University of Alberta

Three Essays in Environmental Economics

by

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Dedication

In memory of late mother, Roselida Were Anyanga (Nyagoro)

Abstract

This body of research is composed of three papers related to critical environmental issues that challenge contemporary society. The first paper considers the impact of extending a lender's liability for environmental damage caused by her borrower in a bilateral moral hazard setting where the lender's actions can influence the distribution of damage realizations. When the firm's asset base is limited relative to the highest possible damage realization, a shift towards greater leverage and more precautionary care is indicated. Extended liability diminishes the firm's solvency prospects.

The second paper examines the implication of alternative *ex-post* liability rules designed to deal with project failure for the nature of contractual arrangements between a foreign investor and a recipient (host) of an energy saving technology. Employing the methods of mechanism design, it is shown that installing liability on the host (she directly controls the failure risk) induces more effort distortion than assigning liability to the investor. Intuitively, installing sanctions on the host diminishes the moral hazard problem, but simultaneously intensify the adverse selection aspects of the agency problem, thereby, increasing the cost of using high-powered incentive schemes.

The third paper refines the second paper by (a) explicitly allowing the foreign investor to have some input into the technology transfer process, and (b) admitting the possibility of private knowledge of wealth on the part of the host. When the investor is held strictly liable, the optimal contract indicates a shift towards more effort by the investor. On the other hand, when the liability is installed on the host, the rent-efficiency trade off arising yields an incentive to overburden the host with too much investment. And the tendency to overburden the host is more significant the higher the host's wealth endowment.

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Contents

1. Introduction

Over the last several decades, environmental matters have gained more attention and concern both nationally and globally. At the local level, producers have been forced to take the environmental consequences of their actions more seriously as people, governments and pressure groups increasingly demand environmentally friendly production. Responsibility for adverse environmental outcomes has not been limited to producers, however. Increasingly, even third parties with whom producers interact, such as lenders, are being exposed to environmental legal liability generated by producers' activities. The most well known piece of legislation in this regard is the US Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). Under the act, a lender may be held liable for hazardous waste cleanup costs if she involved herself in the debtor's operations. More importantly, the act appears to inspired similar legislations in Canada, the United Kingdom and the broader EU (Boyer and Laffont, 1996).

At the global level, the land mark Kyoto Protocol recognizes the adverse impact of human activity on global climate and not only imposes binding commitment on countries to reduce their emissions of anthropogenic green house gases, but also establishes a set of mechanisms to facilitate international transfer of technology as means to mitigate climate change (UN, 2000). One such mechanism is the clean development mechanism (CDM), which allows industrialized countries to meet their domestic emissions requirements by undertaking carbon mitigation projects (offset projects) in developing countries. A second mechanism allows countries to trade in emission reduction credits.

The changing environmental regulatory regime and economic environment presents both challenges and opportunity, but also raises a number of interesting research issues for the regulation of environmental externalities. Will the society be better off in a setting where a lender can be held liable for environmental damages caused by its borrower than in a setting where extended liability does not exist? Will the incentive to exercise precaution be higher under extended liability? How does extending a lender's liability affect the nature of contractual relationship between the lender and the borrower? Suppose that there is market place in which future expected emissions credits can be securitized through derivative instruments such as options and futures and traded in the securities market, who should be held responsible in the event that a carbon offset project fails to deliver the promised credits?The answers to these questions depend on, among other things, the character of the markets in which these activities take and the nature of the information sets held by the contracting parties. This dissertation employs the standard theory of incentives involving a principal and an agent to to shed some light on these issues.

The theory of incentives, which includes both contract theory and mechanism design, has been one of the fastest growing areas in economics. Pioneered by Akerlof (1970), Spence (1973), Stiglitz (1974) and Rothschild and Stiglitz (1976), the theory focuses on the key role of that asymmetric information plays in certain markets. Information is often asymmetrically held between buyers and sellers, but also within an organization between a firm and its workforce. To illustrate this idea, consider a situation where the owner of a firm wishes to hire a manager to run a one-time project. It is plausible to assume that the project's profits will depend on the manager's *actions* as well as some innate characteristics of the manager (e.g., her productivity or ability). Asymmetry of information that relates to the manager's *hidden* actions is often referred to in the literature as *moral hazard*; asymmetric information related to the manager's *private information* is called *adverse selection* (Holmström, 1979; Holmström and Myerson, 1983; Shavell, 1979; Stiglitz, 1974)

It turns out that moral hazard and adverse selection are omnipresent in the economic relationships described in the first two paragraphs of this introduction. This provides the main motivation for this research. In the first paper, we consider the impact of extending a lender's liability for environmental damage caused by her borrower on (a) the design of financial contracts, (b) the optimal level of care, and (c) the firm's prospects for insolvency. In the model, the lender directly intervenes in the project by incurring personally costly actions in order to reduce the firm's exposure to environmental legal liability. Along with the borrower's investment in precaution, the lender's actions influence the distribution of damage realizations. The main innovation in this paper is that the two parties cannot observe each others levels of precaution; that is, relationship specific care is required *subsequent* to the signing of a financial contract, and cannot therefore be contracted upon. In short, the relationship between the manager and the lender suffers from a double-sided moral hazard problem. As is well known, in problems of this kind, the moral hazard incentive cannot be completely resolved by virtue of the fact that any optimal contract has to take into account both the lender's own incentive provision as well as the manager's incentive provision.

Two main results have been obtained in the literature on extended liability and environmental damages. First, when lenders are held liable for environmental damages that arise from the activities of judgement-proof firms, social damages may actually increase not decrease (Pitchford, 1995). Second, and in contrast, creditor liability can increase the level of precaution (Balkenborg, 2001; Lewis and Sappington , 2001; and Heyes, 1996; and Dionne and Spaeter, 2003). These results differ, by and large, on account of the assumptions underlying the allocation of the bargaining power and the nature of the damage function. For instance, Balkenborg assumes that creditors operate in an imperfectly competitive environment, while Lewis and Sappington (2001) assumes that there are many levels of damages, not just two as in Pitchford (1995).

In all these studies, however, the lender is portrayed as a "sleeping" investor who interacts with the firm at arms length. In other words, all the effort necessary to minimize the risk of environmental damage is supplied by the borrower. This depiction of the lender disregards the fact that the lender may intervene in the project and undertake actions that may influence the project's outcome in general and the likelihood of environmental damage in particular. In the first essay of this thesis, in contrast, we endogenize lender's actions. Both directly and indirectly, the lender participates in setting the firm's strategic direction, in particular the investment policy on environmental risk reduction. This modification enables us to admit a richer role for debt and equity in the financial contracts that the firm will adopt.

We find that the impact of extending a lender's liability on precautionary incentives and the firm's solvency hinges critically on the size of the firm's asset base relative to the damage. For situations where the firm's asset value is sufficiently pronounced relative to the highest possible damage realization, an equivalence between extended liability and *no-lender liability* rules is established. Furthermore, social welfare maximization coincides with the private optimum. However, when the firm's assets are more limited, *extended* liability induces a shift towards more debt and lowers the levels of precautionary incentives, and the private optima results in lower levels of investment in damage reduction. Intuitively, in a setting where the lender must not only subordinate his claim against the firm, but also indemnify any residual environmental liability, an optimal financial contract must incorporate more debt and less equity for the lender (more equity for the owner-manager) in order to offset the severe downside risk that the lender faces in the states of the world in which the firm is insolvent. In our framework, debt increases the return to the lender's effort in the state of the world in which the firm is solvent, thereby increasing his incentive to reduce the firm's exposure to environmental risk. At the same time, greater equity (ownership) for the manager entailed by extended liability increases her incentive to advance the firm's prospects. In short, the threat of severe loss of wealth implied by extended liability effectively embeds an exogenous punishment mechanism in the financial contracts, which lessens the moral hazard problem on the part of the lender.

The second paper focuses on international transfer of energy efficient technologies as a means to mitigate global climate change under the aegis of the Kyoto protocol. More precisely, it examines how different schemes of liability to deal with project failure and nondelivery of emissions credits can affect the nature of contractual arrangements between a foreign investor and a recipient (host) of an energy saving technology. Unlike the first essay, the model structure here admits private information on the part of the agent (the host), and in this way incorporates both adverse selection and moral hazard in the same context. Adverse selection arises because the host is privately informed about her capacity to absorb the new technology. Moral hazard is present because the host's effort is unobservable. The project is assumed to generates a stochastic return, which is dependent on the level of investment in the green technology (i.e., effort) undertaken by the host and the host's absorptive capacity.

Employing the methods of mechanism design, we obtain two contrasting results. First, when the investor is endowed with all the bargaining, we find, perhaps surprisingly, that installing the liability on the host (she directly controls the failure risk) induces more effort distortion than assigning the liability to the investor. The intuition for this result is that installing sanctions on the host diminishes the moral hazard problem, but simultaneously intensify the private information aspects of the agency problem, thereby, increasing the cost of using high-powered incentive schemes. Second, when all the bargaining power is allocated to the host, however, host-only liability outperforms investor-only liability in terms of effort incentives. To see the intuitive idea behind these results, note that when the investor is endowed with all the bargaining power, the host's information rents which occur in terms of avoided damages represent a cost to the investor, whilst to the host they constitute a benefit. So the host desires a higher effort level than does the investor. On the other hand, when the balance of the bargaining power shfts in favour of the host, the latter finds it advantageous to optimally internalize all the benefits from expending effort. Consequently, her incentive to labour diligently for the project is increased in a manner analogous to the Spence (1974) education model in which an employee is forced to invest in wasteful education to avoid being mistaken for a less productive worker.

The third paper refines the second paper by (a) explicitly allowing the foreign investor to have some input into the technology transfer process, and (b) admitting the possibility of private knowledge of wealth (expected payoff) on the part of the host. The important contribution of this paper is to combine two-sided moral hazard and adverse selection in the context of international transfer of technology. The results indicate that private information about wealth can have a strong bearing on resource allocation in situations of bilateral moral hazard. More precisely, when the investor is held strictly liable, the optimal contract evokes a shift towards more effort by the investor. On the other hand, when the liability is installed on the host, the rent-efficiency trade off arising yields an incentive to overburden the host with too much investment. And the tendency to overburden the host is more significant the higher the host's wealth endowment.

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2. Paper 1: Extended Liability under double Moral Hazard

2.1. Introduction

The doctrine of extending liability to third parties with whom an injurer transacted business has long fascinated many researchers, especially following the enactment of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA).[1] The possibility that a firm protected by limited liability can cause an environmental damage and then declare bankruptcy (Shavell, 1986 coined the term judgement-proof to describe such firms) appears to many to be inefficient in that it dilutes the firm's incentive to be cautious *ex-ante*. Extending liability for residual damage to third parties with deep pockets, such as the firm's lenders, is viewed as an efficient regulatory response to the problem of judgement-proofness (Shavell, 1986; Boyd and Ingberman, 1997; Heyes, 1996; Innes, 1999). This paper presents a simple model structure capturing the relevance of extended liability for the relationship between an owner-manager of a firm whose activities are potentially damaging and a lender. One objective is to endogenize the lender's participation in the firm's activities. We do so by assuming that the lender controls investment decision on environmental risk reduction. We also wish to examine the interaction of extended liability, expenditure on precaution and the firm's solvency.

The following framework is adopted to analyze these issues. A wealth-constrained owner-manager desires to undertake a project that is privately profitable but carries the risk an environmental catastrophe. To execute the project, the manager must secure financing from an external party who in return receives rights to the project's returns in a sharing rule that combines a fixed payment (debt) with a proportional share of the remainder (equity). The novelty in this paper is that equity allows the lender to influence the firm's strategic direction, particularly investment in environmental risk reduction. This role for financial contracts has

[1] The act empowers courts to surbodinate a lender's entire claim against the borrower if the lender exercised control over the borrower firm. It may have inspired similar legilations in Canada, the United Kingdom and the broader EU (See Boyer and Laffont, 1996).

not been stressed in the literature.

The managerial level of care and the lender's effort influence the probability that a damaging accident occurs. We assume that the two parties cannot observe each others efforts; that is, the relationship between the manager and the lender suffers from bilateral moral hazard. Hence, any optimal contract has to take into account both the lender's own incentive provision as well as the manager's incentive provision.

The optimal combination of equity and debt and the resulting level of effort incentives are derived under three alternative liability concepts: No lender liability, full lender liability and partial lender liability. The impact of extended liability on effort incentives and the firm's solvency hinges critically on the size of the firm's asset base relative to the damage. For situations where the firm's asset value is sufficiently pronounced relative to the highest possible damage realization, an equivalence between extended liability and no lender liability rules is established. Furthermore, social welfare maximization coincides with the private optimum. However, when the firm's assets are more limited, *extended* liability induces a shift toward more debt and lowers the levels of precautionary incentives, and the private optima results in lower levels of investment in damage reduction. Intuitively, in a setting where the lender must not only subordinate his claim against the firm, but also indemnify any residual environmental liability, an optimal financial contract must incorporate more debt and less equity for the lender (more equity for the owner-manager) in order to offset the severe downside risk that the lender faces in the states of the world in which the firm is insolvent. In our framework, debt increases the return to the lender's effort in the state of the world in which the firm is solvent, thereby increasing his incentive to reduce the firm's exposure to environmental risk. At the same time, greater equity (ownership) for the manager entailed by extended liability increases her incentive to advance the firm's prospects. In short, the threat of severe loss of wealth implied by extended liability effectively embeds an exogenous punishment mechanism in the financial contracts, which lessens the moral hazard problem on the part of the lender.

Of course, this is not the first attempt to model this relationship. The implication of extended liability has been persuasively argued by Pitchford (1995) who shows that when lenders are held liable for environmental damages that arise from activities of judgement-proof firms, social damages may actually increase not increase. Boyer and Laffont (1997) and Heyes (1996) find that lender liability may increase the incentive for accident prevention. Similar results have been found by Polinsky (1993), Privileggi et al., (2001), Segerson and Tietenberg (1992) and Shavell (1997), who analyze the problem of extended liability in the context of the relationship between a firm and its manager/employee.

More recently, Balkenborg (2001) has focused on the impact of bargaining power at the contracting stage in an imperfectly competitive world. The author shows that there is a cutoff level of creditor bargaining power, below which increased lender liability increases accidents, and above which it does not. Lewis and Sappington (2001b) considers a setting with many different levels of damages and finds that the lender's deep pockets can be valuable in mitigating the judgement-proof problem. Dionne and Spaeter (2003) use a framework in which investment in precaution affects the distribution of environmental losses and operating revenue to show that extending liability may increase the level of precaution.

In all these studies, however, the lender is portrayed as a "sleeping" investor who interacts with the firm at arms length. In other words, all the effort necessary to minimize the risk of environmental damage is supplied by the borrower. This depiction of the lender disregards the fact that the lender may intervene in the project and undertake actions that may influence the project's outcome in general and the likelihood of environmental damage in particular. In contrast, the present endogenizes the lender's intervention in the project. Both directly and indirectly, the lender is presumed to participate in setting the firm's strategic direction, including the investment policy on environmental risk reduction. This modification enables us to admit a richer role for debt and equity in the financial contracts that the firm will adopt.

