so that they cannot pay *any* of their assessed liability.[2]

Two different legal regimes are commonly used to govern situations with multiple tortfeasors: joint and several liability, under which solvent firms are held liable for the liability attributed to insolvent firms; and several only liability, under which all firms are held liable only for their apportioned share of the liability. In their analysis of liability and negligence rules, Kornhauser and Revesz (1990) find that when firms have predetermined "exogenous" solvencies, neither rule dominates the other in terms of social welfare.[3]

The assumption of fixed solvencies, however, is problematic. In response to the legal regime, firms may alter their solvencies to avoid future liability. The solvencies that firms choose, then, are "endogenous" to the legal regime. Furthermore, this choice of solvency may also affect the likelihood that the firm will disappear, and liability will not be assessed against the firm. This paper extends the Kornhauser and Revesz (1990) model by incorporating an endogenous probability of insolvency and an endogenous solvency.[4] We find that, while firms generate less waste under a joint and several liability rule, firms become insolvent more often. Therefore, the policy maker must balance the environmental gains from a joint and several liability regime with an increase in unfunded liability.[5]

Our model explores this trade-off. Two waste generating firms deposit waste at a site. Both can choose their solvency levels and the amount of waste generated. Increased solvency of a firm is a double edged sword – a firm derives benefit from assets, but a high level of assets implies that a firm has "deep pockets" – it is more likely to be solvent when liability is assessed, and therefore, more likely to pay the share of liability attributable to insolvent firms. Our main result is that increased potential liability causes firms to decrease asset exposure, but may also lead firms to create less waste. First, we find that both several only and joint and several liability induces firms to go bankrupt more often and create more waste than would be the social optimum. Then we find that, for a given level of wealth, joint and several liability induces firms to go bankrupt more often and create more waste than several only liability. This implies that society will be responsible for a larger share of cleanup under joint

[2] The firm may thus disappear in two ways. It may literally have dissolved prior to the release of toxic waste into the environment and hence may not be available for suit. Or it may have no assets. As CERCLA applies to sites that pre-existed statutory requirements for record keeping, the identify of some or all of generators who deposited waste at the site are unknown at many sites on the National Priorities List. These generators have also disappeared, leaving behind their "orphan shares."

[3] Throughout this paper, we define social welfare to be the sum of the benefits of generating waste for the firms, less the cost to the environment of this generation.

[4] We use the words bankruptcy and insolvency interchangeably throughout the paper.

[5] We do not address an important (and controversial) policy issue concerning retrospective liability. Because CERCLA assesses liability *ex post*, if firms "disappear" between the time of depositing waste and the time of liability assessment, the identification of orphan shares of liability at a waste site is oftentimes difficult.

and several liability than under several only liability. Finally, we show that firms with potentially higher liabilities for cleanup will raise less funds in the capital markets, creating "smaller" firms, and thus, the possibility of less waste generated overall.

The paper proceeds by presenting a brief literature review in section 2. Section 3 develops the preliminaries of the model, notation, and assumptions. Section 4 presents the baseline social welfare maximizing case. Section 5 investigates the problem with possible insolvency. Section 6 concludes with possible avenues for further research.

2 Literature Review

Under Superfund, all firms that deposit waste into a particular site are jointly and severally liable for the loss to society it causes, unless the firms can prove that the harm is "divisible," or uniquely attributable to one party or another. Kornhauser and Revesz (1990) develop the basic two-player non-cooperative model for waste disposal with the possibility of insolvency. They find that neither several only liability nor joint and several liability dominates the other from a social welfare perspective, which they define as the sum of the benefits from the firms that produce waste, less the cost to society of waste generation. Two other recent papers, Yahya (2000) and Watts (1998) build on Kornhauser and Revesz (1990) and use a non-cooperative game framework. Watts (1998) examines this problem from the perspective of a Cournot quantity game. She also incorporates an exogenous probability of insolvency, which is not affected by the strategies the firms choose. She finds that neither liability rule dominates the other in terms of social welfare.

Yahya (2000) endogenizes the solvency condition. However, he approaches the problem in a much different manner than that used in this paper. Specifically, he treats the solvency decision as separate from the waste generation decision; i.e., he models the optimal debt-equity ratio decision of a firm under the possibility that an accident may occur. More debt induces less liability; however, more debt increases the possibility of bankruptcy and ensuing bankruptcy costs. Therefore, while he endogenizes the solvency condition, he does not explicitly connect the solvency condition and waste generation decision. In that sense, then, he does not examine solvency as part of the production process per se, he merely looks at it in terms of the financial structure of the firm. In our model, solvency has real benefits, in terms of how the firm behaves in its production process. Furthermore, as is done in this paper, Yahya does not examine the bankruptcy choice in the context of joint torts; he only examines the effect of joint torts on care.

Hansen and Thomas (1999) address a different yet related aspect of the hazardous waste liability problem. They explore the effects of shared liability between the owner of the waste site and the generator of the waste. They find that a shared liability rule may result in a more efficient outcome than a rule where only the owner of the waste site is held liable. This is because the owners of the waste site that take the least amount of care will also submit the lowest bid for accepting the waste. By sharing the liability between the generator and the owner of the waste site, the adverse selection problem is minimized.

Prior to Kornhauser and Revesz (1990), research on the effects of insolvency was not generally integrated with research concerning multiple tortfeasors. Shavell (1987), summarizes the effects of bankruptcy on care and the effects of multiple tortfeasors on care, but does not combine the two. Shavell summarizes by stating that "care" (in the framework used here, negative waste) is increasing in the assets of a firm.[6] Beard (1990) also analyzes a one-person, optimal care game with the possibility of bankruptcy, and shows that Shavell's conclusions may not be robust to all formulations of the problem.

Ringleb and Wiggins (1990) take an empirical approach to the problem. They study industries with high liability for waste and explore the entry of small companies into hazardous industries with the advent of liability rules. They find that a statistically significant number of firms entered these industries with the advent of the new liability rules under CERCLA. They posit that this entry is primarily through divestiture, in order to reduce liability overall to the larger firms from which the smaller firms were created. However, there are two caveats with their approach. One, they fail to provide a formal model for this phenomenon, and instead rely on empirical evidence. Two, it is unclear whether firms can avoid liability simply through divestiture. This paper offers a formal model to try to explain this empirically documented phenomenon.

Finally, Boyd and Ingberman (1999) examine a question similar to the one posed here. They examine the effect of punitive damage rules on deterrence of firms. They examine the endogenous capital decision of firms, which in their view, affects deterrence. They find that punitive damage rules may cause firms to under invest in capital, thereby undermining the intended effects of punitive damages, and decreasing overall efficiency. This is similar in some respects to the question examined in this paper, which is the effect of the liability rule on the capital decisions of firms, within a joint torts context. They model a punitive damages situation where firms first choose a level of capital (that may later be exposed to liability) and then choose "deterrence." They find that excess punitive damages will diminish the capital investment decision, and hence, the amount of care that firms take in response. However, their model differs crucially from ours in two aspects. One, they do not assume that the loss depends on the level of care taken; it merely affects the probability of a loss. Our assumption is that the levels of care and loss are directly related. Two, they assume only one actor. By examining two actors, and the associated behaviors of this type of situation, we can begin to build a more complete picture of the effects of legal rules on firms.