The characterization of lender's involvement in the manner described above presumes that the lender is not inhibited in its relationship with the client firm by any regulatory constraints. This assumption seems to be a reasonable approximation of reality. First, it parallels the type of relationship that typically prevails between venture capitalist and client firms.[2] Second, it is in consonance with the emerging and existing lending practices in a number of countries: In the US, where bank-firm relationships have historically tended to be more limited, banks now have the freedom to hold equity in client firms through merchant banking subsidiaries.[3] The Japanese and German financial systems are well known for their close bank-firm relationship and concentrated ownership. In much of western Europe, banks are allowed to engage in the so-called "universal banking", a practice that essentially gives them the freedom to own and be owned by non-financial firms (Agarwal and Elston, 2001; Cybo-Otton and Murgia, 2000; and Gorton and Schmid, 2000). Despite the expanding array of permissible activities in which the lender can engage and the blurred dichotomy between lending and commerce, there is no study that, to the best of my knowledge, has hitherto examined the implication of these trends in the context of extended liability.

This study is also closely related to the literature that has examined the economic application of double moral hazard. Demski and Sappington (1991) show that double moral hazard can be completely and costlessly resolved if the principal has the option of requiring the agent to purchase the enterprise at a pre-negotiated price. Cooper and Thomas (1985, 1988), Emons (1988) and Mann and Wissink (1988) examine the nature of the optimal warranty and Agrawal (1999), and Eswaran and Kotwal (1985) focus on agricultural contracts. Lafontaine and Shaw (1996) examine royalty contracts in franchising while Romano (1994),

[2] Venture financing is typically a *relationship* financing. For example, in addition to receiving equity, a venture capitalist may obtain the right to sit on the firm's board of directors or act as an officier of the company (Pozdena, 1990; Hellman, 1998).

[3] The Gramm-Leach-Bliley Act of 1999, which repealed sections of the Glass Steagall Act allows financial holding companies to provide equity financing to nonfinancial firms for a limited time period (Barth et al., 2000; Furlong, 2000; Schmid, 2001). Following the US lead, the *Bank Act* of 2001 permits bank holding companies in Canada.

and Bhattacharya and Lafontaine (1995) examine models of double-sided moral hazard to explain the prevalence of linear contracts. Kim and Wang (1998) examines the robustness of linear contracts in the presence of risk aversion.

The rest of this paper is organized as follows. Section 2 develops the central elements of the model. In section 3, we characterize the optimal contract under full information. Section 4 introduces double moral hazard and analyzes the impact of extended liability on the firm's insolvency. In section 5, we highlight some empirically testable hypotheses and conclude. An appendix contains the proofs of our results.

2.2. The basic model

In the spirit of Pitchford (1995), we consider the relationship between three actors: a regulator, an owner-manager, an outside financier, and a victim. The regulator and the victim are passive players in our model. To eliminate any risk-sharing concerns, we assume that all the parties are risk-neutral. The manager would like to undertake a project that is socially beneficial, but carries the risk of an environmental accident.[4] The project is known to require a fixed amount I in order to be executed, but the available initial wealth that the manager can invest is less than the required investment outlay. Thus, for the project to be executed, further funding must be secured from the financier.[5] With outside funds K provided by the financier, the manager's own contribution to the new investment is $w = I - K$, which we assume is costlessly verifiable by the financier.[6] Assume that the owner cannot divert any borrowed funds to finance perquisite consumption. This is a potentially important issue but not the concern of this

[4]Throughout, we use 'manager', 'entrepreneur' and 'firm' interchangeably.

[5]Throughout we use the term 'financier' and 'lender' interchangeably. The lender could be thought of as a bank, a venture capital firm or any other creditor. As we show below, the distinguishing feature of our model is that the lender is portrayed as an active participant rather than a sleeping investor.

[6]We make this assumption for expositional ease only. It is well known that individuals more often than not possess private information about their limited wealth (See, for example, Lewis and Sappington, 2000). Thus, an expanded model could allow the owner-manager to have private knowledge about her limited wealth, and assign all the bargaining power to the financier.

paper. Throughout, we take K (and therefore w) as given, not to be determined in the model.

The nature of the project is as follows. There is a single period, which is divided into two points of time: t=0 (beginning) and 1 (end). No one discounts between the beginning and the end of the period. At time t =0, the manager makes a decision on the level of investment in care to undertake in order to minimize the risk of environmental accident. The monetary equivalent disutility of this investment is represented by $e \in \Re_+$.

A special focus of this paper is on the financier's ongoing intervention in the project, especially his role in reducing the project's exposure to environmental liability. The standard approach in the literature has been to assume that the likelihood of environmental damage depends solely om the borrower's effort. We abandon this assumption here because we believe that the lender can acquire control rights, and indeed has a vested interest in exercising decision and control rights over the firm on an ongoing basis. This is because poor environmental performance by the firm may increase the likelihood of environmental legal liability and impede the lender's ability to recoup the loaned funds.[7] Thus, in addition to funding the project, we assume that the financier commits resources at time $t = 0$ to ensure that the project is operated in an environmentally sound manner.[8] The monetary cost of these resources is represented by $a \in \Re_+$. Variable a embodies all the factors that can be instrumental in limiting the project's exposure to environmental risk. It might, for example, correspond to planning, consulting, advising, monitoring, oversight and due diligence, which are performed by the financier both as an officer of the company and a shareholder. Here, we refer to a simply as the lender's 'effort'.

At time $t = 1$, the project realizes an exogenously given net return v, from

[7]Evidence of a positive correlation between environmental performance and financial performance has been provided by a number of studies, including Hamilton (1995), Hart (1995), and Blacconierre and Patten (1993).

[8]For instance, the financier, perhaps a venture capitalist, a bank or his representative may sit on the board of directors of the firm or otherwise explicitly exercise control over the firm and improve the firm's performance (See, for example, Sahlman, 1990; and Kroszner and Strahan, 2000).

which all payments are drawn. We assume that v is costlessly verifiable. In addition, the project generates a stochastic environmental damage $\tilde{l}$, which has support in the interval $[0, L]$. Denote by $F(l/e, a)$ the cumulative distribution function of l given effort levels a and e by the lender and the manager, respectively. $f(l/e, a) > 0$ is the corresponding density function.[9] Thus, unlike other studies that have examined the role of the financier in similar settings, herein we assume that the financier's intervention may actually increase the firm's expected end-of-period cash flow.[10] We make the following assumptions with respect to the distribution of l.

Assumption 1. For any $l \in [0, L]$, $f(l/e, a)$ is twice differentiable and concave in a and e.

Assumption 2. $F_e(l/e, a) \geq 0 \; \forall \; l, a$ and $F_a(l/e, a) \geq 0 \; \forall \; l, e$.

Assumption 3. $F_{ee}(l/e, a) \leq 0$ and $F_{aa}(l/e, a) \leq 0$. [11]

Assumption 4. $\lim_{e \downarrow 0} F_e(l/e, a) = \infty$ and $\lim_{a \downarrow 0} F_e(l/e, a) = \infty$.

Assumption 5. $\lim_{e \downarrow \infty} F_e(l/e, a) = \lim_{a \downarrow \infty} F_e(l/e, a) = 0$.

Assumption 1 is necessary for the existence of an optimal solution. Assumption 2 indicates that higher effort levels renders lower environmental damage l more likely in the sense of stochastic dominance. Assumption 3 indicates stochastically diminishing marginal productivity of effort levels supplied by the two parties. Assumptions 3, 4 and 5 are sufficient to guarantee a unique interior solution. Following standard practice, we note that since our support is fixed, $F_e(0/e, a) = F_e(L/e, a) = F_a(0/e, a) = F_a(L/e, a) = 0$ for any action (a, e).

A contract requires the financier to provide the sum of K dollars, and it specifies a sharing rule for the final project return. We restrict ourselves to a class of sharing rules that have both debt and equity components. Thus, the manager

[9]This formulation follows that of Demski and Sappington (1991).

[10]Besanko and Kanata (1993), and Diamond (1984, 1993) have examined the role of banks as delegated monitors. Besanko and Kanata (1993) is closer to our study since it assumes that monitoring increases the entrepreneur's effort, which in turn improves the likelihood of the firm's success.

[11]Throughout subcripts will denote partial derivatives.

makes two kinds of payments to the lender: κ will denote a fixed payment (debt) while $(1-\beta)$ will denote a contingent dividend or the lender's equity stake in the project ($\beta \in [0,1]$.)[12] Let r denote the return per dollar invested elsewhere. Then rK is the opportunity cost of the lender's invested capital K. We assume that the manager faces limited liability. This implies that the manager cannot lose more than her equity in the event of insolvency.

If the firm is bankrupt at the end of the period, then the manager receives nothing and the lender becomes the residual claimant of the firm's assets after the victim has been compensated. For a given net return v and debt obligation κ, there is a critical amount of environmental liability l^* at which the manager is just able to meet her legal obligations; That is, for positive levels of κ and v

$$v - \kappa - l^* = 0. \tag{2.1}$$

Clearly, this equation defines l^* as a function of κ:

$$l^* = l^*(\kappa). \tag{2.2}$$

Thus, l^* is the threshold such that if $l \leq l^*$, the manager can meet all her payment obligations. On the other hand, if $l > l^*$, bankruptcy is inevitable and the lender and the victim become the residual claimants. It follows that the probability that the firm is solvent is $\Pr ob(l \leq l^*) = \int_0^{l^*} f(l/e,a)dl = F(l^*/e,a)$. Note that $dl^*/d\kappa < 0$, implying that the critical value of l at which the firm is just able to meet all its legal obligation is decreasing in κ.

The manager decides the amount to invest in care, e. The lender chooses the amount to spend on effort a. Thus the optimal levels of a and e are endogenously derived in this framework. The owner's objective is to maximize her end-of-period cash flow, U^o, which can be written as follows:

[12] Dionne and Spaeter (2003) focus on a standard debt contract, thereby precluding any role for equity participation and the lender's intervention in the project.

$$U^o = \beta \int_0^{l^*} [v - \kappa - l]\, f(l/e, a) dl - e. \tag{2.3}$$

The first term on the right hand side of equation (2.3) represents the payoff to the manager if the project remains solvent at the end of the period. Recall that this will occur when $l \leq l^*$. Given limited liability, only the equity of the manager is exposed to tort risk. The last term on the RHS (2.3) is the cost of undertaking effort on the part of the manager. The lenders expected payoff depends on the concept of liability employed and will be presented shortly.

The sequence of events is as follows: In stage 1, the regulator publicly announces the liability rule. In the second stage, the owner offers the financier a contract stipulating how she will compensate the lender for the K dollars he supplies to the firm. In the third stage the lender accepts or reject the contract proposed by the owner.[13] If the contract is accepted, the lender is allocated control rights over the firm. In stage 4, the lender and the manager simultaneously choose their effort in order to maximize their returns given $\{\beta, \kappa\}$ and the liability rule. Final project outcome is observed and compensation made according to the contract selected by the manager in the second stage.

Following Pitchford (1995), we examine three regimes of liability in turn. *No lender* liability refers to a situation where the lender bears no burden for the victim's compensation in the event of insolvency. Full lender liability describes a setting where the lender is obliged to compensate any residual damages. Partial lender liability refers to the case in which the lender indemnifies only a fraction of the residual liability.

Throughout, we assume that the manager holds all the bargaining power. This may be a reasonable assumption where there is no competition among borrowers, for example, if there is only one suitable project that the lender can finance or where there is intense *ex-ante* competition among potential lenders.

[13]In the following, we assume that the project is always undertaken. Thus, the owner offers a contract that guarantees the lender at least his outside opportunity profit.

2.3. Full information solutions

Before proceeding to characterize the firm's private optimum under bilateral information asymmetry, we consider two benchmark cases. The first case assumes a setting where no moral hazard problem arises because the two parties can observe each others efforts, and the optimal effort is prescribed by maximizing social welfare. The expected social value of the project is $S(e,a) = v - \int_0^L lf(l/e,a)dl - a - e$ where $\int_0^L lf(l/e,a)dl = \int_0^L F(l/e,a)dl$ represents the expected social damage from the project. The socially optimal level of effort is the solution to the following problem: $\max_{e,a} S(e,a)$. It is straightforward to see that the concavity of $F(l/e,a)$ in a and e guarantees the existence and uniqueness of the socially efficient effort combination (e^s, a^s) such that

$$\int_0^L F_e(l/e^s, a^s)dl = \int_0^L F_a(l/e^s, a^s)dl = 1. \tag{2.4}$$

Condition (2.4) equates the expected marginal benefit of damage-reducing effort to the marginal cost.

In the second benchmark case, the optimal contract is determined through private interaction between the two parties (hereafter referred to as the private optimum). In this case, the manager and the lender will care only about their own welfare and not about the welfare of the victim. Since the manager commands all the bargaining power, she will extract all the surplus, leaving the lender's profit identically equal to zero, while ensuring that both parties undertake the level of effort that maximizes the expected (private) total surplus. Thus, under *no lender liability*, the optimal contract is determined by the solution to $\max_{a,e} U = \int_0^{\min\{v,L\}} [v-l]\, f(le,a)dl - rK - a - e$. The (unique) optimal combination of efforts $(\bar{e}^*, \bar{a}^*)$ satisfies

$$\int_0^{\min\{v,L\}} F_e(l/\bar{e}^*, \bar{a}^*)dl = \int_0^{\min\{v,L\}} F_a(l/\bar{e}^*, \bar{a}^*)dl = 1 \tag{2.5}$$

Interpreted, equation (2.5) says that at the optimum, the expected marginal return from effort must be just equal to the marginal disutility of effort. Observe that the marginal benefit from effort is evaluated over all possible states of nature; that is, both in the states of the world in which the firm is solvent, $l \in [0, l^*]$ and in the insolvency states, $l \in [l^*, \min\{v, L\}]$. In short, efforts are rewarded according to the expected *total (private)* gains that accrue to both parties.

Under *full lender liability*, the financier must take into account the potential negative cash flow in deciding whether to finance the project. Denote by $(\tilde{e}^*, \tilde{a}^*)$ the optimal combination of effort under full lender liability in order to distinguish it from the corresponding combination under no lender liability. Then, the condition for maximal individual effort is given by

$$\int_0^L F_e(l/\tilde{e}^*, \tilde{a}^*)dl = \int_0^L F_a(l/\tilde{e}^*, \tilde{a}^*)dl = 1. \tag{2.6}$$

The key aspect of the optimal solution in this setting is that the expected marginal return to effort in the states of the world in which the firm is insolvent is calculated over the interval $[l^*(\kappa), L]$, thereby ensuring that there is no uncompensated liability. Consequently, individual effort is rewarded according to the social gains.

Partial lender liability requires the lender to pay a fraction $\rho \in (0, 1)$ of the damages whenever l exceeds v.[14] Accordingly, the maximum loss that the lender can suffer in the event of insolvency, for a given net value of the firm v, is given by $\min\{L, v + \rho(L - v)\}$. This limit collapses to L when $\rho = 1$ (full lender liability) and to $\min\{L, v\}$ (*no lender* liability) when $\rho = 0$. When $L > v$, $L > v + \rho(L - v) > v$ and $\min\{L, v + \rho(L - v)\} = v + \rho(L - v)$. On the other hand, when $L < v$, $L < v + \rho(L - v) < v$ and $\min\{L, v + \rho(L - v)\} = L$. The

[14]We can also think of partial liability as a situation in which the lender is held strictly liable, but exogenous imperfections in the liability system lead the lender to compensate only a fraction of the damage.

condition for optimal effort $(\breve{e}^*, \breve{a}^*)$ is

$$\int_0^{\min\{L, v+\rho(L-v)\}} F_e(l/\breve{e}^*, \breve{a}^*)dl = \int_0^{\min\{L, v+\rho(L-v)\}} F_a(l/\breve{e}^*, \breve{a}^*)dl = 1 \quad (2.7)$$

Equation (2.7) reveals that effort may not be rewarded according to the social gain. To illustrate, suppose that $L \leq v$ then effort will be compensated according to the social gains. On the other hand, if $L > v$ so $L > v + \rho(L-v) > v$ and $\min\{L, v+\rho(L-v)\} = v+\rho(L-v)$, then the optimal contract will internalize only a fraction of environmental harm and private returns to effort will not coincide with the social value of effort.

The following proposition summarizes the discussion thus far.

Proposition 1. *Suppose that there is full information. Then,* $a^s = \tilde{a}^* = \breve{a}^* = \bar{a}^*$ *and* $e^s = \tilde{e}^* = \breve{e}^* = \bar{e}^*$ *if* $L \leq v$*;* $a^s = \tilde{a}^* > \breve{a}^* > \bar{a}^*$ *and* $e^s = \tilde{e}^* > \breve{e}^* > \bar{e}^*$ *if* $L > v$.

Proof: See the appendix

When the highest possible damage realization is insubstantial relative to v, the manager fully internalizes the damage and the lender's deep pockets are rendered superfluous to the victim's compensation regardless of the regime of liability. On the other hand, when L is substantial, the total expected surplus accounts for only a fraction of the damage under *no lender liability* and *partial lender liability*. In this case, however, shifting the legal liability to the lender corrects the underincentive for individual effort by reflecting the full marginal benefit from effort.

2.4. Double moral hazard

Suppose, now, that the lender's effort a is neither observable nor verifiable by the manager (and therefore not contractible). Obviously, a forcing contract is not feasible and the owner must offer an incentive contract. As is well known, a one sided moral hazard problem can be completely resolved by making a risk neutral agent the residual claimant. In our framework, however, the owner's effort is not also observable and therefore not contractible. In short, there exists a "double-sided" moral hazard problem and the optimal contract has to take into account both the lender's own incentive provision as well as the manager's incentive provision.[15]

In the following, we initially discuss the solution that occurs when there is no lender liability. The optimal outcome in this setting is then subsequently compared to the situations that develops when the liability can be extended to the lender.

2.4.1. No lender liability

Imposing the burden for the victim's compensation on the manager in full may not necessarily be attainable in this situation. Due to limited liability, the manager cannot have any negative cash flows regardless of the size of the environmental damage. Thus, if the project is solvent, the manager pays off all her obligations and shares the residual earnings with the lender according to the terms of the financial contract. In the event of insolvency, the manager loses only her equity stake in the project. On the other hand, the lender receives all of the firm's residual assets after the victim has been compensated. If the firm's assets are less than the level of damages; that is, if $v < l$, the lender gets nothing and the damages are not fully indemnified. Thus, if the lender accepts contract $\{\beta, \kappa\}$, then the expected payoff to the lender is

$$\begin{aligned} U^B(e;\beta,\kappa,a) = (1-\beta)\int_0^{l^*} [v-\kappa-l]\, f(l/e,a)dl + F(l^*/e,a)\kappa \\ + \int_{l^*}^{\min\{v,L\}^*} [v-l]\, f(l/e,a)dl - a. \end{aligned} \quad (2.8)$$

[15]The framework we follow below is analogous to that employed in the literature on team production. In this setting one player designs the compensation scheme as a Stackelberg leader, and thereafter participates in the production as a team member (McAfee and McMillan, 1991).

The first integral on the RHS of equation (2.8) denotes the expected value of the lender's payoff if the project is solvent. The second term represents the expected value of the promised principal that the lender would receive as a lender to the project (Recall that $F(l^*/e,a)] = \int_0^{l^*} f(l/e,a)dl$ is the probability of solvency.) The second integral term on the RHS denotes the expected value of the lender's cash flow if the project is insolvent. Note that this value is evaluated over the interval $[l^*(\kappa), \min\{v, L\}]$ implying that in the absence of extended liability, the victim cannot receive more than the value of firm's assets. The last term is the monetary cost of effort expended by the lender.

An important consideration is the lender's preferences over (β,κ) pairs.[16] This can be illustrated by characterizing the lender's indifference curves. Fixing the lender's expected payoff at $U^B(e;\beta,\kappa,a) = \underline{U^B}$, the indifference curves give the locus of the combinations of β and κ for which the lender will be indifferent. Implicit differentiation of $U^B(e;\beta,\kappa,a) = \underline{U^B}$ yields upward sloping indifference curves,

$$\frac{\partial\kappa}{\partial\beta} = -\frac{\partial U^B(e;\beta,\kappa,a)/\partial\beta}{\partial U^B(e;\beta,\kappa,a)/\partial\kappa} = \frac{\int_0^{l^*} [v-\kappa-l]\, f(l/e,a)dl}{\beta\int_0^{l^*} f(l/e,a)dl + [v-l^*]f(l^*/e,a)} > 0. \quad (2.9)$$

Condition (2.9) asserts that an increase in β, by increasing the manager's stake in the project, effectively reduces the lenders expected return in the state of the world in which the firm is solvent, and therefore requires an increase in κ to maintain the the lender at his reservation payoff.

Effort choice At the effort selection stage of the game, the manager takes as given the lender's effort a, and the financial contract (β,κ) from the second stage of the game. Thus, her incentive compatibility condition is given as follows:

$$\max_e U^o(e;\beta,\kappa,a) = \beta\int_0^{l^*} [v-\kappa-l]\, f(l/e,a)dl - e \quad (2.10)$$

[16]Dionne and Spaeter (2003) restrict themselves to a debt contract as the only optimal mechanism to compensate the lender.

Differentiating (2.10) with respect to e yields the first-order condition that determines the manager's optimal level of precautionary effort:

$$U_e^o(e;\beta,\kappa,a) = \beta\int_0^{l^*} F_e(l/e,a)dl - 1 = 0^{17}. \qquad (2.11)$$

This says that at the optimum, the manager's expected return from investment in precaution over the states of nature for which the firm is solvent must be just equal to the marginal disutility of undertaking precaution. Note that the concavity of $F(l/e,a)$ ensures that the second-order condition associated with the choice of precaution

$$\overline{SOC_e} = U_{ee}^o(e;\beta,\kappa,a) = \beta\int_0^{l^*} F_{ee}(l/e,a)dl < 0 \qquad (2.12)$$

holds globally.

An interesting question is how the manager's choice of care e will change in response to changes in her equity stake β and the level of debt κ; that is, what are the signs of $\frac{de}{d\beta}$ and $\frac{de}{d\kappa}$? The total differentiation of the first order condition (2.11) yields $de/d\beta = -\int_0^{l^*} F_e(l/e,a)dl \Big/ \overline{SOC}_e > 0$ and $de/d\kappa = \beta F_e(l^*/e,a)/\overline{SOC}_e < 0$. Holding the level of debt κ and the lender's effort constant, an increase in the manager's stake in the project increases the manager's level of investment in precaution. This is because an increase in β increases the fruits of the manager's effort in the states of the world in which the firm is solvent. On the other hand, a higher level of debt, by reducing the firm's residual assets, increases the likelihood of insolvency, thereby reducing the range of states of the world in which the manager receives a return from her effort.

The lender's problem at the effort selection stage is analogous. He chooses a to maximize his expected payoff, taking e, β and κ as given; that is, the lender's

[17]This follows from the fact that $\int_0^{l^*} f'(l)g(l)dl = f(l)g(l)|_0^{l^*} - \int_0^{l^*} f(l)g'(l)dl$.

incentive compatibility condition is

$$\max_a U^B(a;\beta,\kappa,e) = (1-\beta)\int_0^{l^*} [v-\kappa-l]\, f(l/e,a)dl + F(l^*/e,a)\kappa \qquad (2.13)$$
$$+\int_{l^*(\kappa)}^{\min\{v,L\}} [v-l]\, f(l/e,a)dl - a.^{18}$$

The first-order condition with respect to a yields

$$U_a^B(a;\beta,\kappa,e) = \left[(1-\beta)\int_0^{l^*} F_a(l/e,a)dl + \int_{l^*(\kappa)}^{\min\{v,L\}} F_a(l/e,a)dl\right] - 1 = 0 \qquad (2.14)$$

Compared to the manager's effort choice decision given by (2.11), the lender evaluates the marginal benefit of undertaking effort over all states of the world, not only for states of the world in which the project is insolvent. Again the concavity of $F(l/e,a)$ in a ensures that the second-order condition holds globally.

Before turning to a formal statement of the manager's problem, we briefly review the effect of debt and equity on the lender's incentive to expend effort. From the total differentiation of the first order condition given by (2.14), and upon rearrangement of terms, we obtain,

$$da/\,d\beta = \int_0^{l^*} F_a(l/e,a)dl \Big/ \overline{SO\bar{C}_a} < 0 \qquad (2.15)$$

and

$$da/\,d\kappa = -\,\beta F_a(l^*/e,a)/\,\overline{SO\bar{C}_a} > 0 \qquad (2.16)$$

where $\overline{SO\bar{C}_a}$ is the second-order condition associated with the choice of a. Equation (2.15) shows that an increase in the manager's equity stake dulls the lender's incentive for effort since an increase in β decreases the return to the lender's effort in the states of the world in which the firm is solvent. The effect of debt on the lender's incentive is unambiguously positive reflecting the fact that a higher level of debt increases the average return to the lender in states of the world in which the firm is solvent, thereby enhancing the lender's incentive to reduce damage.

Financial contract In the penultimate stage of the game, the manager determines the optimal combination of β and κ given the rule of liability that is in place. By contrast with full information framework, the optimal financial structure in the presence of double-sided moral hazard will maximize the manager's expected private returns subject to the lender's participation constraint and *two* incentive constraints; namely, the lender's own incentive compatibility constraint and the manager's incentive constraint. Thus, the manager solves:

$$\max_{\{\beta,\kappa\}} \beta \int_0^{l^*} [v - \kappa - l] f(l/e, a) dl - e \tag{2.17}$$

subject to

$$e \equiv e(\beta, \kappa) \text{ as defined by } 2.11 \tag{2.18}$$

$$a \equiv a(\beta, \kappa) \text{ as defined by } 2.14 \tag{2.19}$$

and

$$U^B(e; \beta, \kappa, a) \geq rK. \tag{2.20}$$

Constraints (2.18) and (2.19) are the owner's and the lender's incentive compatibility constraints, respectively. They ensure that the two parties choose their effort optimally for any given equity-debt combination (β, κ). Since the manager holds all the bargaining power, the participation constraint can be replaced by equality without loss of generality.[19] Making use of this assumption, the manager's problem can be restated as:

$$\max_{\{\beta,\kappa\}} \int_0^{l^*} [v - l] f(l/e, a) dl + \int_{l^*(\kappa)}^{\min\{v,L\}} [v - l] f(l/e, a)] dl - rK - a - e \tag{2.21}$$

[19]This is essentially a zero-profit constraint on the part of the lender. It underpins our assumption of perfect competion in the loanable funds market.

subject to (a, e) satisfies (2.18) and (2.19) for (β, κ). In effect, the contracting problem reduces to that of maximizing the total expected earnings of the lender and the manager subject to the incentive constraints. Proposition 2 gives the solution to the manager's problem.

Proposition 2. *In the absence of extended liability, (i) the necessary conditions for optimal expenditure on managerial and lender's efforts satisfy*

$$\left[\int_0^{\min\{v,L\}} F_e(l/e,a)dl - 1\right]\frac{de}{d\beta} + \left[\int_0^{\min\{v,L\}} F_a(l/e,a)dl - 1\right]\frac{da}{d\beta} = 0 \quad (2.22)$$

and

$$\left[\int_0^{\min\{v,L\}} F_e(l/e,a)dl - 1\right]\frac{de}{d\kappa} + \left[\int_0^{\min\{v,L\}} F_a(l/e,a)dl - 1\right]\frac{da}{d\kappa} = 0; \quad (2.23)$$

(ii) the optimal contract, denoted by $\{\bar{\beta}, \bar{\kappa}\}$, is characterized as:

$$\frac{(1-\bar{\beta})}{\bar{\beta}} = \frac{F_e(l^*/e,a)}{F_a(l^*/e,a)}\left[1 - \int_{l^*(\kappa)}^{\min\{v,L\}} F_a(l/e,a)dl\right] \text{ and} \quad (2.24)$$

$$F(l^*/e,a)\bar{\kappa} = a + rK - (1-\bar{\beta})\int_0^{l^*}[v-l]f(l/e,a)dl - \int_{l^*(\kappa)}^{\min\{v,L\}}[v-l]f(l/e,a)dl. \quad (2.25)$$

Proof: See the appendix

The first two conditions capture the essential contracting friction spawned by the competing interests of the two players. An increase in β (κ) enhances the manager's (lender's) incentives but has a countervailing effect in that its results in an incentive loss on the part of the lender (manager). At the optimum, these two offsetting effects must just be equal; it must not be possible through any feasible readjustment in β (κ) to increase the manager's incentives without sacrificing the lender's incentive to expend damage-reducing effort.

To obtain more intuition for conditions (2.22) and (2.23), recall that if individual effort levels were observable and therefore contractible, the full information levels of managerial and lender's preventive-care would satisfy $\int_0^{\min\{v,L\}} F_e(l/e,a)dl - 1 = 0$ and $\int_0^{\min\{v,L\}} F_a(l/e,a)dl - 1 = 0$, respectively. However, equations (2.22) and (2.23) reveal that in the presence of double moral hazard, $\int_0^{\min\{v,L\}} F_e(l/e,a)dl > 1$ and $\int_0^{\min\{v,L\}} F_a(l/e,a)dl > 1$. Since $\int_0^{\min\{v,L\}} F_e(l/e,a)dl$ and $\int_0^{\min\{v,L\}} F_a(l/e,a)dl$ are now larger, it follows, by virtue of assumption 2, that there is an undersupply of resources by both parties.

We may now ask how the private outcomes given by (2.22) and (2.23) compare to those that would be chosen by a social planner who maximizes social welfare. If the objective was the maximization of social welfare (recall that $S = v - \int_0^L lf(l/e,a)dl - a - e$), then imposing the same constraints as those given by (2.18)-(2.20), the necessary condition for optimal effort would satisfy

$$\left[\int_0^L F_e(l/e,a)dl - 1\right]\frac{de}{d\beta} + \left[\int_0^L F_a(l/e,a)dl - 1\right]\frac{da}{d\beta} = 0 \qquad (2.26)$$

and

$$\left[\int_0^L F_e(l/e,a)dl - 1\right]\frac{de}{d\kappa} + \left[\int_0^L F_a(l/e,a)dl - 1\right]\frac{da}{d\kappa} = 0. \qquad (2.27)$$

Even though the objective function under social welfare maximization accounts for all possible damage realizations, this effect is tempered with by the presence of moral hazard on the part of the two parties and the resulting countervailing effects of any incentive scheme. Hence, the social planner optimally induces distortions in damage-reducing efforts relative to the full information outcome. Comparing conditions (2.26) and (2.27) with the corresponding conditions obtained under the private decision making, it is clear that while the social planner evaluates the marginal benefit from care over all possible damage realizations, the owner's incentive to internalize the social damages under the private optimum is tied to the firm's asset bounds. More precisely, if $\min\{v, L\} = L$, if the firm's assets are sufficiently large, social welfare maximization coincides with the private optimum. On the other hand, if $\min\{v, L\} = v$, if the firm's assets are more limited, the solution to the private optimum induces lower levels of investment in precaution.