[6]See chapter 7, page 182.

3 The Model

The main objective of this paper is to compare the optimizing behavior of firms under different liability regimes for the pollution they and others create. Pollution creation is a double edged-sword for these firms. Firms derive a benefit from generating waste. However, the waste generated must be deposited somewhere and once deposited, may create environmental costs and, as a result of the liability regime, potential damages to pay.

A simple example will help. There are two companies, 1 and 2. Each wants to build a plant in an industrial park with a shared waste management system. In order to do so, each must raise funds in the capital markets. Once the companies raise the funds, they decide how to allocate these funds to two different purposes. One purpose for the funds is to invest in a production technology which creates environmental waste that is dumped. The other purpose for the funds is to invest in a technology that does not create waste, but creates physical assets – for example, the physical plant or the machines in the plant. Assume that the technology that creates the waste is not valued by creditors in the case of insolvency, but the assets are available to creditors in the case of insolvency.

The share of funds that the companies decide to allocate to the technology that creates waste and the technology that creates assets depends on three factors. The first is the production process. The companies derive benefit from creating waste. In addition, the technology that creates waste may make the assets valued by creditors marginally more productive, marginally less productive, or have no effect. Similarly, the companies derive benefit from assets. The technology that creates assets may also make the waste production marginally more productive, marginally less productive, or have no effect. There are also costs associated with investing in each of these technologies.

The second factor that determines the allocation of funds is the potential for insolvency. We assume that there is some possibility that each one of the companies may become insolvent before liability is assessed. This probability of insolvency depends on the share of funds allocated to assets. More assets implies a lower expected probability of insolvency, and also, a lower variance of the rate of insolvency.

The third factor that determines the allocation of funds is the governing legal rule. The two companies dump the waste. The companies are responsible for cleaning up the waste. The legal rule dictates how the companies share responsibility for waste production. There are three main attributes of the legal rule. One part is the environmental harm created by the two companies dumping. The second part is that the two companies share responsibility for this harm. The third part is that company 1 may become responsible for company 2's share of the harm if company 2 goes insolvent, and vice versa. The probability of becoming insolvent depends on the share of the funds allocated to creating assets. The responsibility for cleanup of the waste in the case of insolvency depends on the legal rule.

The production process, the possibility of insolvency and the legal rule imply that the decision of one company affects the decision of the other company. Thus the shares of funds allocated by company 1 affects the shares of funds allocated by company 2, and vice versa.

The result is the following. When company 1 and company 2 raise money in the capital markets, they raise relatively less funds when the companies are held responsible for the environmental damage caused by the other, if the other should become insolvent. Two intuitive explanations exist. On the supply side, company 1 and company 2 may have a harder time finding investors because of the added portfolio risk. On the demand side, company 1 and company 2 may not desire to raise as much funds for a riskier investment. The net result is that there are less funds to divide between waste and assets. Thus less waste is produced, but less assets are created. The companies are more likely to become insolvent and less likely to pay their share of liability.

3.1 The Firms, the Production Technology, and the Environmental Loss

In this section, we begin the description of our formal model.[7]

Assume there are two profit-maximizing firms, $i = 1, 2$. Both use the same production technology to produce identical goods. There are two main attributes of the production process. First, the firm must generate capital in the capital markets, denoted W_i. Some of the capital goes towards a technology that creates assets. The amount of assets is denoted by k_i and the price of assets is denoted r_k. Note that r_k could potentially be interpreted as the return on physical assets in the market. The second attribute of the production process is that there is a technology that creates waste, x_i, which the firm then deposits into the environment. We assume that the sum of $r_k k_i$ and x_i must be less than or equal to W_i.

A greater amount of assets allows the firm to operate on a larger scale. This benefits the firm. However, these physical assets exhibit decreasing returns to scale: as the total amount of assets increases, the marginal benefit of the assets decreases. Similar to our assumption about physical assets in the production process for the firm, we assume that waste generation exhibits decreasing returns to scale: as the total amount of waste increases, the marginal benefit from generating waste decreases. The question arises as to how physical assets and waste interact in production. It may either be that (1) as more physical assets are used, the marginal benefit to the firm of generating waste increases (complements), or (2) as more physical assets are used, the marginal benefit to the firm of generating waste decreases (substitutes). Arguably the former is more realistic. Assuming that waste and physical assets are complements implies that if a firm has a greater amount of physical assets, the benefits of waste production to the firm increase. Assuming that waste and physical assets are substitutes implies that if a firm has a great deal of physical assets, it may have access to cleaner technology, or that firms with a larger amount of physical

[7]Much of the notation in this paper parallels that of Kornhauser and Revesz (1989).

assets may have other incentives not to generate as much waste. Nevertheless, waste and physical assets are never perfect substitutes in production. This implies that, in equilibrium, all firms must use some capital and generate some waste.

Formally, we can express this as follows. Let $B_i(x_i, k_i)$ be the benefit function for firm i. This function is strictly concave, continuous, and three times differentiable, which implies

$$\frac{\partial B_i(x_i,k_i)}{\partial x_i} > 0, \frac{\partial B_i(x_i,k_i)}{\partial k_i} > 0, \frac{\partial^2 B_i(x_i,k_i)}{\partial x_i^2} < 0, \frac{\partial^2 B_i(x_i,k_i)}{\partial k_i^2} < 0,$$

$$\text{and } \frac{\partial B_i(x_i,k_i)}{\partial x_i \partial k_i} > 0 \text{ or } \frac{\partial B_i(x_i,k_i)}{\partial x_i \partial k_i} < 0.$$

The last expression depends on whether waste and physical assets are complements are substitutes.

Furthermore, we assume that

$$\begin{aligned} \lim_{x_i \longrightarrow 0} \frac{\partial B_i}{\partial x_i} &= \infty \text{ and } \lim_{x_i \longrightarrow 0} \frac{\partial B_i}{\partial k_i} = \infty; \\ \lim_{x_i \longrightarrow \infty} \frac{\partial B_i}{\partial x_i} &= 0 \text{ and } \lim_{x_i \longrightarrow \infty} \frac{\partial B_i}{\partial k_i} = 0, \end{aligned}$$

which implies that all firms create some waste and use some assets in equilibrium.