Equation (2.25) implicitly defines the expected fixed (debt) payment. The latter contains four terms: The first two guarantee the lender his outside opportunity payoff and a compensation for his effort. The last two components, which enter the expression for $\bar{\kappa}$ in a negative fashion, reduce the lenders return by his expected dividend and the expected value of residual assets left after the victim has been compensated. Thus, if the lender is willing to invest in the project as a shareholder, he must expect a lower fixed (debt) payment is return.

Equation (2.24) reveals that the manager's equity stake β depends crucially on the term $F_e(l^*/e, a)/\ F_a(l^*/e, a)$, which can be heuristically interpreted as a measure of the relative productivity of the manager's effort. The greater the value of $F_e(l^*/e, a)$ relative to $F_a(l^*/e, a)$, the lower the level of β and the higher will be the lender's equity participation. To see the intuition, note that equity limits the manager's return in the states of the world in which the firm is solvent. Hence, a high productivity manager, for whom an accident is less likely, optimally signals the value of his effort by selecting a lower equity share.

Given the positive relationship between β and κ, equation (2.24) leads to the intuitively appealing prediction that the lender will be offered a lower fixed (debt) payment, and will secure a relatively large stake in the venture when the manager has a higher marginal productivity of effort. This result parallels that found in Lewis and Sappington (2000b). In their model, however, agents with higher marginal productivity end up with lower stakes in a rational attempt to increase their chance of operating a project.

2.4.2. Full lender liability

We now examine the properties of the corresponding solution when the lender must indemnify any residual damage. The key point to note here is that the ability to attach the lender's unbounded assets in the event of insolvency ensures not only that no damage is left uncompensated, *ex-post*, but also serves as an effective punishment mechanism on the part of the lender. Consequently, in order to induce the lender to finance the project, she must be sufficiently compensated for the severe downside potential. At the same, the potential loss of wealth enhances the lender's incentive to reduce damage, thereby diminishing her moral hazard incentive.

With the manager holding all the bargaining power, her problem [FL] now reads:

$$\max_{\{\beta,\kappa\}} \beta \int_0^{l^*} [v - \kappa - l]\, f(l/e, a)dl - e \tag{2.28}$$

subject to

$$e \in \arg\max \beta \int_0^{l^*} [v - \kappa - l]\, f(l/e, a)dl - e \tag{2.29}$$

$$a \in \arg\max (1-\beta) \int_0^{l^*} [v - \kappa - l]\, f(l/e, a)dl + F(l^*/e, a)\kappa + \int_{l^*(\kappa)}^{L} [v - l] f(l/e, a)dl - a \tag{2.30}$$

and

$$\tilde{U}(e, a, \beta, \kappa) = (1-\beta) \int_0^{l^*} [v - \kappa - l]\, f(l/e, a)dl + F(l^*/e, a)\kappa + \int_{l^*(\kappa)}^{L} [v - l] f(l/e, a)dl - a \geq rK. \tag{2.31}$$

Equations (2.29) and (2.30) are the incentive compatibility constraints while equation (2.31) is the participation constraint. The following proposition summarizes the solution to the manager's problem [FL]. The proof is analogous to that of proposition 3 and is therefore omitted.

Proposition 3. *Under full lender liability, (i) the necessary conditions for optimal expenditure on managerial and lender's efforts satisfy*

$$\left[\int_0^{L} F_e(l/e, a)dl - 1\right] \frac{de}{d\beta} + \left[\int_0^{L} F_a(l/e, a)dl - 1\right] \frac{da}{d\beta} = 0 \tag{2.32}$$

and

$$\left[\int_0^L F_e(l/e,a)dl - 1\right]\frac{de}{d\kappa} + \left[\int_0^L F_a(l/e,a)dl - 1\right]\frac{da}{d\kappa} = 0; \tag{2.33}$$

(ii) the optimal contract, denoted by $\{\tilde{\beta}, \tilde{\kappa}\}$ is characterized as:

$$\frac{1-\tilde{\beta}}{\tilde{\beta}} = \frac{F_e(l^*/e,a)}{F_a(l^*/e,a)}\left[1 - \int_{l^*(\kappa)}^L F_a(l/e,a)dl\right] \tag{2.34}$$

and

$$F(l^*/e,a)\tilde{\kappa} = a + rK - (1-\tilde{\beta})\int_0^{l^*}[v-l]\,f(l/e,a)dl - \int_{l^*(\kappa)}^L [v-l]\,f(l/e,a)dl. \tag{2.35}$$

The first two equations of proposition 3 report that, as in the previous section, there will be underinvestment of resources by both parties. By contrast with the previous setting, however, the optimal policy under full lender liability may yield a higher level of effort incentives. This can be seen as follows: Consider a situation where $L < v$. Obviously, $\min\{v, L) = L$, and it is clear that equations (2.22) and (2.32) will coincide. In other words, when the scale of the firm's assets are sufficiently large relative to all possible damage realizations, then extending liability is no different from no lender liability because the manager takes full account of the damage that she will have to pay in the event of an accident. This equivalence is not sustained in situations where $L > v$, however. In this case $\min\{v, L) = v$, and (2.22) and (2.32) become

$$\left[\int_0^v F_e(l/e,a)dl - 1\right]\frac{de}{d\beta} + \left[\int_0^v F_a(l/e,a)dl - 1\right]\frac{da}{d\beta} = 0 \tag{2.36}$$

and

$$\left[\int_0^v F_e(l/e,a)dl + \int_v^L F_e(l/e,a)dl - 1\right]\frac{de}{d\beta} + \left[\int_0^v F_a(l/e,a)dl + \int_v^L F_a(l/e,a)dl - 1\right]\frac{da}{d\beta} = 0, \tag{2.37}$$

respectively. It is apparent from (2.37) that the effect of extended liability is embodied in the terms $\int_v^L F_e(l/e,a)dl$ and $\int_v^L F_a(l/e,a)dl > 0$. Along with the requirement that $\frac{da}{d\beta}$ is nonpositive, condition (2.32) now implies that both $\int_0^v F_e(l/e,a)dl$ and $\int_0^v F_e(l/e,a)dl$ have decreased relative to the setting where there is no extended liability. That is, both parties expend more effort to reduce environmental damage under extended liability than under *no lender* liability.

To see the intuition for this observation, recall that when $v < L$, *no lender* liability results in uncompensated damage in the event that the worst possible damage manifests since courts cannot attach the lender's assets. In this case the lender suffers no punishment beyond losing her initial investment. However, under full lender liability, the financier is rendered vulnerable to severe punishment in the event of insolvency's by her unbounded wealth. This increases the value to her of putting forth adequate effort without diminishing the manager's incentive. As a result, the manager finds it advantageous to acquire a larger equity stake (and issue more debt) relative to the setting without extended liability. And the resulting diminution in the lender's effort incentives is more than offset by the enhanced incentives induced by the threat of punishment and the higher level of debt, κ. In short, the threat of severe loss of wealth embeds an exogenous punishment mechanism in the compensation package, which lessens the degree of moral hazard problem on the part of the lender.

It should also be obvious that under full lender liability, social welfare maximization will always be equivalent to the private optimum regardless of the firm's asset base.

2.4.3. Partial lender liability

To examine the nature of the optimal contract under partial lender liability, we simply add to the owner's unconstrained maximization problem defined by equations (2.28) and (2.29), the following constraints:

$$a \in \arg\max (1-\beta)\int_0^{l^*}[v-\kappa-l]\,f(l/e,a)dl + F(l^*/e,a)\kappa + \int_{l^*(\kappa)}^{\min\{L,v+\rho(L-v)\}}[v-l]f(l/e,a)dl - a \tag{2.38}$$

and

$$\breve{U}(e,a,\beta,\kappa) = (1-\beta)\int_0^{l^*}[v-\kappa-l]\,f(l/e,a)dl + F(l^*/e,a)\kappa + \int_{l^*(\kappa)}^{\min\{L,v+\rho(L-v)\}}[v-l]f(l/e,a)dl - a \geq rK. \tag{2.39}$$

Constraints (2.38) and (2.39) are the usual incentive and participation constraints, respectively. Note that the incentive condition on the part of the manager is unchanged from that under full lender liability since limited liability implies that the owner can lose no more than her equity, regardless of the regime of liability that is in place. The solution to problem [PL] is summarized in the following proposition:

Proposition 4. *Suppose that the regime of liability allocation holds the lender partially liable for environmental damage. Then, (i) the necessary conditions for optimal expenditure on managerial and lender's efforts satisfy*

$$\left[\int_0^{\min\{L,v+\rho(L-v)\}} F_e(l/e,a)dl - 1\right]\frac{de}{d\beta} + \left[\int_0^{\min\{L,v+\rho(L-v)\}} F_a(l/e,a)dl - 1\right]\frac{da}{d\beta} = 0 \tag{2.40}$$

and

$$\left[\int_0^{\min\{L,v+\rho(L-v)\}} F_e(l/e,a)dl - 1\right]\frac{de}{d\kappa} + \left[\int_0^{\min\{L,v+\rho(L-v)\}} F_a(l/e,a)dl - 1\right]\frac{da}{d\kappa} = 0; \tag{2.41}$$

(ii) the optimal contract, denoted by $\{\breve{\beta},\breve{\kappa}\}$, is characterized as

$$\frac{1-\breve{\beta}}{\breve{\beta}} = \frac{F_e(l^*/e,a)}{F_a(l^*/e,a)}\left[1-\int_{l^*(\kappa)}^{\min\{L,v+\rho(L-v)\}} F_a(l/e,a)dl\right] \tag{2.42}$$

and

$$\breve{\kappa}F(l^*/e,a) = a+rK-(1-\breve{\beta})\int_0^{l^*}[v-l]\,f(l/e,a)dl-\int_{l^*(\kappa)}^{\min\{L,v+\rho(L-v)\}}[v-l]\,f(l/e,a)dl. \tag{2.43}$$

Proof: See the appendix

Expressions (2.40) and (2.41) mirrors the general conclusion from the previous two sections; that is, both parties will undersupply effort relative to the full information level and the private optimum will be dominated by the social optimum when $\min\{L,v\}=v$. It is of interest, however, to compare the effort distortions reported in (2.40) and (2.41) with those in the previous sections, and evaluate the underlying financial structures. That is, is there a qualitative difference between the nature of the financial contract that the manager will adopt in the absence of extended liability and under extended liability?

2.4.4. Liability allocation, financial structure and precautionary incentives

It turns out that the relative ranking of the alternative liability regimes in terms of their impact on the financial structure and effort incentives hinges critically in the difference $L-v$, the size of the highest possible damage realization relative to the firm's asset value. To illustrate, consider a situation where $v \geq L$ so $\min\{v,L\}=L$ and $\min\{L,v+\rho(L-v)\}=L$. In this case, (2.40) becomes

$$\left[\int_0^L F_e(l/e,a)dl-1\right]\frac{de}{d\beta}+\left[\int_0^L F_a(l/e,a)dl-1\right]\frac{da}{d\beta}=0 \tag{2.44}$$

implying that effort distortions and the underlying financial contracts will be identical across the three regimes. When $v \geq L$, limited liability implies that the owner can never lose more than her equity. In addition, the firm's unbounded assets insulate the lender's wealth from being expropriated for the victim's compensation regardless of whom the financial burden is installed. Consequently, both parties will be indifferent between no lender liability and either of the extended liabilities, and the structure of financial contracts adopted by the owner will be identical across the three liability regimes.

Suppose now that $v < L$ so that $\min\{v, L\} = v$. This can be interpreted as a situation in which either the firm faces a potentially huge environmental damage or its asset bounds are exceedingly tight. In terms of equation (2.42), it implies that $\min\{L, v+\rho(L-v)\} = v+\rho(L-v)$ since $L > v+\rho(L-v) = v(1-\rho)+\rho L > v$. Hence, (2.40) can be written more conveniently as

$$\left[\int_0^v F_e(l/e,a)dl + \int_v^{v+\rho(L-v)} F_e(l/e,a)dl - 1\right]\frac{de}{d\beta}$$

$$+\left[\int_0^v F_a(l/e,a)dl + \int_v^{v+\rho(L-v)} F_a(l/e,a)dl - 1\right]\frac{da}{d\beta} = 0. \qquad (2.45)$$

Comparing (2.45) with (2.37), one can see that $\int_v^{v+\rho(L-v)} F_e(l/e,a)dl > \int_v^L F_e(l/e,a)dl$ and $\int_v^{v+\rho(L-v)} F_a(l/e,a)dl > \int_v^L F_a(l/e,a)dl$, implying that the two terms $\int_0^v F_e(l/e,a)dl$ and $\int_0^v F_a(l/e,a)dl$ must be smaller under *full lender* liability than under *partial lender* liability. That is, more effort distortions are optimally induced under partial lender liability than under full lender liability. This implies that $\tilde{\beta} > \breve{\beta}$ and $\tilde{\kappa} > \breve{\kappa}$. Arguing in a similar manner as above, one can show that the level of underinvestment in effort will be greater under *no lender liability* than under partial lender liability; that is, $\breve{\beta} > \bar{\beta}$ and $\breve{\kappa} > \bar{\kappa}$.

It is significant to note that even though extending the lender's legal obligation induces a bias towards more debt when $v < L$, this shift is more pronounced under *full* lender liability than it is under *partial* lender liability. Intuitively, *partial* lender liability causes an increase in the range of the states of the world in which the lender faces a negative cash flows. However, this increase is not as prominent as it is under *full lender liability.* By installing only a fraction of the burden on the lender, partial lender liability effectively imposes an exogenous a limit on the downside risk to which the lender is subjected, thereby diminishing the ability of the punishment mechanism to curtail the lender's moral hazard incentives. From propositions 2, 3 and 4, we obtain:

Corollary 2. *The effect of extended liability on the financial contracts and effort incentives can be characterized thus:*

(i) If $v \geq L$, *then extended liability and no lender liability are equivalent, that is,* $\breve{\beta} = \bar{\beta} = \tilde{\beta}$, $\breve{\kappa} = \bar{\kappa} = \tilde{\kappa}$, $\tilde{e} = \bar{e} = \breve{e}$ and $\breve{a} = \bar{a} = \tilde{a}$;

(ii) If $v < L$, *then extending liability induces a substitution of debt for equity, and the substitution is more pronounced under full liability liability than under partial lender liability, that is,* $\tilde{\beta} > \breve{\beta} > \bar{\beta}$ *and* $\tilde{\kappa} > \breve{\kappa} > \bar{\kappa}$. *The levels of effort incentives are highest under extended liability.*

Proof: See the appendix

2.4.5. Extended liability and solvency

In our model the firm is insolvent only if the environmental damage is very high, i.e. if and only if $l > l^*(\kappa)$, where $l^*(\kappa) = v - \kappa$. Therefore, the probability that the firm fails depends exclusively on its exposure to the environmental risk, which in turn depends on the level of debt κ issued by the owner. Recall that 1-$F(l^*(\kappa)/e, a) = 1 - \int_0^{l^*(\kappa)} f(l/e, a)dl$ is the probability of insolvency. Hence, for any given levels of effort, a higher level of debt lowers the likelihood of solvency.

The proposition below, summarizes the impact of extended liability on the project's prospects for solvency.

Proposition 5. *For any given effort combination* (e, a), *the relationship between the regime of liability and the probability of insolvency can be characterized as follows:*

(i) If $v \geq L$, *then extending liability has no impact on the firm's probability of failure;*

(ii) If $v < L$, then extended liability induces a higher insolvency rate.

Proposition 5 follows trivially from the fact that when $v \geq L$, the optimal policy calls for the owner to select the same level of debt regardless of the liability rule. This implies that $l^*(\breve{\kappa}) = l^*(\bar{\kappa}) = l^*(\tilde{\kappa})$. Consequently, the range of states of the world in which $l > l^*(\kappa)$ will the the same across all the liability regimes. For situations where $v < L$, however, $\tilde{\kappa} > \breve{\kappa} > \bar{\kappa}$ and $l^*(\bar{\kappa}) > l^*(\breve{\kappa}) > l^*(\tilde{\kappa})$ implying a higher range of insolvency states under extended liability than under no lender liability. In short, when $v < L$, extended liability increases effort incentives, but also induces a bias toward debt, which reduces the range of states of the world in which the firm is solvent.

2.5. Conclusion

We have explored the nature of financial contracts between a risk-neutral owner-manager of an environmentally risky project and a risk-neutral lender when both parties may influence damage realizations. Our objective was to examine how extending liability to the lender can affect the nature of the optimal contract, and how this in turn can affect the induced levels of effort and the firm's solvency.

Depending upon the size of the firm's assets, extending liability may or may not affect the likelihood of the levels of effort incentives and the firm's insolvency. If the firm's residual assets are sufficient to pay off the damage liability; that is, if the environmental harm is minor compared to the firm's asset, then extended liability and no lender liability are equivalent. On the other hand, if the lender must pay for the victim's compensation, then extended liability outperforms the *no lender* liability regime in terms of the level of effort incentives, but also induces a bias toward debt, which dampens the firm's solvency prospects.

Our model also predicts a relationship between the marginal productivity of effort and equity participation consistent with that implied in the signalling literature. In our model, however, a more productive principal offers a lower equity stake as a signal that a major damage is less likely.

The model also yields empirically testable hypotheses. First, there should be a relationship between the type of financial claim issued by the firm and environmental risk. More debt should be associated with firms susceptible to large environmental risks, while more equity should be issued by firms with less exposure to environmental disaster. This implies that a variable indicating the type of financing arrangement adopted by the firm should be included in the regression explaining the probability that a firm caused an environmental accident.

Second, there should be a relationship between the type of ownership claim issued by a firm and the regime of liability. To test this hypothesis, one could gather firm-specific data (on financing patterns of firms engaged in operations with environmental risks) spanning the period before and after the enactment of CERCLA (or similar legislation) and add institutional framework as an explanatory variable of the firm's capital structure. More precisely, a dummy variable indicating the presence of extended liability could be included in explaining the probability that a firm issued debt/equity.

There remains some interesting extensions. Our model considered the case where the owner's contribution towards the new investment is observable or costlessly verifiable. A natural extension is to consider an expanded model in which the owner is endowed with privileged information about her contribution. One could also admit the possibility that the owner may reduce the size of the investment and divert some of the loaned funds for perquisite consumption. The lender's contractual challenge would then involve inducing the owner to exercise adequate precaution as well as undertaking the required investment. Another extension might admit alternative specification of risk preferences. A typical small business may not hold a large portfolio of projects and may therefore be unable to diversify away all risks associated with a project. It may therefore be appropriate to model the manager as a risk-averse economic agent. Finally, the assumption of unbounded wealth for the lender could relaxed to admit the possibility of bankruptcy on the part of the lender.

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3. Paper 2: Technology transfer, project failure and liability allocation under moral hazard and private knowledge of absorptive capacity

3.1. Introduction

It is well known that trading of emissions rights can automatically achieve a given reduction in emissions in a flexible and a cost-effective manner (e.g., Fischer et al., 1998). The Kyoto Protocol extends this theme to a global context by proposing a number of project-based mechanisms that authorize industrialized countries to meet their emissions reduction obligations by (a) supporting carbon mitigation projects in economies in transition or developing countries, and (b) trading in emissions reductions credits generated from these activities.[20] While entirely innovative, the potential of purely transitory emissions reduction or actual level of emissions reduction falling short of the anticipated level raises the distinct possibility that emissions reduction credits may be spurious.

To ensure the validity and enhance the credibility of the emissions reduction credits, there must be rules assigning legal responsibility in the event of non-delivery of the promised credits.[21] *Ex-post* certification of emissions credits based on direct monitoring and verification can ensure a high level of compliance, thereby, eliminating any concern about the credibility of emissions credits. However, this approach is likely to be encumbered with at least two problems: First, prospective credits might have to be held in abeyance between certification, thereby reducing liquidity in the market for emissions credits. Second, certification after-the-fact may engender high transaction costs. The suggested solution

[20] Often called "flexibility mechanisms", these instruments include, (a) the Clean Development Mechanism (CDM), which allows industrialized countries to support carbon mitigation projects in developing countries and use the emissions reduction credits generated to offset their own greenhouse gas (GHG) emissions at home, (b) Joint implementation (JI), which allows industrialized countries to sponsor similar projects in economies in transition and (c) international trading of offset credits. The protocol currently awaits ratification by Russia in order to take effect.

[21] A CDM project may fail to generate the amount of emission reduction promised either because of misrepresentation before the fact or less than expected performance after the fact. This paper assumes that non-delivery of promised emissions credits is due solely to non-performance.

is to allow trading of emissions credits prior to certification with post-trade liability rules aimed at maintaining the integrity of the trading system (Toman and Cazorla [1998], United Nations [2000] and Kerr [1998]). Naturally, a number of questions of after-the-fact liability do arise. Who should be held responsible in the event of non-delivery of promised credits? Should liability be assigned to the project host, the project sponsor (investor), or both parties? How are the optimal incentive provisions affected by the nature of the liability rule in place? This study employs the mechanism design framework to shed some light on these issues. More precisely, it examines the interaction between of rules of liability allocation and the contractual arrangements between an investor from a country currently obliged to limit the emissions of greenhouse gases and a host entity from a country without current binding emissions targets.

In the model, the investor contracts with the host to undertake a greenhouse gas reduction project and funds the necessary technological switch. The model incorporates both adverse selection and moral hazard. There is adverse selection because the host is privately informed about her capacity to absorb the new technology. Moral hazard arises because the host's effort is unobservable. The project generates a stochastic return, which is dependent on the scale of investment in the green technology (i.e., effort) undertaken by the host and the host's absorptive capacity.

In a setting in which the host's absorptive capacity is common knowledge, there are no surprises: The moral hazard problem is completely resolved regardless of the scheme of liability. When adverse selection is added to the model, however, a surprising result emerges. A scheme of liability that holds the host - who directly controls the project risk - strictly liable is dominated by a scheme of liability that assigns the entire liability to the investor in terms of the level of investment (effort) incentives. A scheme of liability that assigns joint responsibility to the two parties induce investment incentives that are somewhere between those induced by host liability and investor liability. In short, installing liability on the investor, either in part or in full, is superior to imposing liability on the host in its entirety. This result stands in stark contrast to a simple and spontaneous intuition, which would suggest that the problem of underincentive could be largely mitigated by imposing liability for low investment on the party that supplies the productive investment, since then the objective function of the shirking agent would be closely aligned with the outcome.

Why is effort distortion more pronounced under a host liability scheme than an investor liability scheme? The explanation for this result is as follows: When both adverse selection and moral hazard are present simultaneously, two interrelated factors come into play in determining the level of effort incentives under host liability. One is the fact that the threat of punishment for a poor project outcome induces the host to work harder in order to avoid the potential loss of wealth in the failure state. Consequently, the importance of the moral hazard aspect of investment is diminished. The other, less obvious yet more intriguing is that the imposition of the burden on the host enhances her ability to command information rent. In this case, therefore, the marginal cost of investment as perceived by the foreign investor is much higher as it must additionally include a higher marginal information rent paid to the host to mitigate her incentive to understate her absorptive capacity. In sum, a liability rule that holds the host strictly liable makes the moral hazard problem less acute, but simultaneously intensifies the private information (adverse selection) aspects of the problem, thereby increasing the cost of using high-powered incentive schemes.

The results derived here stem from some very special features of our model. Risk neutral preferences and unbounded wealth for the investor are just but a few of such special features. Thus, if the investor can also default on liability, for example, then the superiority of investor liability over host liability may no longer be tenable. Nevertheless, these results have important implication for the regulation of international transfer of environmental technology as a means to accelerate the mitigation of climate change and project-based trading of emissions credits. They suggest that if a party that funds a green house gas (GHG) reduction project can observe neither the level of investment nor the absorptive capacity of the recipient, then better supply of investment can be achieved by imposing the entire liability on the investor or on both parties rather than imposing the entire liability on the host.

The rest of this paper is structured as follows: The next section relates the paper to extant literature on the subject. Section 2.3 presents the basic model. Section 2.4 examines the model under full information. Sections 2.5 and 2.6 discuss the limited information solution. Section 2.7 concludes. An appendix provide the proofs.

3.2. Related literature

This study is in the same spirit as previous works that have examined the problem of optimal regulation of externalities. In studies by Kolstad et al., (1990) Polinsky and Shavell (1993), Feess (1999), Demougin and Fluet (1999) and Privileggi et al., (2001), for example, individuals or corporations engage in risky activities that can cause large harms. The magnitude or probability of these harms can be reduced through precautionary action. The models employed in all these studies are in the principal-agent framework. While there is no information asymmetry in Kolstad et., al (1990), Polinsky and Shavell (1993) analyze the interaction between penalties on harms and contracting in a model with "hidden action" but no adverse selection. Feess (1999) compares strict liability, partial liability and vague negligence in a model with moral hazard and environmental auditing. Demougin and Fluet (1999) examine the implication of negligence and strict liability in an agency model that admits a moral hazard and an adverse selection problem separately.

The present paper differs from those cited above in two respects: First, the focus in the model presented herein emphasizes the hitherto unexplored interrelationship between liability allocation and the integrity of international trading of project-based emissions credits. Second, the problem of liability allocation is analyzed in the context of both moral hazard and adverse selection. To my knowledge, there has been no simultaneous treatment of both hidden action and hidden information in this context.

Closely related are those studies that have examined the problem of enforcement and compliance in a system of tradable emissions permits. Standlund and Dhanda (1999), Keeler (1991) and Malik (1990) have focussed on the efficiency of permits systems relative to command and control instruments and the optimal allocation of enforcement effort by an enforcement agency. In our context, non-compliance arises if the actual level of emissions reduction falls short of the anticipated level or emissions reduced are not sustained over the long-term. Additionally, enforcement is by way of post-trade liability allocation. Thus, this paper differs from those by Standlund and Dhanda (1999), Keeler (1991) and Malik (1990) in the two important ways: First, enforcement is exogenous. Second, compliance is made endogenous by conditioning it on unobservable effort and absorption ability.

The theme of this paper also overlaps with a number of areas in international technology transfer. Most recent works in this realm include Choi (2001) who uses an incomplete contract model of the licensing relationship to explain the prevalence of royalty contracts, and Tao and Wang (1998), who focus on contractual joint ventures between multinationals and local firms in an environment characterized by weak enforcement of binding contracts. Although both studies employ the principal-agent framework, they assume away the crucially important role played by the absorptive capacity of the technology recipient in ensuring successful technology transfer. In these studies, imperfect information arises from hidden action (moral hazard) only. This paper assumes an environment in which the foundation of imperfection arises from both moral hazard and hidden information (adverse selection).

Limited attempts have been made to examine the implications of project-based mechanisms for international environmental policy. A short list of existing works include Janssen (1999), Fischer (2002) and Wirl et al., (1998). Janssen (1999) focuses on the problem of contract enforcement. Fischer (2002) evaluates the efficacy of alternative baseline rules in a situation with asymmetric information while Wirl et al., (1998) focus on strategic reactions by CDM hosts in a three-layer hierarchical framework. However, none of these studies specifically examine post-trade liability rules can enhance and maintain the credibility of project-based mechanisms. Yet, such an investigation can uncover the comparative performance of alternative liability regimes and provide scope for regime ranking according to their overall impact on the level of effort incentives.

3.3. Basic Model

There are three risk-neutral players in the model: an entity that is eligible to host a GHG reduction project, a project sponsor from an industrialized country and an international environmental authority (IEA). For semantic convenience, we shall refer to the first two parties as the host and the investor, respectively. The IEA has preferences over greenhouse gas emissions (the IEA's utility is decreasing in the level of emissions). It approves all offset projects, and most importantly, has access to a comprehensive set of sanctions that it can impose for project nonperformance. The host currently uses a dirty technology involving an inefficiently high rate of emissions of GHGs. The rate of emissions can be significantly reduced by adopting a clean technology at a sunk cost of K, while the available initial wealth that the host can invest is μ. We assume throughout that $\mu < K$. This assumption is necessary to ensure that the host obtains external financing from the foreign investor.

Should the technological switch take place successfully, the host's rate of emissions would fall below some business as usual (baseline) level, thereby generating an environmental value (commodity) called certified emissions reduction credits (CERs).[22] We will denote by Δ the quantity of CERs generated by the project in the event of success. If the technological switch is not successful, however; that is, if the project is not successful, no net emissions credits are generated.

The nature of the production technology is follows. There is a single period, which is divided into two points of time: t=0 (beginning) and 1 (end). At time

[22] For heuristic reasons, we abstract from the determination of project baseline.

t =0, the project is approved (or in the parlance of the Kyoto Protocol, verified and registered) and the regime of liability is announced. Following UN (2000), we assume that there is a CER's market place in which future expected emissions credits can be securitized through derivative instruments such as options and futures and traded in the securities market.[23] Also at time $t = 0$, the new technology is installed at cost K. To develop the capacity to adapt and use foreign technology, the manager commits resources, whose costs are represented by e. At time $t = 1$, the project's outcome is realized. Assume that the outcome is observed by all parties. Between time $t = 0$ and $t = 1$, nature intervenes, so the project's outcome is uncertain. More formally, given the scale of investment (effort) e, the project yields a stochastic output

$$q = \begin{cases} \Delta & \text{with probability } p(e,\omega) \\ 0 & \text{with probability } 1 - p(e,\omega) \end{cases},$$

where ω is a measure of the ability or the capacity of the host to absorb the technology. The probability function $p(e,\omega)$ satisfies: $p_e(e,\omega)>0$, $p_{ee}(e,\omega)<0$, $p_{e\omega}(e,\omega) > 0$ and $p_\omega(e,\omega) > 0$; that is, effort increases the likelihood of success at a decreasing rate, and higher absorptive capacity increases both the likelihood of success and the marginal return from effort.

The host has a superior information than the investor about ω. In particular, the host knows the exactly value of ω from the outset while the investor's knowledge of ω is limited, however. The investor only knows that the technology-absorption parameter ω is distributed over the interval $[\underline{\omega}, \bar{\omega}]$ with density function $f(\omega) \equiv dF(\omega)/d\omega$, where $F(\omega)$ is the distribution function of ω. Denote by $\underline{\omega}$ the least absorptive capacity possible. As is standard in the incentive literature, we assume the following with respect to $F(\omega)$:[24]

[23] The idea of commoditizing environemtnal values through such innovative financial instruments is not entirely new. Futures contracts have been enlisted in the fight against acid rain in the US. When the Environmental Protection Agency (EPA) decided to allow a market for sulphur dioxide emissions allowance under the 1990 emendments to the Clean Air Act, the Chicago Board of Trade developed a futures contract for trading of air pollution futures. The principal reason for this was to provide liquidity to the market in emissions allowances.