The technology that creates assets is costly to the firm. We assume that the associated cost function, $c(k_i)$, which is identical across firms, is strictly positive and increasing, continuous, and three times differentiable, which implies that $c'(k_i) > 0$ and $c''(k_i) \geq 0$.[8]

The above assumptions imply firm i's profit function,

$$\Pi_i(x_i, k_i) = B_i(x_i, k_i) - c(k_i).$$

The benefit of waste generation less the cost of assets yields the firm's profits.[9]

But, there is one more potential cost to the firm – damages for polluting the environment. Because we have assumed the same production technology for both firms, we may further assume that the waste generated by both firms is identical. Furthermore, the effect of the waste generation on the environment is cumulative. While we assume that the marginal private benefits of waste generation decrease as the amount of waste increases, this is not the case for the amount of societal damage resulting from waste generation. More pollution implies more loss to society, and this loss increases at an increasing rate.

[8] We are therefore assuming that no firm has an advantage in acquiring assets over any other. Relaxing this assumption is a possible avenue for further research.

[9] We assume that the firms operate in a perfectly competitive environment, thereby eliminating possible strategic effects that might occur if the two firms were operating in an oligopolisitc market. This would be an interesting avenue for further research.

We define the loss function to be $L = L(x_1, x_2)$. This function captures the cost to society caused by the waste of both firms. Assuming that firms emit identical waste, the loss function is equivalent to

$$L(x_1, x_2) = L(x_1 + x_2) = L(X).$$

We assume that this function is strictly convex, continuous, and three times differentiable, which implies that

$$\frac{\partial L}{\partial x_1} = \frac{\partial L}{\partial x_2} > 0; \frac{\partial^2 L}{\partial x_i^2} = \frac{\partial^2 L}{\partial x_i \partial x_j} > 0; i, j = 1, 2; i \neq j.$$

Furthermore, no waste generated implies no loss to society, and an infinite amount of waste generated implies an infinite amount of loss to society, or

$$\lim_{x_i \longrightarrow 0} \frac{\partial L}{\partial x_i} = 0 \text{ and } \lim_{x_i \longrightarrow \infty} \frac{\partial L}{\partial x_i} = \infty.$$

It is possible that there are regions of the environmental loss function that are concave. For example, suppose that the shared waste management site employed a technology for containing waste that was fairly efficient from an environmental point of view. However, at some point, there is a potential for waste to enter the water system, where no such controls are available. Thus, included under the umbrella of a convex loss function is an infinite cleanup cost; that is, after a certain level of waste, the loss to society would become infinite. In this case, no firm would be able to pay their apportioned liability.

3.2 Insolvency

We now address the focus of this paper: the "disappearing defendant" problem. It may be that the firm becomes insolvent in the time between generating waste through production, and the government's assessment of liability. In our model, we assume that, if the firm is insolvent, it pays none of its share of the liability but that the firm received the benefit of its production; that is the flow of profits precedes the flow of liability. We assume that the probability with which this occurs depends on the level of assets of the firm.

Let T be a continuous random variable with support $\left[\underline{T}, \overline{T}\right]$, and let $p_i(t; k_i)$ denote the probability density function of this random variable with parameter k_i. Let $P_i(t; k_i)$ denote the cumulative distribution function of this random variable, where

$$P_i(t; k_i) = \int_{\underline{T}}^{t} p_i(s; k_i)\, ds.$$

$P_i(t; k_i)$ is the probability that firm i will be insolvent when liability is assessed in state of the world t. This implies that in state of the world $\underline{T}$, the probability that the firm is insolvent is zero (or the firm is always solvent), while in state of the world $\overline{T}$, the firm is always insolvent. If we interpret t to be time, then the probability that the firm disappears is zero if liability is assessed at the time of creating waste, or $\underline{T}$, and the probability that the firm disappears approaches 1 as t goes to $\overline{T}$. Thus the probability that firm i is solvent at time t is simply $1 - P_i(t; k_i)$.

The expectation of this random variable T is

$$E[T] = \int_{\underline{T}}^{\overline{T}} s p_i(s; k_i)\, ds.$$

The assets of the firm, k_i, is a parameter of the distribution function, and thus, the expectation of the random variable T. We assume that

$$\begin{aligned} \frac{\partial E[T]}{\partial k_i} &< 0 \text{ and} \\ \frac{\partial Var[T]}{\partial k_i} &< 0. \end{aligned}$$

This assumption implies that as the assets of firm i increases, the expectation that the firm is insolvent decreases. Moreover, we assume that as the assets of firm i increase, the variance of insolvency decreases. Intuitively, these assumptions make sense. A firm that has a greater amount of assets has a lower probability of becoming insolvent. A lower variance also makes sense for larger firms: large firms are more established and less "variable" in some sense than smaller firms.[10] Finally, we also make the following distributional assumption,

$$\frac{d}{dt}\left(\frac{p_i(t; k_i)}{1 - P_i(t; k_i)}\right) \geq 0,$$

or that the distribution is "increasing," that is, as the time horizon gets longer, the probability that the firm is insolvent increases.[11]

3.3 The Legal Rules: Several Only Liability versus Joint and Several Liability

The analysis below compares two legal rules. The first is a rule of several only liability (SOL) under which each firm is liable only for its apportioned share of the cost of waste deposited at a site. The second rule is joint and several liability with contribution (JSL), under which each firm is potentially held liable for more than its share of the waste deposited at a site.[12] If both parties are

[10] While this may seem to be a restatement of the "too-big-to-fail" hypothesis, evidence exists that younger, smaller, less established firms are more likely to fail than older, more established firms. See, for example, Caves (1998).

[11] We are simply assuming that the function has a monotone hazard rate. Two distributions that exhibit all of these properties are the exponential and the normal.

[12] The legal regime of joint and several liability is very complex, so that regimes of joint and several liability may differ on many dimensions. In the context of two tortfeasors, however, all regimes will have the property we assume: that each firm is responsible for its own share if both are solvent, and for the entire liability if the other tortfeasor is insolvent.

solvent (meaning able to pay their liability) and if the costs of litigation are independent of the rule, then the two rules are equivalent.[13] The two rules differ primarily in who bears the costs of an insolvent defendant – either society (SOL) or another defendant (JSL).

Joint and several liability differs importantly from several only liability because, under joint and several liability, each party may be forced to bear the losses created by the other party. Each firm can reduce its expected liability in either (or both) of two ways: it can decrease the amount of waste it generates or it can reduce the amount of assets it has, thereby reducing the probability that it will pay any of the environmental losses.

In order to make the exposition clearer, we write down the expected liability under several only liability and joint and several liability. In addition, for ease of exposition, we write the problem in terms of pro-rata shares of liability, rather than apportioned shares for liability.[14]

Under several only liability, the expected liability of firm i if liability is assessed at time t^* is

$$\begin{aligned}\text{Expected liability under SOL} &= \left(1-\int_{\underline{T}}^{t^*} p_i\left(s;k_i\right)ds\right)\left(\frac{L\left(x_i+x_j\right)}{2}\right)+\left(\int_{\underline{T}}^{t^*} p_i\left(s;k_i\right)ds\right)(0)\\ &= \left(1-P_i\left(t^*;k_i\right)\right)\left(\frac{L\left(x_i+x_j\right)}{2}\right).\end{aligned}$$

Similarly, under joint and several liability, the expected liability is

$$\begin{aligned}\text{Expected liability under JSL} &= \left(1-\int_{\underline{T}}^{t^*} p_i\left(s;k_i\right)ds\right)\left(1-\int_{\underline{T}}^{t^*} p_j\left(s;k_j\right)ds\right)\left(\frac{L\left(x_i+x_j\right)}{2}\right)\\ &\quad+\left(1-\int_{\underline{T}}^{t^*} p_i\left(s;k_i\right)ds\right)\left(\int_{\underline{T}}^{t^*} p_j\left(s;k_j\right)ds\right)\left(L\left(x_i+x_j\right)\right)\\ &\quad+\left(\int_{\underline{T}}^{t^*} p_i\left(s;k_i\right)ds\right)(0)\\ &= \left(1-P_i\left(t^*;k_i\right)\right)\left(1-P_j\left(t^*;k_j\right)\right)\left(\frac{L\left(x_i+x_j\right)}{2}\right)\\ &\quad+\left(1-P_i\left(t^*;k_i\right)\right)\left(P_j\left(t^*;k_j\right)\right)\left(L\left(x_i+x_j\right)\right)\\ &= \left(1-P_i\left(t^*;k_i\right)\right)\left(1+P_j\left(t^*;k_j\right)\right)\left(\frac{L\left(x_i+x_j\right)}{2}\right).\end{aligned}$$

These expressions imply that the expected liability of firm i depends critically on both the assets and waste generation of the firm j. Under several only liability, the expected liability of firm i depends explicitly on the waste generation of firm

[13] Note that we are ignoring litigation costs in this framework. One legal rule may dominate the other in terms of social efficiency depending on the distribution of these costs.

[14] This implies that we divide the loss by two, rather than using apportioned shares, where the share for firm i is $x_i/\left(x_i+x_j\right)$. Our qualitative results will not change if this assumption is relaxed, and if the environmental damage is “convex enough.”

j and implicitly on the assets of firm j, while under joint and several liability, the expected liability of firm i depends explicitly on *both* the waste generation and assets of firm j. The expected liability in both regimes also depends on the time at which liability is assessed, t^*.

The question remains as to how the expected liability changes with an increase in the amount of assets of a firm. First, assume that the constraint on assets and waste is binding, or $r_k k_i + x_i = W_i$. Holding the assets of the other firm constant, we need to investigate the same condition under both regimes:

$$\begin{aligned} & \frac{\partial}{dk_i}\left(\left(1-P_i\left(t^*;k_i\right)\right)\left(\frac{L\left(W_i-r_k k_i+x_j\right)}{2}\right)\right) \\ = \quad & -\frac{\partial P_i}{\partial k_i}\left(\frac{L\left(W_i-r_k k_i+x_j\right)}{2}\right)-r_k\left(1-P_i\left(t^*;k_i\right)\right)\left(\frac{1}{2}\right)\left(\frac{\partial L}{\partial x_i}\right). \end{aligned}$$

The first expression is greater than zero, and represents the increase in the expected value of the liability, due to a decrease in the expected probability of insolvency. The second term is less than zero, and represents the decrease in the expected value of the liability due to a decrease in the level of waste.

There are two cases to consider:

- Expected liability increases with assets.

For the expected value of the liability to increase with assets, the following must hold:

$$-\frac{\partial P_i}{\partial k_i}\left(\frac{L\left(W_i-r_k k_i+x_j\right)}{2}\right)-r_k\left(1-P_i\left(t^*;k_i\right)\right)\left(\frac{1}{2}\right)\left(\frac{\partial L}{\partial x_i}\right)\geq 0.$$

Rewriting, this implies that

$$\frac{-\dfrac{\partial P_i}{\partial k_i}}{\left(1-P_i\left(t^*;k_i\right)\right)}\geq\frac{r_k\left(\frac{1}{2}\right)\dfrac{\partial L}{\partial x_i}}{L\left(x_i+x_j\right)}. \tag{1}$$

- Expected liability decreases with assets.

This implies

$$\frac{-\dfrac{\partial P_i}{\partial k_i}}{\left(1-P_i\left(t^*;k_i\right)\right)}\leq\frac{r_k\left(\frac{1}{2}\right)\dfrac{\partial L}{\partial x_i}}{L\left(x_i+x_j\right)}.$$

Either of these could potentially hold, but the following line of reasoning shows that the expected value of the liability increasing in the level of assets is more realistic (and more interesting for our problem as a whole). Return to the simple example of two plants dumping in a shared site. If the company dumps a little more or a little less waste, it may be unlikely that the damage changes all that much. Moreover, infinite damage to society (or "very large" cleanup costs) are included under this assumption. This scenario describes the magnitude of the losses, not the marginal effects. Letting the loss goes to infinity implies

$$\frac{-\dfrac{\partial P_i}{\partial k_i}}{\left(1 - P_i\left(t^*; k_i\right)\right)} \geq 0.$$

This must necessarily be the case. The denominator of this expression is a probability. Because all firms use some physical assets in equilibrium, the denominator is bounded above zero. The numerator of this expression is greater than or equal to zero, due to our distributional assumptions.

3.4 Timing of the Game

The timing of the game is:

- Stage 0: Firms raise funds in the market, denoted as W_i, $i = 1, 2$.
- Stage 1: Firms simultaneously choose how to allocate W_i to x_i and k_i, with the constraint that $x_i + r_k k_i \leq W_i$. Firms are aware of the legal rule to which they will be subject at a later date.
- Stage 2: The firms produce.
- Stage 3: At time t^*, the regulator implements the legal rule, and the regulator assesses liability.

4 Benchmark Equilibria: Maximizing Social Welfare

We use the social welfare maximizing solution as a benchmark. To determine the social welfare maximizing solution, we assume that there exists a social planner who chooses both the level of capital used and the amount of waste generated by both firms. The social planner will choose to maximize the sum of the benefits to the two firms of using capital and generating waste, less the cost to society of generating waste.[15] The social planner will internalize all externalities stemming from the joint waste generation problem. The social planner also assumes all firms are perfectly solvent when liability is assessed, thus placing the burden for cleanup squarely on the two firms. We define the social optimum as the solution to this problem.

In terms of our model, the social planner chooses levels of waste and assets to solve

$$\Gamma^* = \max_{x_1, k_1, x_2, k_2} B_1\left(x_1, k_1\right) + B_2\left(x_2, k_2\right) - c\left(k_1\right) - c\left(k_2\right) - L\left(x_1 + x_2\right) \qquad (2)$$

[15] The goal of a legal liability rule may or may not be the achievement of these particular optimal conditions, and the rule may add or subtract other components to society's welfare.

subject to the constraints

$$\begin{aligned} r_k k_1 + x_1 &\leq W_1 \text{ and} \\ r_k k_2 + x_2 &\leq W_2. \end{aligned} \tag{3}$$

In this sense, the social planner takes the value of the firms given by the market, and chooses the optimal amount of waste and assets subject to these constraints. Let $\lambda_i, i = 1, 2$ denote the Lagrangean multipliers associated with the constraints in (3). The first order conditions for this problem are

$$\frac{\partial \Gamma^*}{\partial x_i} = \frac{\partial B_i}{\partial x_i} - \frac{\partial L}{\partial x_i} - \lambda_i = 0, \; i = 1, 2 \text{ and} \tag{4}$$

$$\frac{\partial \Gamma^*}{\partial k_i} = \frac{\partial B_i}{\partial k_i} - c'(k_i) - \lambda_i r_k = 0, \; i = 1, 2. \tag{5}$$

The social planner sets the marginal benefit of generating waste equal to the marginal cost of generating waste, and likewise for the marginal benefit of using assets equal to the marginal cost of using assets.