[24] See, for example, Fudenberg and Tirole, 1991, p. 267.

Assumption 1 *The distribution of types $F(\omega)$ satisfies the monotone hazard rate property:* $\frac{\partial}{\partial\omega}\left[\frac{1-F(\omega)}{f(\omega)}\right] \leq 0.$

We assume that project failure inflicts an environmental damage X, which is borne by the IEA. We introduce a somewhat unconventional assumption with regard to X by defining environmental damage more broadly to include (a) the cost of restoring GHG emissions to where they would be if the project had succeeded and (b) the disutility suffered by the IEA as a result of the damage to the credibility of the international system of emissions trading.[25]

We assume that the IEA has access to a comprehensive set of sanctions that it can invoke to maintain the integrity of the system. More precisely, we assume that the IEA can impose sanctions, financial or otherwise, in the amount of $L = X$ according to some predetermined rule of liability allocation. We believe that this is a reasonable assumption because even if the IEA lacked the ability to directly install financial sanction, it could still achieve its objective indirectly by applying non-pecuniary measures such as refusing to approve future projects, issuing public approbation, suspending treaty privileges and even invoking trade sanctions (Wiser and Goldberg, 2000.) In short, reputation concerns on the part of the two parties may make any threat to impose sanctions by the IEA credible.

Before emissions reduction activities can be undertaken and carbon credits generated, the host and the investor must negotiate a contract specifying how the proceeds from the project will be shared. Such a contract must be based on variables that are verifiable by the investor or a third party. A contract specifies the following: $\beta(\omega) \geq 0$, the host's share of the project's proceeds or reward for success, and $\kappa(\omega)$ an up-front transfer of funds or the fixed component of the compensation package. In this case, $\kappa(\omega)$ can also be used as a proxy of foreign direct investment, the amount of capital that the host receives in return for ceding a proportion of $(1-\beta)$ of the project's proceeds. Thus, we restrict our attention to linear transfer functions of the form:

[25] See, for example, Wiser and Goldberg, 2000.

$$s(\omega) = \kappa(\omega) + \begin{cases} \beta(\omega)\Delta & \text{if } \Delta > 0 \\ 0 & \text{otherwise} \end{cases} \quad \omega \in [\underline{\omega}\ , \overline{\omega}]\,.^{26} \tag{3.1}$$

We assume that the two parties have the option to invest on the world market at the world interest r. Since the total output of the project is random, it is possible for the host to reduce her scale of investment below an appropriated level, and keep for herself or invest elsewhere the difference between the value of funds received from the investor and what she has actually expended on investment. With an initial wealth of μ and up-front transfer from the investor of $\kappa(\omega)$, the host's dividends or private savings in period 0, after incurring e in investment, is $\mu + \kappa(\omega) - e$. Thus, absent any liability scheme, the host's expected payoff at the end of period 1 is

$$\beta(\omega)p(e,\omega)\Delta + [1+r][\mu + \kappa(\omega) - e], \tag{3.2}$$

where $[1+r][\mu + \kappa(\omega) - e]$ represents the return from investing her period 0 savings/dividends on the world market. The corresponding expected payoff for the investor is

$$[1 - \beta(\omega)]p(e,\omega)\Delta - [1+r]\kappa(\omega), \tag{3.3}$$

where $[1+r]\kappa(\omega)$ is the opportunity cost of investing $\kappa(\omega)$ dollars in the project.

Two points are worth noting here. First, since neither effort nor type is observable (except under full information), the only possible basis for the contract is the observed output of credits. Second, since the host has private information about the productivity of investment, the nature of the contractual arrangement between the investor and the host will depend on the bargaining capabilities of the two parties. In this paper, we will for the most part assume that the bargaining power is concentrated in the hands of the investor. This is a reasonable assumption in situations where there is competition for foreign technology among potential hosts; where there is an elastic supply of host entities willing to compete for investment funds.[27] Thus, during contract negotiation, it will be appropriate to assume that the investor can make a take-it or leave-it offer to the host. In the concluding sections, we briefly relax this assumption to consider the corresponding solution when the host can dictate the terms of the contract.

3.4. Full information solution

Before proceeding to characterize the optimal private contracts under limited information, we record two benchmark cases. The first case considers the social problem and derives the socially optimal level of effort. The second case considers a setting where no adverse selection or moral hazard problem arises because both effort and type are known to the investor, but the optimal incentive contracts are determined through private interaction between the two parties.

3.4.1. The social problem

The socially optimal level of effort can be determined by maximizing the expected social value of the project, which is simply the aggregate net benefits of the project. The net value $p(e,\omega)\Delta + [1+r][\mu - e]$ is the sum of the utilities of the host and the investor while the expected damage $[1\text{-}p(e,\omega)]X$ is the monetary equivalent disutility of failure incurred by the IEA. Thus the net expected social surplus is $p(e,\omega)[\Delta + X] - X + [1+r][\mu - e]$. The social problem is $\max_e W = p(e,\omega)[\Delta + X] - X + [1+r][\mu - e]$. The concavity of $p(e,\omega)$ in e guarantees the existence and uniqueness of a socially efficient level of effort such that

$$p_e(e^s,\omega)[\Delta + X] - [1+r] = 0. \tag{3.4}$$

The social optimum identifies the optimal effort where the incremental expected benefit of the project, defined as the sum of the reduction in accumulation of carbon (increase in clean air) and avoided damages, equals the incremental benefit from an alternative investment. We will label this out-

[27] The idea that host-countries compete for foreign direct investment is well documented in the literature. See, for example, Koray and Taylor (2000), and Haufler and Wooton (1999).

come the social optimum. Assume that the maximal social value of the project $p(e^s, \omega)[\Delta + X] - X + [1 + r][\mu - e^s]$ is positive so that it is always optimal to undertake the project.

3.4.2. The investor's problem

Now consider a setting where no adverse selection or moral hazard problem arises because both effort and type are known to the investor, but the optimal incentive contracts and effort choices are determined through private interaction between the investor and the host. Under symmetric information, the optimal effort level necessarily maximizes the sum of utilities $p(e, \omega)\Delta + [1 + r][\mu - e]$ of the investor and the host for which the first order condition is $p_e(e, \omega)\Delta - [1 + r] = 0$.

Whereas the social optimum takes into account the environmental damage associated with project failure, the investor, acting in his own best interest does not do so. Clearly, the absence of damage liability entails lower levels of effort than under the social optimum. This is because effort is rewarded according to the investor's private gains only, which are lower than the social returns. Given that the absence of damages would entail lower effort exerted by the host than is socially desirable, it is reasonable to expect that a provision in support of damage liability can rectify this underincentive problem.[28]

A number of liability regimes have been suggested to deal with the underincentive problem highlighted above.[29] In this paper, we restrict attention to only three regimes of liability allocation. The first regime holds the investor strictly liable (Hereafter, *investor liability*). In the second setting, the financial responsibility for project failure is borne in its entirety by the host (Hereafter, *host liability*). A final situation is where both parties are held liable in the event of project failure. Throughout we refer to this scheme as *joint liability.*

Note that if L were strictly non-pecuniary; that is, if the IEA could not exer-

[28] Liability allocation belongs to a broad class of policies that can be implemented to regulate an externality after it has happened. Other forms of policies apply *ex-ante* and include such measures as taxes, quotas and standards (See, for example, Kolstad et at., 1990).

[29] See UN (2000) and Kerr (1998) for an exhaustive discussion of the rules of liability allocation.

cise financial sanctions, then host liability could be interpreted as a situation in which the IEA selectively punishes the host by, for example, refusing to approve any projects involving that host entity, while sparing the investor any such punishment; investor liability could be interpreted as a situation in which the non financial sanctions fall entirely on the investor to the exclusion of the host; joint liability could refer to a situation in which both parties were subjected to non financial sanctions. We now examine the nature of optimal incentive provision under each liability system in turn.

Host liability Host liability rule appeals to the notion of fairness because the host - who directly controls the project risk - is held responsible for project non-performance, rather than the investor. Simple intuition would suggest that imposing liability for low effort on the party that supplies the effort can mitigate any incentive problems since then the objective function of the shirking agent would be closely aligned with the outcome. As we show below, this may not necessarily hold when the two parties hold asymmetric information sets.

To focus the discussion, we need to ask whether the entire liability amount L can be paid in full by the host; that is, is it possible that the project fails and the host has insufficient resources to compensate the IEA? In the absence of an insurance market to underwrite any adverse contingencies, the fraction of the liability that is actually indemnified will depend crucially on the host's ability to pay; that is, it will be dependent on whether the host has the requisite financial resources to meet her obligation. Thus, an eventual penalty L set by the IEA must be up to some liability maximum that depends on the hosts residual wealth.

We formally incorporate this feature in our model by assuming that if the liability is installed on the host, then it is only paid with probability $\lambda(\mu) \in [0,1]$, where $\lambda'(\mu) > 0$, $\lambda''(\mu) \leq 0$, $\lambda(\infty) = 1$ and $\lambda(0) = 0$. The function $\lambda(\mu)$ implicitly captures the ease with which the IEA can apply sanctions to the host or the effectiveness of any sanctions that are imposed. For $\lambda(\mu)$=0, this restriction implies that either the host has no residual wealth of her own or it is impossible for the IEA to enforce any sanctions. If this happened, host liability as considered here would not be feasible and the entire liability would be uncompensated. As the host's wealth increases; that is, as the host gets more susceptible to sanctions, $\lambda(\mu)$ increases and/or it becomes easier for the IEA to enforce sanctions.

Given the default probability $\lambda(\mu)$, any host promised (β, κ) in compensation and facing a penalty L has an expected payoff of $\bar{U} = p(e,\omega)\Delta\beta + [1+r][\mu + \kappa - e] - [1-p(e,\omega)]\lambda(\mu)L$.[30] The investor's payoff, on the other hand, is simply $\overline{\pi} = p(e,\omega)\Delta(1-\beta) - [1+r]\kappa$. His optimization problem in this world of full information is straightforward: He simply sets the transfer payments to extract all the rents from the host while ensuring that she undertakes the level of effort that maximizes the expected total surplus. This is accomplished by solving $\max_e p(e,\omega)[\Delta + \lambda(\mu)L] + [1+r][\mu - e] - L$. One can easily verify that there is a unique optimal effort level $\bar{e}^*(\omega)$ that maximizes the expected total surplus and satisfies

$$p_e(\bar{e}^*(\omega),\omega)[\Delta + \lambda(\mu)L] - [1+r] = 0. \tag{3.5}$$

Equation (3.5) says that the optimal effort $\bar{e}^*(\omega)$ is characterized by the equality of the marginal benefit from investing in the project and the marginal return from holding an alternative asset. Comparing (3.5) with the corresponding condition for the social optimum, (3.4), we see that the socially optimal level of effort is generally not achievable under host liability because the parameter λ imposes an exogenous limit on the loss of wealth to which the host can be subjected. Because the host faces an expected loss of $[1- p(e,\omega)]\lambda(\mu)L$ in the event of project failure, so long as $\lambda < 1$, she cannot feasibly pay the full amount of L in the bad state. The possibility of uncompensated liability limits the ex-ante return from expending effort in terms of avoided damage. Thus, when $\lambda < 1$, $\bar{e}^* < e^s$.

[30] Note that in this formulation, $[1 - p(e,\omega)]\lambda(\mu)L$ may also be innocuously interpreted as the cost to the host of underperforming. It may, for instance, represent the expected loss in reputation, which may adversely affect the host's ability to obtain funding in the future. Diamond (1984), Bulow and Rogoff (1989), and Sherstyuk (2000) invoke a similar assumption. If interpreted in this way, then $\lambda(\mu)$ may well represent the susceptibility of the host to such costs.

An important question is how L, r and the host's initial wealth μ affect the equilibrium level of investment e. To answer this question, note that the second-order condition for a maximum is satisfied since $p_{ee}(e, \omega)[\Delta + \lambda(\mu)L] = SO\hat{C} < 0$. An application of the implicit function theorem to the first-order condition (3.5) yields three comparative statics of interest:

$$\frac{d\bar{e}^*}{dL} = \frac{-p_e(\bar{e}^*, \omega)\lambda(\mu)}{SO\hat{C}} > 0; \; \frac{d\bar{e}^*}{d\mu} = \frac{-p_e(\bar{e}^*, \omega)\lambda'(\mu)L}{SO\hat{C}} > 0; \; \frac{d\bar{e}^*}{dr} = \frac{1}{SO\hat{C}} < 0. \tag{3.6}$$

The first two expressions say that an exogenous rise in the host's wealth or the level of liability will lead to an increase in the equilibrium level of investment (effort). The rationale behind these unambiguous results is straightforward. When the two parties have symmetric information sets, an increase in either L or μ implies a reduction in the total surplus that the two parties have to share, thereby increasing the *ex-ante* marginal return from effort in terms of avoided liability. Accordingly, the investor prescribes a higher level of effort in order to reduce the risk of a bad outcome. As we demonstrate later, such unequivocal results need not hold when contracting takes place in an environment in which the two parties are endowed with different information sets. The last expression simply says that an exogenous increase in the world interest rate will lead to a decrease in the level of investment in energy efficient technologies in host countries. Intuitively, an increase in r increases the opportunity cost of investing in the emissions reduction project.

Investor liability In our framework, the international investor is presumed to act as a principal to the host. Hence, a rule providing for investor liability can be justified by arguing that it is within the means of the investor to provide adequate incentives to induce appropriate effort on the part of the host.[31] Throughout, we assume that the investor has sufficient resources to meet all her legal obligations.

[31] As an alternative, investor liability could also be interpreted as a situation in which the investor has a reputation to protect, whilst the host does not. For example, the investor may have borrowed from a third party in order to finance the technological switch; Clearly, project failure would damage the investor's reputation, whilst leaving the host's credibility unscathed.

Thus, whenever sanctions are imposed on the investor in their entirety, the entire liability amount L is paid and consequently, there is no uncompensated liability.

Under investor liability regime, the utility functions of the investor and the host for a given compensation (β, κ) are given, respectively, by $\tilde{\pi} = p(e,\omega)\Delta(1-\beta) - [1+r]\,\kappa - [1-p(e,\omega)]L$ and $\tilde{U} = p(e,\omega)\Delta\beta + [1+r][\mu+\kappa-e]$. In this case, the expected total surplus is $p(e,\omega)[\Delta + L] + [1+r][\mu - e] - L$. Thus, the investor solves the following problem [FI]:

$$\max_{e} p(e,\omega)(1-\beta) - [1+r]\kappa - [1-p(e,\omega)]L \tag{3.7}$$

Maximization of (3.7) with respect to e gives the following first-order condition for an interior maximum:

$$p_e(\tilde{e}^*(\omega),\omega)[\Delta + L] - [1+r] = 0. \tag{3.8}$$

The solution to the investor's problem identifies the optimal level of investment where the incremental expected benefit from investment defined as the sum of the increase in CERs and avoided liability equals the incremental opportunity cost of investment, which is $[1+r]$. Notice that since $L = X$, investor liability not only internalizes the entire liability but also induces the socially optimal level of investment. This result is not dependent on the host's level of wealth.