Assuming an interior solution will imply that the constraints are binding. Solving the first order conditions gives the socially optimal levels of $x_i^*(W_i, W_j, r_k, t^*)$ and $k_i^*(W_i, W_j, r_k, t^*)$, $i = 1, 2, \; i \neq j$ as a function of the funds raised by each firm in the market, the price of assets, and the time of implementation of the legal rule.

Substituting the socially optimal level of waste and assets into the welfare equation yields our baseline level of social welfare,

$$\Lambda^* = B_1(x_1^*, k_1^*) + B_2(x_2^*, k_2^*) - c(k_1^*) - c(k_2^*) - L(x_1^* + x_2^*). \tag{6}$$

5 Insolvency

With the above benchmark in mind, we now examine the effect of the different legal rules on the decision for insolvency in a non-cooperative framework. We denote the equilibria under this regime as $\left(x_i^{SOL}, k_i^{SOL}\right), i = 1, 2$ for several only liability and $\left(x_i^{JSL}, k_i^{JSL}\right), i = 1, 2$ for joint and several liability.

5.1 Several Only Liability

Our two firms are now simultaneously and non-cooperatively choosing how to allocate wealth between waste and assets. This is equivalent to a situation where there may be some delay in the decision to emit waste, but the two firms do not know the other's potential solvency or the level of the other's assets. The basic premise is that both firms cannot adjust waste levels according to the solvency of the other firm.

- The Maximization Problem

Under several only liability, firm i chooses to allocate wealth W_i to waste and assets to solve

$$\Gamma_i^{SOL} = \max_{x_i, k_i} \quad B_i\left(x_i, k_i\right) - c\left(k_i\right) - \left(1 - P_i\left(t^*; k_i\right)\right)\left(\frac{L\left(x_i + x_j\right)}{2}\right) \tag{7}$$

subject to the constraint

$$r_k k_i + x_i \leq W_i, , i, j = 1, 2, i \neq j. \tag{8}$$

The first order conditions for this problem are

$$\frac{\partial \Gamma_i^{SOL}}{\partial x_i} = \frac{\partial B_i}{\partial x_i} - \left(1 - P_i\left(t^*; k_i\right)\right)\left(\frac{1}{2}\right)\frac{\partial L}{\partial x_i} - \lambda_i = 0, \; i = 1, 2 \text{ and} \tag{9}$$

$$\frac{\partial \Gamma_i^{SOL}}{\partial k_i} = \frac{\partial B_i}{\partial k_i} - c'\left(k_i\right) + \frac{\partial P_i}{\partial k_i}\left(\frac{L\left(x_i + x_j\right)}{2}\right) - \lambda_i r_k \tag{10}$$
$$= 0, \; i = 1, 2.$$

Assuming an interior solution will imply that the constraints are binding. Solving the first order conditions gives the levels of waste and assets as a function raised by each firm in the market, the price of assets, and the time of implementation of the legal rule, namely $x_i^{SOL}\left(W_i, W_j, r_k, t^*\right)$ and $k_i^{SOL}\left(W_i, W_j, r_k, t^*\right), \; i = 1, 2, \; i \neq j$.

Substituting these values into the welfare equation yields the level of welfare under several only liability:

$$\begin{aligned} \Lambda^{SOL} = \; & B_1\left(x_1^{SOL}, k_1^{SOL}\right) + B_2\left(x_2^{SOL}, k_2^{SOL}\right) \\ & - c\left(k_1^{SOL}\right) - c\left(k_2^{SOL}\right) - L\left(x_1^{SOL} + x_2^{SOL}\right). \end{aligned} \tag{11}$$

- Investigating the Equilibrium

As a first step, we want to look at how a hypothetical change in the level of waste from firm 1 will affect the waste decision of firm 2. Suppose that firm 1 decreases its waste generation, and increases its usage of assets. It may be the case that firm 2 decides to increase the level of assets it uses because firm 1 is now less likely to be insolvent, or firm 2 decides to decrease the amount of assets it uses, because the total amount of waste in the environment has decreased, and therefore, firm 2 wants to increase its waste generation. Note again that we are not describing the ultimate equilibrium; rather, we are just discussing how firm 2 may react to a change in waste from firm 1.

It is important to note that holding the levels of wealth constant, it may be the case that if firm 1 decreases its amount of waste, then firm 2 may decrease its amount of waste as well. This may happen under the following scenario. Suppose that firm 1 is close to insolvent, while firm 2 is very solvent. If firm 1 decreases the amount of waste it emits, there will be less for firm 2 to clean up. The possibility of firm 1's insolvency has made firm 2 generate more waste as well; if firm 1 cleans up its act, it may be good for firm 2 to do so as well. This is a similar result as found in Kornhauser and Revesz (1990). However, this is under a scenario where presumably, the expected value of the liability under insolvency may be decreasing in the level of assets.

Not surprisingly, then, there are multiple equilibria for this problem. For the purposes of this paper, it is more instructive to examine the region where the equilibria change as a result of the legal rule, and where the constraints on assets and waste are binding. This rules out equilibria where one or both of the firms exit (or never enter) production, because the expected cost of cleanup is too high. This may be informative from a social policy perspective, however, and would be interesting for further research.

We assume that we are examining a scenario where the reaction function of firm i is decreasing in x_j, or equivalently,

$$x_i'(x_j) < 0,$$

where $x_i'(x_j)$ denotes the reaction function of firm i to a change in the waste level of firm j.

For the equilibrium to be stable, the following condition must hold:

$$|x_i'(x_j)| \left|x_j'(x_i)\right| < 1, \tag{12}$$

and we can now show the following Proposition.

Proposition 1 *For given levels of W_i and W_j, $x_i^{SOL} > x_i^*$ and $k_i^{SOL} < k_i^*$.*

Proof. This result is easier to see if we assume the constraints are binding, solve for the optimal waste decision under both regimes, and prove by contradiction.