An important consideration is how the investor's choice of e changes with a change in the level of liability L; that is, what is the sign of $\frac{d\tilde{e}^*}{dL}$? The answer to this question requires the total differentiation of the first order condition given in (3.8). First, note that the second-order condition for a maximum is satisfied since $p_{ee}(e(\omega),\omega)[\Delta + L] = SO\tilde{C} < 0$. Now, the result of total differentiation of the first-order condition (3.8), upon rearrangement of terms, is $\frac{d\tilde{e}^*}{dL} = \frac{-p_e(e^*,\omega)}{SO\tilde{C}} > 0$, implying that increasing the level of liability has the effect of increasing the level of effort prescribed by the investor.

Joint liability We have seen above that limited wealth on the part of the host may lead to uncompensated liability and diminished effort incentives, relative to the social optimum, in the absence of an insurance market. Since the investor is assumed to have sufficient wealth to meet all of her legal obligations, the IEA can plausibly mitigate the underincentive effects of the host's limited wealth by holding the investor responsible for any residual liability uncompensated by the host. In this case, should μ (and therefore $\lambda(\mu)$) be sufficiently low that the host is unable to pay her portion of the liability in full, the residual liability would be automatically assigned to the investor. This regime has the appealing feature of making all the parties to the project bear the responsibility for any damages associated with project failure. It may also represent a phase in climate change negotiations when both the industrialized and developing countries face binding commitment to reduce their emissions.

More formally, suppose that the host is required to bear a proportion ρ of the liability L with the investor absorbing the balance. This implies that in event of a bad outcome, the host would pay ρL but with probability $\lambda(\mu)$. The investor, on the other hand, would be held liable for $(1-\rho)L$ plus any residual liability unpaid by the host, $[1-\lambda(\mu)]\rho L$. Thus, the investor's expected liability would be $[1-p(e,\omega)][1-\lambda(\mu)\rho]L$. The utility functions of the investor and the host for a given contract are, respectively, $\breve{\pi} = p(e,\omega)\Delta(1-\beta) - [1+r]\kappa - [1-p(e,\omega)][1-\lambda(\mu)\rho L]$ and $\breve{U} = p(e,\omega)\Delta\beta + [1+r][\mu + \kappa \text{-e}] - [1-p(e,\omega)]\rho\lambda(\mu)L$. The investor designs the contract for a type ω by solving the following problem [FJ]:

$$\max_{e} p(e,\omega)[\Delta + L] - L + [1+r][\mu - e]. \tag{3.9}$$

As before, maximization of the objective function (3.9) yield the following first order condition for an interior maximum:

$$p_e(\breve{e}^*(\omega),\omega)[\Delta + L] - [1+r] = 0. \tag{3.10}$$

Compared with the host liability setting, there is no uncompensated liability. Thanks to the investor's unlimited wealth, the optimal contract fully internalizes the liability arising from project failure. Not surprisingly, the host's level of wealth has no effect on the level of effort specified by the investor.

Proposition 5 below summarizes the relationship between the scheme of liability in force and the level of effort under full information. This result will be used in the next section to compare the level of effort under full information with that achieved when the two parties possess asymmetric information sets.

Proposition 6. *With full information:*

(i) $\tilde{e}^* = \breve{e}^*$*;*

(ii) Suppose that $\lambda(\mu) = 1 - \exp - (\phi\mu)$*, where* $\phi > 0$*. Then as* $\mu \longrightarrow \infty$*,* $\tilde{e}^* = \breve{e}^* = e^s = \bar{e}^*$.

Proof: See the appendix.

Property (i) of proposition 5 implies that assigning the liability strictly to the investor or holding both parties jointly liable is equivalent in terms of effort incentives. The intuition for this is as follows. Since the host's effort and ability are observable, and the level of output verifiable, forcing contracts are feasible. The only constraint the investor faces is that the contract offered to the host provide him with at least his opportunity payoff. Thus, the full information solution necessarily involves the effort level that maximizes the sum of utilities of the host and the investor. Investor and joint liability regimes result in no uncompensated liability: In either case, the sum of utilities is given by $p(e,\omega)[\Delta + L] + [1+r][\mu - e] - L$ so the investor is indifferent between the two regimes.

Property (ii) simply records the fact that the level of resources the host can forfeit to compensate for liability can affect the extent to which the liability is internalized in this full information setting. When the host's wealth is infinitely large, the financial burden imposed on the host is always paid in full, there is no residual liability and the investor optimally prescribes the level of effort that internalizes the entire liability. In this case, the three regimes of liability are equivalent in terms of their effect on effort choice. However, when μ is more limited such that $\lambda < 1$, the host cannot meet her obligations in full. In this case host liability results in a residual liability, which in the absence of an insurance market cannot be compensated.

Welfare under full information It is of interest to consider the impact of changes in parameters L and μ on the investor's welfare. It turns out that in the absence of agency problems, the investor's optimal welfare decreases in both the level of the financial penalty L, and the host's level of wealth, μ. Furthermore, this result holds regardless of the liability regime in force. The reason is that the optimal investor welfare varies according to the net balance of two effects. First, a higher value of L implies an increase in the investor's payoff, due to the impact of incremental L on increasing the marginal return from effort. We call this the *effort incentive effect.* Second, an increase in L reduces the investor's revenue earned from project activities by necessitating either higher transfer payments from the investor to the host to ensure her participation (under host and joint liability) or by directly reducing the investor's payoff under investor liability. We call this the *revenue effect.* In the appendix, we show that the negative revenue effect dominates the effort incentive effects.

The deleterious effect of the host's wealth on the investor's maximal payoff can also be explained in the same fashion: higher wealth owned by the host implies an increase in the host's expected liability, which results in an increase in transfers from the investor to the host to guarantee her participation. In the absence of agency problems, only the negative *revenue effect* occurs. Hence, the sign of $\frac{d\pi(\omega)}{dL}$ is unambiguously negative. These results are summarized in the following proposition.

Proposition 7. *Under full information, the optimal investor welfare is decreasing in both the level of liability and the level of wealth possessed by the host.*

Proof: See the appendix.

We have seen previously that both investor and joint liability regimes dominate host liability in terms of the optimal effort level when the host's level of wealth is sufficiently limited. But does higher level of effort necessarily imply a higher level of social welfare for the two regime? To answer this question, recall that the IEA applies any penalty revenue towards restoring GHG emissions to where they would be if the project had succeeded. Thus, if project failure causes X dollars worth of damages of which $\min\{L, \lambda(\mu)L\}$ is removed via the IEA's action, then the IEA's welfare, defined over net emissions, can be given by $B = [1 - p(e^*, \omega)][\min\{L, \lambda(\mu)L\} - X]$. Assuming a utilitarian welfare function, the maximal expected welfare of the project is $W(\omega) = B + \pi^*(\omega)$ $= p(e^*, \omega)[\Delta + X] - X + [1+\mathrm{r}][\mu - e^*]$. It is straightforward to show that $W_e(\omega) = p_e(e^*, \omega)[\Delta + X] - [1 + r] \lesseqgtr 0$ for $e^* \gtreqless e^s$. These imply that social welfare will be increasing in e for $e < e^s$ but will be decreasing in e for $e > e^s$. Since $\tilde{e}^* = \breve{e}^* > \bar{e}^*$, it follows that investor and joint liability regimes delivers a higher level of social welfare than host liability.

The intuition for this is the following: The investor's incentive to prescribe the efficient effort level under full information is determined not only by the size of L, but also how often it is actually paid. Under host liability, the investor is not obligated to pay any portion of the liability that is uncompensated by the host, and consequently, he has no incentive to prescribe the appropriate level. In this case, if μ is limited in the sense that $\lambda(\mu) < 1$, the social damage associated with the project is not fully internalized. The following proposition is an immediate and intuitive result from the foregoing discussion and is thus presented without proof:

Proposition 8. *Under full information, the investor and joint liability regimes deliver the highest level of social welfare.*

3.5. Pure moral hazard

Ordinarily, one would expect the host to choose effort such that the marginal benefit of effort equals its marginal cost. That is not necessarily the case with asymmetric information, however. If the host's effort e is not observable or verifiable, the investor cannot stipulate perfectly how much the host should invest in the green technology. Because investment is unobserved, the investor now faces the additional constraint that the host must be at an optimum with regard to his or her level of investment given the incentive scheme. In the following, we examine the implication of this additional contract for the host's effort incentives under the three alternative liability regimes.

3.5.1. Host liability

The investor's problem [MH] when only the moral hazard problem is present can be stated as follows:

$$\max_{\beta,\kappa} p(e,\omega)\Delta(1-\beta) - [1+r]\kappa \tag{3.11}$$

subject to

$$p(e,\omega)\Delta\beta + [1+r][\mu+\kappa-e] - [1-p(e,\omega)]\lambda(\mu)L \geq 0 \tag{3.12}$$

and

$$e \in \arg\max_{e} p(e,\omega)\Delta\beta + [1+r][\mu+\kappa-e] - [1-p(e,\omega)]\lambda(r)L. \tag{3.13}$$

Constraint (3.12) is the individual rationality (participation) constraint. It ensures that the host, whatever her type, gets at least her reservation utility or outside opportunity payoff, which is assumed to be zero. The only difference between problem [MH] and [FH] results from the additional constraint (3.13).

This constraint says that in the presence of moral hazard, the host must also be at an optimum with regard to her level of effort given incentive scheme (β, κ). Problem [MH] above can be reformulated in the following convenient form. By employing κ from the definition of the host's expected payoff $\bar{U}$ we obtain $\kappa = [\bar{U}+[1-p(e,\omega)]\lambda(\mu)L-[1+r][\mu-e]-p(e,\omega)\Delta\beta]/[1+r]$. This is then substituted into equation (3.11) to yield

$$p(e,\omega)[\Delta + \lambda(\mu)L] + [1+r][\mu - e] - \lambda(\mu)L - \bar{U}. \tag{3.14}$$

Notice that κ drops out, and is indeterminate. The first-order condition associated with (3.13) is

$$p_e(e,\omega)[\Delta\beta + \lambda(r)L] - [1+r] = 0. \tag{3.15}$$

Totally differentiating (3.15), we see that effort increases with the host's share output in equilibrium: $\frac{de}{d\beta} = -\frac{p_e(e,\omega)}{p_{ee}(e,\omega)[\Delta\beta+\lambda(\mu)L]} > 0$. Maximization of (3.14) with respect to β gives the following first-order condition for an interior maximum:

$$[p_e(e,\omega)[\Delta + \lambda(\mu)L] - (1+r)]\frac{de}{d\beta} = 0, \tag{3.16}$$

where $\frac{de}{d\beta}$ derives from (3.13). Since $\frac{de}{d\beta} > 0$, from (3.13), first-order condition 3.16 reduces to

$$p_e(e,\omega)[\Delta + \lambda(\mu)L] - [1+r] = 0. \tag{3.17}$$

Now using (3.15) and (3.17, we get the host's reward for success is given by

$$p_e(e,\omega)\Delta[1-\beta] = 0 \tag{3.18}$$

Since $p_e(e,\omega) > 0$, the latter-most equation implies $\beta = 1$. In response to such a contract, the host's effort choice is $p_e(e,\omega)[\Delta + \lambda(\mu)L] - [1+r] = 0$; that is, the optimal level of effort is the same under moral hazard as it is under full information. This is indicative of the standard result in the literature that if the agent is risk-neutral, then the moral hazard problem can be completely resolved by making the agent the residual claimant.

3.5.2. Investor liability

Consider, now, the other extreme in which the investor is held liable in the event of project failure. Existing literature has not adequately dealt with the question of how reallocating liability between a principal and an agent can affect the principal's interest in the agent's effort (or the level of precaution). In the Privileggi (2000) model, for instance, the principal is assumed to observe the agent's action. Consequently, the impact of liability allocation is modelled by assuming that the principal maximizes expected net benefit independently of the agent's effort under agent liability but selects the effort level under principal liability. If the agent's effort is not observable by the principal as presumed in our case, however, no contract can be written on effort and an analytic approach different from Privileggi's must be employed.

It is well known that a single moral hazard problem can be completely resolved by making a risk neutral agent the residual claimant. In our setting, this implies that the investor can achieve the full information outcome by ceding his interest in the project and off-loading the liability amount onto the host in return for a fixed fee. Given the host's limited asset bounds, however, we must place an upper bound on κ to guarantee the existence of an optimal contract. Otherwise, the investor can set $\kappa < -\mu$, shift the entire amount L to the host, and thus end up with no feasible solution.

Formally, the investor's problem [MI] reads:

$$\max_{\beta,\kappa,e} p(e,\omega)\Delta(1-\beta) - [1+r]\kappa - [1-p(e,\omega)]L \tag{3.19}$$

subject to

$$\tilde{U} = p(e,\omega)\Delta\beta + [1+r][\mu + \kappa - e] \geq 0 \tag{3.20}$$

$$e = \arg\max p(e,\omega)\Delta\beta + [1+r][\mu + \kappa - e]. \tag{3.21}$$

and

$$\beta \leq 1 \text{ or } 1\text{-}\beta \geq 0 \tag{3.22}$$

$$\kappa \geq -\mu \tag{3.23}$$

Constraint (3.20) is the usual participation constraint while constraint (3.21) ensures that the host is at an optimum with respect to effort. Constraint (3.22) implies that the share value must not exceed unity. The last constraint captures the fact that the host is wealth constrained and rules out situations such as $\kappa < -\mu$. This constraint is needed to guarantee the existence of an optimal contract when the host is risk neutral. The first-order condition associated with (3.21)

$$p_e(e,\omega)\Delta\beta - (1+r) = 0, \tag{3.24}$$

from which we can obtain $\frac{de}{d\beta} = -\frac{p_e(e,\omega)}{p_{ee}(e,\omega)\beta} > 0$. Let λ, γ and $\varkappa$ be the Lagrangian multipliers corresponding to (3.20) and (3.21), respectively. Solving (3.24) for $e(\beta,\omega)$ and substituting in the objective function, the first-order conditions (together with the associated complementary slackness conditions) are given by:

$$\beta: \quad p_e(e,\omega)[\Delta(1-\beta)+L]\frac{de}{d\beta} + \lambda\left[p_e(e,\omega)\Delta\beta - (1+r)\right]\frac{de}{d\beta} - \gamma = 0, \tag{3.25}$$

and

$$\kappa: \quad \text{-}[1+r][1-\lambda] + \varkappa = 0. \tag{3.26}$$

We now consider the following exhaustive and mutually exclusive cases depending on whether the three constraints bind or not.