We can rewrite (4) and (9) as

$$\begin{aligned}
\frac{\partial \Gamma^*}{\partial x_i} &= \frac{\partial B_i}{\partial x_i} - \frac{\partial L}{\partial x_i} - \frac{\partial B_i}{\partial k_i} + r_k c'(k_i) = 0 \text{ and} \\
\frac{\partial \Gamma_i^{SOL}}{\partial x_i} &= \frac{\partial B_i}{\partial x_i} - (1 - P_i(t^*; k_i)) \left(\frac{1}{2}\right) \frac{\partial L}{\partial x_i} \\
&\quad - \frac{\partial B_i}{\partial k_i} + r_k c'(k_i) - \frac{\partial P_i}{\partial k_i} \left(\frac{L(x_i + x_j)}{2}\right) \\
&= 0.
\end{aligned}$$

Let $\frac{\partial B_i^*}{\partial x_i^*}$ denote the function $\frac{\partial B_i}{\partial x_i}$ evaluated at the point (x_i^*, k_i^*), and likewise for $\frac{\partial B_i^{SOL}}{\partial x_i^{SOL}}$. In order to show that $x_i^{SOL} > x_i^*$, we suppose not, that is, $x_i^{SOL} \leq x_i^*$. This leads to the following string of inequalities:

$$\begin{aligned}
0 &= \frac{\partial B_i^*}{\partial x_i^*} - \frac{\partial L^*}{\partial x_i^*} - \frac{\partial B_i^*}{\partial k_i^*} + r_k c'\left(k_i^*\right) \\
&< \frac{\partial B_i^*}{\partial x_i^*} - \frac{\partial B_i^*}{\partial k_i^*} + r_k c'\left(k_i^*\right) - \left(1 - P_i\left(t^*; k_i^*\right)\right)\left(\frac{1}{2}\right)\frac{\partial L}{\partial x_i^*} \\
&\quad - \frac{\partial P_i}{\partial k_i^*}\left(\frac{L\left(x_i^* + x_j\left(x_i^*\right)\right)}{2}\right) \\
&\leq \frac{\partial B_i^{SOL}}{\partial x_i^{SOL}} - \frac{\partial L^{SOL}}{\partial x_i^{SOL}} - \frac{\partial B_i^{SOL}}{\partial k_i^{SOL}} + r_k c'\left(k_i^{SOL}\right) - \left(1 - P_i\left(t^*; k_i^{SOL}\right)\right)\left(\frac{1}{2}\right)\frac{\partial L}{\partial x_i^{SOL}} \\
&\quad - \frac{\partial P_i}{\partial k_i^{SOL}}\left(\frac{L\left(x_i^{SOL} + x_j\left(x_i^{SOL}\right)\right)}{2}\right) \\
&= 0.
\end{aligned}$$

Contradiction. ■

Thus we find that firms generate more waste and go insolvent more often than would otherwise be the social optimum. Firms do not internalize their entire cost of waste production; hence, we see increased levels of waste.

5.2 Joint and Several Liability

Under several only liability, we know that firms 1 and 2 will be liable for, at most, its respective apportioned share of the total liability. However, under joint and several liability, there is a distinct possibility that given the amount of assets already chosen by the two firms, if firm 1 becomes insolvent, firm 2 will have to pay the liability of firm 1, and vice versa. This possibility creates an incentive for the firms to expand their generation of waste under several only liability relative to that under joint and several liability, for any given amounts of assets used by firms 1 and 2.

- The Maximization Problem

Under joint and several liability, firm i chooses to allocate wealth W_i to waste and assets to solve

$$\Gamma_i^{JSL} = \max_{x_i, k_i} \quad B_i\left(x_i, k_i\right) - c\left(k_i\right) - \left(1 - P_i\left(t^*; k_i\right)\right)\left(1 + P_j\left(t^*; k_j\right)\right)\left(\frac{L\left(x_i + x_j\right)}{2}\right) \tag{13}$$

subject to the constraint

$$r_k k_i + x_i \leq W_i, , i, j = 1, 2, i \neq j. \tag{14}$$

The first order conditions for this problem are

$$\begin{aligned}\frac{\partial \Gamma_i^{JSL}}{\partial x_i} &= \frac{\partial B_i}{\partial x_i} - (1 - P_i(t^*; k_i))(1 + P_j(t^*; k_j))\left(\frac{1}{2}\right)\frac{\partial L}{\partial x_i} - \lambda_i = 0, \quad (15)\\ i &= 1, 2\\ &\text{and}\\ \frac{\partial \Gamma_i^{JSL}}{\partial k_i} &= \frac{\partial B_i}{\partial k_i} - c'(k_i) + \frac{\partial P_i}{\partial k_i}(1 + P_j(t^*; k_j))\left(\frac{L(x_i + x_j)}{2}\right) - \lambda_i r_k \quad (16)\\ &= 0,\ i = 1, 2.\end{aligned}$$

Assuming an interior solution will imply that the constraints are binding. Solving the first order conditions gives the levels of waste and assets as a function raised by each firm in the market, the price of assets, and the time of implementation of the legal rule, namely $x_i^{JSL}(W_i, W_j, r_k, t^*)$ and $k_i^{JSL}(W_i, W_j, r_k, t^*)$, $i = 1, 2,\ i \neq j$.

Substituting these values into the welfare equation yields the level of welfare under joint and several liability:

$$\Lambda^{JSL} = B_1\left(x_1^{JSL}, k_1^{JSL}\right) + B_2\left(x_2^{JSL}, k_2^{JSL}\right) - c\left(k_1^{JSL}\right) - c\left(k_2^{JSL}\right) - L\left(x_1^{JSL} + x_2^{JSL}\right). \quad (17)$$

- Investigating the Equilibrium

Just as with several only liability, our problem is subject to multiple equilibria. Again, however, we assume that we are examining a scenario where the reaction function of firm i is decreasing in x_j, or equivalently, $x_i'(x_j) < 0$. At the same time, this implies that $x_i'(k_j) > 0$.

Similar to several only liability, we have the following Proposition.

Proposition 2 *For given levels of W_i and W_j, $x_i^{JSL} > x_i^*$ and $k_i^{JSL} < k_i^*$.*

Proof. Again, this result is easier to see if we assume the constraints are binding, solve for the optimal waste decision under both regimes, and prove by contradiction.

We can rewrite (4) and (15) as

$$\begin{aligned}\frac{\partial \Gamma^*}{\partial x_i} &= \frac{\partial B_i}{\partial x_i} - \frac{\partial L}{\partial x_i} - \frac{\partial B_i}{\partial k_i} + r_k c'(k_i) = 0 \text{ and}\\ \frac{\partial \Gamma_i^{JSL}}{\partial x_i} &= \frac{\partial B_i}{\partial x_i} - (1 - P_i(t^*; k_i))(1 + P_j(t^*; k_j))\left(\frac{1}{2}\right)\frac{\partial L}{\partial x_i}\\ &\quad - \frac{\partial B_i}{\partial k_i} + r_k c'(k_i) - \frac{\partial P_i}{\partial k_i}(1 + P_j(t^*; k_j))\left(\frac{L(x_i + x_j)}{2}\right)\\ &= 0.\end{aligned}$$

Let $\frac{\partial B_i^{JSL}}{\partial x_i^{JSL}}$ denote the function $\frac{\partial B_i}{\partial x_i}$ evaluated at the point $\left(x_i^{JSL}, k_i^{JSL}\right)$. In order to show that $x_i^{JSL} > x_i^*$, we suppose not, that is, $x_i^{JSL} \leq x_i^*$. This leads to the following string of inequalities:

$$
\begin{aligned}
0 &= \frac{\partial B_i^*}{\partial x_i^*} - \frac{\partial L^*}{\partial x_i^*} - \frac{\partial B_i^*}{\partial k_i^*} + r_k c'\left(k_i^*\right) \\
&< \frac{\partial B_i^*}{\partial x_i^*} - \frac{\partial B_i^*}{\partial k_i^*} + r_k c'\left(k_i^*\right) - \left(1 - P_i\left(t^*; k_i\right)\right)\left(1 + P_j\left(t^*; k_j\right)\right)\left(\frac{1}{2}\right)\frac{\partial L}{\partial x_i^*} \\
&\quad - \frac{\partial P_i}{\partial k_i^*}\left(1 + P_j\left(t^*; k_j\right)\right)\left(\frac{L\left(x_i^* + x_j\left(x_i^*\right)\right)}{2}\right) \\
&\leq \frac{\partial B_i^{JSL}}{\partial x_i^{JSL}} - \frac{\partial B_i^{JSL}}{\partial k_i^{JSL}} + r_k c'\left(k_i^{JSL}\right) - \left(1 - P_i\left(t^*; k_i^{JSL}\right)\right)\left(1 + P_j\left(t^*; k_j^{JSL}\right)\right)\left(\frac{1}{2}\right)\frac{\partial L}{\partial x_i^{JSL}} \\
&\quad - \frac{\partial P_i}{\partial k_i^{JSL}}\left(1 + P_j\left(t^*; k_j^{JSL}\right)\right)\left(\frac{L\left(x_i^{JSL} + x_j\left(x_i^{JSL}\right)\right)}{2}\right) \\
&= 0.
\end{aligned}
$$

Contradiction. ■

Again, we find that firms generate more waste and go insolvent more often than would otherwise be the social optimum. Firms do not internalize their entire cost of waste production; hence, we see increased levels of waste.

5.3 Comparison of Equilibria

We know that because the firms are acting non-cooperatively, under both legal regimes, the amount of waste each generates in equilibrium will be greater than the socially optimal amount of waste, and the amount of assets each employs is less than the social optimum. The question is how they are relative to one another.

- Several Only Liability versus Joint and Several Liability

We can now show the following:

Proposition 3 *For given levels of W_i and W_j, $x_i^{JSL} > x_i^{SOL}$ and $k_i^{JSL} < k_i^{SOL}$.*

Proof. Using the same logic of Propositions 1 and 2, we assume that $x_i^{JSL} \leq x_i^{SOL}$ and we construct the following string of inequalities:

$$
\begin{aligned}
0 &= \frac{\partial B_i^{SOL}}{\partial x_i^{SOL}} - \frac{\partial B_i^{SOL}}{\partial k_i^{SOL}} + r_k c'\left(k_i^{SOL}\right) - \left(1 - P_i\left(t^*; k_i^{SOL}\right)\right)\left(\frac{1}{2}\right)\frac{\partial L}{\partial x_i^{SOL}} \\
&\quad - \frac{\partial P_i}{\partial k_i^{SOL}}\left(\frac{L\left(x_i^{SOL} + x_j\left(x_i^{SOL}\right)\right)}{2}\right) \\
&< \frac{\partial B_i^{SOL}}{\partial x_i^{SOL}} - \frac{\partial B_i^{SOL}}{\partial k_i^{SOL}} + r_k c'\left(k_i^{SOL}\right) - \left(1 - P_i\left(t^*; k_i^{SOL}\right)\right)\left(1 + P_j\left(t^*; k_j^{SOL}\right)\right)\left(\frac{1}{2}\right)\frac{\partial L}{\partial x_i^{SOL}} \\
&\quad - \frac{\partial P_i}{\partial k_i^{SOL}}\left(1 + P_j\left(t^*; k_j^{SOL}\right)\right)\left(\frac{L\left(x_i^{SOL} + x_j\left(x_i^{SOL}\right)\right)}{2}\right) \\
&\leq \frac{\partial B_i^{JSL}}{\partial x_i^{JSL}} - \frac{\partial B_i^{JSL}}{\partial k_i^{JSL}} + r_k c'\left(k_i^{JSL}\right) - \left(1 - P_i\left(t^*; k_i^{JSL}\right)\right)\left(1 + P_j\left(t^*; k_j^{JSL}\right)\right)\left(\frac{1}{2}\right)\frac{\partial L}{\partial x_i^{JSL}} \\
&\quad - \frac{\partial P_i}{\partial k_i^{JSL}}\left(1 + P_j\left(t^*; k_j^{JSL}\right)\right)\left(\frac{L\left(x_i^{JSL} + x_j\left(x_i^{JSL}\right)\right)}{2}\right) \\
&= 0.
\end{aligned}
$$

Contradiction. ■

Thus we find, at an interior optimum, that firms go bankrupt more often under joint and several liability than under several only liability, and generate more waste under joint and several liability than under several only liability.

The key to understanding these results are the assumptions made on the expected liability in the case of insolvency. If we assume that the expected value of the liability increases in assets, joint and several liability always implies a higher expected liability than several only liability for a given level of assets. Firms recognize this, and adjust asset levels and waste accordingly, in order to reduce this expected liability.

- The Investor's Decision

All of these conclusions so far have been made under fairly restrictive assumptions. But one thought experiment will show our final result, which is that there is less investment in firms under joint and several liability than under several only liability, implying that firms go insolvent more often under joint and several liability, but potentially create less total waste.

Consider a risk averse investor deciding how to invest funds, W_0. We know that if the asset has a positive return, the investor will place at least some funds in the risky asset. Let W_i be the amount of funds that the investor puts into a firm that is subject to liability for waste generation.

We have seen that firms will adjust their waste generation and assets in response to the liability rule. If we assume that these firms operate in a competitive marketplace, and if firms are able to raise the same amount of funds under both liability regimes, W_i, then the expected return to firms under both liability rules should be equal. However, the variance of the investment under joint and several liability must be greater than the variance of the investment under several only liability. This implies that the risk averse investor would require a higher mean return on the investment under joint and several liability than under several only liability.[16] Because there is no "upside" to this risk, due to our assumption that the expected liability increases in assets, this implies that the risk averse investor will invest less funds in an asset with higher variance than with lower variance. This implies that in equilibrium, risk averse investors will place fewer funds into companies that operate under joint and several liability than under several only liability.

Proposition 4 $W_i^{JSL} \leq W_i^{SOL}$.

Proof. In order to show that this is the case, it is sufficient to show that several only liability second order stochastically dominates joint and several liability. We examine the expected profit functions of the firms,

$$\Pi_i^{SOL} = B_i\left(x_i^{SOL}, k_i^{SOL}\right) - c\left(k_i^{SOL}\right) - \left(1 - \int_{\underline{T}}^{t^*} p_i\left(s; k_i^{SOL}\right) ds\right)\left(\frac{L\left(x_i^{SOL} + x_j^{SOL}\right)}{2}\right) \text{ and}$$

$$\begin{aligned}\Pi_i^{JSL} &= B_i\left(x_i^{JSL}, k_i^{JSL}\right) - c\left(k_i^{JSL}\right) \\ &\quad - \left(1 - \int_{\underline{T}}^{t^*} p_i\left(s; k_i^{JSL}\right) ds\right)\left(1 + \int_{\underline{T}}^{t^*} p_j\left(s; k_j^{JSL}\right) ds\right)\left(\frac{L\left(x_i^{JSL} + x_j^{JSL}\right)}{2}\right).\end{aligned}$$

Assume that $\Pi_i^{SOL} = \Pi_i^{JSL}$. Π_i^{JSL} puts a relatively greater share of the funds in the risky assets than Π_i^{SOL}. Assuming there is a riskless outside option in which to invest, these risk averse investors will put relatively more funds in the riskless asset under JSL than under SOL. This implies that there is less investment overall in firms under joint and several liability than under several only liability. ■

This decrease in funds under JSL implies that the firms are smaller. Smaller firms implies less waste, and less solvent firms.

Note, however, that we are holding the number of firms constant. If the number of firms is allowed to vary, and there are a greater number of smaller firms, total waste generation potentially increases. Several only liability will not have this affect, and social welfare calculations should take this affect into account.

6 Conclusions and Suggestions for Further Research

This paper extends the model in Kornhauser and Revesz (1990) by endogenizing the solvency decision of firms in the face of possible liability. We have found that

[16]Under our assumption of the expected payout increasing in the level of assets, this must necessarily be the case. Another way of looking at this is that several only liability second order stochastically dominates joint and several liability.

an endogenous solvency framework causes firms to “disappear” more often under joint and several liability than under several only liability. However, joint and several liability may also reduce the amount of waste generated by decreasing the amount invested in these potentially waste generating firms. Although the government and taxpayers potentially bear a greater share of the cleanup cost under joint and several liability, it may be the case that the cleanup cost is lower under joint and several liability than under several only liability, due to lower amounts of waste produced. The change in capital structure of the firms and the resulting inefficiencies should not be slighted, however.

Our results may not be robust to other sets of assumptions, and may change if things are not as “well-behaved.” In addition, we assume a fixed number of firms. Increasing the number of firms allowed to dump in a site may change our results.

There are many possible extensions of the model. One would be to relax the (implicit) assumption of perfect competition of the two firms in their primary production market. Strategic waste dumping may occur if the two firms compete in the market for goods or the market for funds, and are able to affect the equilibrium price in one or both of these markets. Another extension would be to examine the optimal number of firms dumping at a site. There may be a point where the potential for insolvency outweighs the potential for paying for cleanup, leading to a less stable equilibrium than that described here. Other extensions would include a full set of welfare calculations based on the various scenarios.

The essence of the matter is this. Generating more waste increases the harm to the environment, and possibly increases liability. Higher assets raises exposure to liability. Under joint and several liability, the total amount of waste generated may decrease, but firms are more likely to go bankrupt than under several only liability. By explicitly incorporating capital and waste as decision variables for the firm, we can gain insight into the optimal behavior of firms under different liability rules.

References

[1] Beard, T. Randolph. “Bankruptcy and Care Choice,” *Rand Journal of Economics*, vol. 21, 1990, p. 626-634.

[2] Boyd, James and Ingberman, Daniel E. “The Search for Deep Pockets: Is ‘Extended Liability’ Expensive Liability?” *Journal of Law, Economics and Organization*, vol. 13, 1997, p. 232 ff.

[3] Boyd, James and Ingberman, Daniel E. “Do Punitive Damages Promote Deterrence?” *International Review of Law and Economics*, vol. 19, March 1999, p. 47-68.

[4] Caves, Richard E. "Industrial Organization and New Findings on the Turnover and Mobility of Firms," *Journal of Economic Literature*, vol. 36, no. 4, December 1998, p. 1947-1982.

[5] Dixit, Avinash. *Optimization in Economic Theory.* Oxford: Oxford University Press, 1990.

[6] Hansen, Robert G. and Thomas, Randall S. "The Efficiency of Sharing Liability for Hazardous Waste: Effects of Uncertainty Over Damages," *International Review of Law and Economics,* vol. 19, p. 135-157, March 1999.

[7] Kornhauser, Lewis A. and Revesz, Richard L. "Apportioning Damages Among Potentially Insolvent Actors," C.V. Starr Center for Applied Economics Working Paper No. 89-22, New York University, September 1989.

[8] Kornhauser, Lewis A. and Revesz, Richard L. "Apportioning Damages among Potentially Insolvent Actors," *Journal of Legal Studies*, vol. 19, June 1990, p. 617-651.

[9] Kornhauser, Lewis A. and Revesz, Richard L. "Settlements Under Joint and Several Liability," *New York University Law Review*, vol. 68, no. 3, 1993, p. 427-493.

[10] Laffont, Jean-Jacques. *The Economics of Uncertainty and Information.* Cambridge: MIT Press, 1989.

[11] Pitchford, Rohan. "How Liable Should a Lender Be? The Case of Judgment-Proof Firms and Environmental Risk," *American Economic Review*, vol. 85, no. 5, December 1995, p. 1171-1186.

[12] Ringleb, Al H., and Wiggins, Steven N. "Liability and Large-Scale, Long-Term Hazards," *Journal of Political Economy*, vol. 98, Issue 3, June 1990, p. 574-595.

[13] Samuelson, Paul A. "The Pure Theory of Public Expenditure," *Review of Economics and Statistics*, vol. 36, no. 4, 1954, p. 387-389.

[14] Shavell, Steven. *Economic Analysis of Accident Law.* Cambridge, MA: Harvard University Press, 1987.

[15] Shavell, Steven. "On Moral Hazard and Insurance," *Quarterly Journal of Economics*, vol. 93, no. 4, November 1979, p. 541-562.

[16] Watts, Alison. "Insolvency and Division of Cleanup Costs," *International Review of Law and Economics*, vol. 18, no. 1, 1998. p. 61-76.

[17] Summers, J.S. "The Case of the Disappearing Defendant: An Economic Analysis," *University of Pennsylvania Law Review*, vol. 132, December 1983, p. 145-185.

[18] Wiggins, Steven N. and Ringleb, Al H. "Adverse Selection and Long-term Hazards: The Choice Between Contract and Mandatory Liability Rules," *Journal of Legal Studies*, vol. 21, 1992, p. 189-216.

[19] Yahya, Moinuddin. *Capital Structure in the Law and Regulation.* Unpublished Ph.D. dissertation, University of Toronto, 2000.