Case I. The participation constraint does not bind. We can identify two sub-cases: (i) $\beta < 1$, $\kappa + \mu > 0$. In this case, 1-$\beta > 0$ implying that $\gamma = 0$. Since the participation constraint is not binding, $\lambda = 0$. Condition (3.23) implies that $\varkappa = 0$. Equation (3.25) reduces to $p_e(e,\omega)[\Delta(1-\beta)+L] = 0$, from which we obtain $[\Delta(1-\beta)+L] = 0$ or $[\Delta + L]$=$\Delta\beta$ or $\beta = 1 + L/\Delta > 1$, which is a contradiction. (ii) $\beta < 1$, $\kappa + \mu = 0$; that is, the host forfeits her entire wealth and the wealth constraint is binding. In this case, 1-$\beta > 0$ implying that $\gamma = 0$. Since the participation constraint is not binding, $\lambda = 0$. Condition (3.23) implies that $\varkappa > 0$. Equation (3.25) reduces to $p_e(e,\omega)[\Delta(1-\beta)+L] = 0$, from which we obtain $[\Delta(1-\beta)+L] = 0$ or $[\Delta + L]$=$\Delta\beta$ or $\beta = 1 + L/\Delta > 1$, which is a contradiction. (iii) $\beta = 1$ and $\kappa + \mu > 0$. This implies that the host's wealth constraint is not binding. In this case, $\gamma > 0$, $\lambda = 0$, $\varkappa = 0$ and (3.24) implies that $p_e(e,\omega)[\Delta(1-\beta)+L]\frac{de}{d\beta} - \gamma = 0$. Since $\gamma \geq 0$, there is no contradiction. With $\beta = 1$, the optimal level of effort is given by $p_e(e,\omega)\Delta - (1+r) = 0$. The host earns economic rent since $\tilde{U} > 0$, $\kappa > -\mu$, $e > 0$, but the damage, L is not fully internalized. (iv) $\beta = 1$ and $\kappa + \mu = 0$. This implies that the host's wealth constraint is binding. In this case, $\gamma > 0$, $\lambda = 0$, $\varkappa > 0$. Equation (3.24) implies that $p_e(e,\omega)[\Delta(1-\beta)+L]\frac{de}{d\beta} - \gamma = 0$ while equation (3.26) implies that $\varkappa > 0$. Since $\gamma \geq 0$ and $\varkappa > 0$, there is no contradiction. With $\beta = 1$, the optimal level of effort is given by $p_e(e,\omega)\Delta - (1+r) = 0$. The host earns rent since $\tilde{U} > 0$, $e > 0$, but the damage is not fully internalized. Cases I (iii) and I (iv) are all feasible outcomes. But since the investor's expected payoff decreases in κ and since μ is observable, she will set κ such that $\kappa + \mu = 0$. Hence, we rule out case I (iii).

Case II. The participation constraint binds, $\beta = 1$ and $\kappa + \mu > 0$. Since $1 - \beta = 0$ and $\kappa + \mu > 0$, it follows that $\gamma > 0$ and $\varkappa = 0$. Equation (3.26) now implies that $\lambda = 1$. From (3.25), we have $p_e(e,\omega)[\Delta + L] - (1+r)]\frac{de}{d\beta} - \gamma = 0$. From (3.24), $p_e(e,\omega)\Delta\beta - (1+r) = 0$, $p_e(e,\omega)[\Delta + L] - (1+r)] > 0$ implying that $\gamma > 0$. Hence, there is no contradiction.

Case III. The participation constraint binds, $\beta = 1$ and $\kappa + \mu = 0$. Since

$1-\beta=0$ and $\kappa+\mu=0$, it follows that $\gamma>0$ and $\varkappa>0$. Equation (3.26) now implies that $\lambda=1-\varkappa/(1+r)$. From (3.25), we have

$$p_e(e,\omega)[(\Delta+L)-(1+r)]\frac{de}{d\beta}-\frac{\varkappa}{(1+r)}\left[p_e(e,\omega)\Delta\beta-(1+r)\right]\frac{de}{d\beta}-\gamma=0. \quad (3.27)$$

Making use of (3.24), equation (3.27) can be written as $p_e(e,\omega)[(\Delta+L)-(1+r)]\frac{de}{d\beta}-\gamma=0$. Since $\gamma>0$ and $\varkappa>0$ by assumption, equation (3.27) implies that $p_e(e,\omega)[\Delta+L]-(1+r)]>0$ and there is no contradiction since $p_e(e,\omega)\Delta\beta-(1+r)=0$.

Case IV. The participation constraint binds and $\beta<1$ and $\kappa+\mu>0$. Since $1-\beta>0$ and $\kappa+\mu>0$, it follows that $\gamma=0$ and $\varkappa=0$. Also, (3.26) implies that $\lambda=1$. From (3.25), we have $p_e(e,\omega)[\Delta+L]-(1+r)]\frac{de}{d\beta}=0$, from which we obtain $p_e(e,\omega)(\Delta+L)-(1+r)=0$. But for this expression to hold simultaneously with (3.24), we must have $\beta=1+L/\Delta$ or $\beta>1$, which contradicts our earlier assumption. Reasoning in a similar manner, it can be shown that $\beta<1$ and $\kappa+\mu>0$ is not feasible when the participation constraint binds. Thus, the only feasible solution is given by case I (iv).

We conclude that in any optimal contract, $\beta=1$, $\kappa+\mu=0$ and the condition for optimal effort choice is given by

$$p_e(e,\omega)\Delta-(1+r)=0. \quad (3.28)$$

Faced with limited wealth on the part of the agent, the investor optimally requires the host to deliver her entire wealth and in return cedes any claims on the project without shifting his legal liability. By ceding his stake in this manner, the investor forfeits the ability to embed a punishment mechanism in the optimal contract. Consequently, the host's effort choice decision does not take into account the marginal benefit of investment which occurs in terms of avoided damages, and the equilibrium contract induces a socially inefficient level of effort. If μ were arbitrarily high; that is, if the host's asset base was unbounded, then the investor could make κ arbitrarily high and force the full information outcome. The foregoing result parallels that found in Demougin and Fluet (1999).

3.5.3. Joint liability

Suppose now that a moral hazard problem is present and the regime of liability assigns joint responsibility to both parties with the investor obligated to absorb any portion of the liability that is not indemnified in the event that the host's wealth is insufficient. In this setting, the investor will solve the following problem [MJ]:

$$\max_{\beta} p(e,\omega)\Delta(1-\beta) - [1+r]\kappa - [1-p(e,\omega)][1-\lambda(\mu)\rho L] \tag{3.29}$$

subject to

$$\breve{U} = p(e,\omega)\Delta\beta + [1+r][\mu+\kappa-e] - [1-p(e,\omega)]\lambda(\mu)\rho L \geq 0 \tag{3.30}$$

$$e \in \arg\max_{e} p(e,\omega)\Delta\beta + [1+r][\mu+\kappa-e] - [1-p(e,\omega)]\lambda(\mu)\rho L, \tag{3.31}$$

$$\beta \leq 1 \text{ or } 1\text{-}\beta \geq 0, \tag{3.32}$$

and

$$\kappa \geq -\mu. \tag{3.33}$$

As in the previous section, it is straightforward to show that any optimal contract must have $\beta = 1$ and $\kappa = \mu$; that is, the investor must cede her stake in the project in return for a fixed fee without transferring her legal liability. This yields the following first-order condition with respect to effort:

$$p_e(e,\omega)[\Delta + \lambda(\mu)\rho L] - (1+r) = 0 \quad (3.34)$$

As before, the effort choice condition accounts for only a fraction of the damage. Thus, the moral hazard problem is not completely resolved in this setting so long as $\rho > 0$ and the level of effort incentives is not socially optimal. The discussion above is now summarized in the following proposition.

Proposition 9. *Suppose type is observable but effort is not. Then host liability induces the full information outcome. Investor liability and joint liability result in less than the full information level of effort.*

3.6. Combining hidden action and adverse selection

Consider, now, a situation in which both type and effort are not observable. The contract design problem can be analyzed within a mechanism design framework. By the revelation principle, there is no loss in generality in focusing on a direct mechanism in which the investor provides the host with incentives that induce truthful behavior (e.g., Fudenberg and Tirole, 1991 and Laffont and Tirole, 1993). In a direct mechanism, the investor offers a standard screening contract $C = \{s(\hat{\omega}) : \hat{\omega} \in [\underline{\omega}, \overline{\omega}]$, prescribing a level of transfer $s(\hat{\omega})$ conditional upon the host's announcement $\hat{\omega}$. We assume that the investor can credibly commit not to renegotiate the contract.

The investor selects $s(\hat{\omega})$ to maximize her expected payoff. In so doing, he or she takes into account the response of the privately informed host. As in similar models, the optimal actions of the privately informed host gives rise to two kinds of constraints that the investor must take into account when designing the mechanism. The first kind ensures that the host reports her type ω truthfully. These constraints are called the *incentive compatibility* constraints. The second kind of constraints are the *individual rationality* constraints. They require that the host, whatever his type, gets his reservation payoff, the payoff that the host would get by not participating in the project.

Using the revelation principle, we identify an equilibrium. An equilibrium consists of a menu of transfers s and a vector of reports $\hat{\omega} \in [\underline{\omega}\ , \overline{\omega}]$ that implicitly determine the level of effort incentives.

The sequence of events is as follows: In the first stage, The IEA publicly announces the liability rule and the size of the penalty L. Nature then draws a type ω for the host from a set of feasible types $\omega \in [\underline{\omega}\ , \overline{\omega}]$. Only the host learns her ability. In the second stage, the investor and the host agree on a menu of contracts. The host reports his type and then chooses a level of effort to supply given the compensation package and the liability rule. Final project output is observed and the transfers implied by the menu of contracts are implemented.

3.6.1. The host is strictly liable

A type ω who has a level of wealth μ faces an expected penalty (or disutility) of $[1 - p(e, \omega)]\lambda(\mu)L$. Thus, given the structure of contingent contracts as in (3.1), a host type ω that reports that her type is $\hat{\omega} \in [\underline{\omega}\ , \overline{\omega}]$ has an expected payoff $U(\hat{\omega}, \omega, e(\hat{\omega}, \omega))$:

$$U(\hat{\omega}, \omega, e(\hat{\omega}, \omega)) = p(e, \omega)\Delta\beta(\hat{\omega}) + [1+r][\mu + \kappa(\hat{\omega}) - e] - [1 - p(e, \omega)]\lambda(\mu)L. \quad (3.35)$$

The investor's utility function is obtained as:

$$\pi = p(e, \omega)\Delta[1 - \beta(\hat{\omega})] - [1 + r]\kappa(\hat{\omega}). \quad (3.36)$$

Ex ante, the investor does not know the host's absorptive capacity. His expected utility is

$$E\pi = \int_{\underline{\omega}}^{\overline{\omega}} [p(e, \omega)\Delta[1 - \beta(\omega)] - [1 + r]\kappa(\omega)]\, dF(\omega). \quad (3.37)$$

Thus, the screening problem under host liability [AH] is as follows:

$$\max_{\{\beta(\hat{\omega}),\kappa(\hat{\omega})\}} E\pi = \int_{\underline{\omega}}^{\overline{\omega}} [p(e,\omega)\Delta[1-\beta(\omega)] - [1+r]\kappa(\omega)]\, dF(\omega) \tag{3.38}$$

subject to

$$U(\omega,\omega,e(\omega,\omega)) \geq 0 \quad \forall\omega \in [\underline{\omega}\ ,\overline{\omega}]\,, \tag{3.39}$$

$$U(\omega,\omega,e(\omega,\omega)) \geq U(\hat{\omega},\omega,e(\hat{\omega},\omega)) \quad \forall(\hat{\omega},\,\omega) \in [\underline{\omega}\ ,\overline{\omega}]\,, \tag{3.40}$$

and

$$e(\hat{\omega},\omega) \in \arg\max_{e} p(e,\omega)\Delta\beta(\hat{\omega}) + [1+r][\mu+\kappa(\hat{\omega})-e] - [1-p(e,\omega)]\lambda(\mu)L. \tag{3.41}$$

where $E[.]$ is the expectation operator.

The participation constraint (3.39) for the host ensures that she receives nonnegative expected profit, regardless of her type and report. Constraint (3.40) is the incentive compatibility condition for the host. It states that the host finds it optimal to truthfully report her type. Equation (3.41) says that the host chooses the level of effort optimally given contract $C = \{s(\hat{\omega}) : \hat{\omega} \in [\underline{\omega}, \overline{\omega}]\}$.

The first-order condition for optimal effort is derived from (3.41) and is given by

$$p_e(e(\hat{\omega}),\omega)[\Delta\beta(\hat{\omega}) + \lambda(\mu)L] - (1+r) = 0. \tag{3.42}$$

Thus, the investor designs $C = s(\hat{\omega})$ such that the marginal benefit of effort is just equal to the marginal cost of effort. Totally differentiating (3.42), we see that the level of effort incentives increases with the host's share of project returns in equilibrium:

$$\frac{de}{d\beta} = -\frac{p_e(e(\hat{\omega}),\omega)\Delta}{p_{ee}(e(\hat{\omega}),\omega)[\Delta\beta(\hat{\omega}) + \lambda(\mu)L]} > 0. \tag{3.43}$$

For allocation $(\beta(\omega),\kappa(\omega))$ to be implemented as a direct mechanism, two sets of incentive compatibility condition must be satisfied. First, $\beta(\hat{\omega})$ must be monotonic. Second, $U(\hat{\omega}, \omega, e(\hat{\omega}, \omega))$ must be increasing. To prove that $\beta(\hat{\omega})$ is monotonic, we borrow from McAfee and McMillan (1987) and Fudenberg and Tirole (Ch. 7, 1991). An allocation is a pair of non-stochastic function $y = (\beta(\omega), \kappa(\omega))$. Recall that $U(\hat{\omega}, \omega, e(\hat{\omega}, \omega)) = p(e, \omega)\Delta\beta(\hat{\omega}) + [1+r][\mu + \kappa(\hat{\omega}) - e] - [1 - p(e, \omega)]\lambda(\mu)L$ is the indirect utility function of the host; i.e., the utility the host type ω receives when reporting $\hat{\omega}$. When evaluating U, it is standard to let $U(\omega) \equiv U(\omega, \omega, e(\omega, \omega))$ denote the host's indirect utility function when she truthfully reports her type. The monotonicity/sorting condition is defined by

$$\frac{\partial}{\partial \omega}\left(\frac{\partial U(\omega)/\partial \beta}{\partial U(\omega)/\partial \kappa}\right) = \left[p_{\omega}(e, \omega)\Delta + p_{e\omega}(e, \omega)[\Delta\beta(\omega) + \lambda(\mu)L]\frac{de}{d\beta}\right] > 0. \quad (3.44)$$

The necessary condition for allocation $(\beta(\omega), \kappa(\omega))$ to be implemented as a direct mechanism is that $\left[\frac{\partial}{\partial \omega}\left(\frac{\partial U(\omega)/\partial \beta}{\partial U(\omega)/\partial \kappa}\right)\right]\frac{\partial \beta}{\partial \omega} \geq 0$. Thus $\beta(\hat{\omega})$ is non decreasing in type. This condition asserts that higher types (for whom success is most likely) prefer higher β while lower types prefer lower β. Thus, as the host's absorptive capacity increases, she is less willing to give up an increment in β in return for an increase in κ. This parallels the single crossing property in standard screening models.

The remaining incentive compatibility condition can be obtained as follows: Providing the mechanism is differentiable, when truth-telling is optimal, then we have $\partial U(\hat{\omega}, \omega, e(\hat{\omega}, \omega))/\partial \hat{\omega}|_{\hat{\omega}=\omega} = 0$. The total derivative of $U(\omega)$ with respect to the host's type report can be obtained from the Envelope Theorem as

$$\begin{aligned} \left.\frac{dU(\hat{\omega}, \omega, e(\hat{\omega}, \omega))}{d\omega}\right|_{\hat{\omega}=\omega} &= \left.\frac{\partial U(\hat{\omega}, \omega, e(\hat{\omega}, \omega))}{\partial \hat{\omega}}\right|_{\hat{\omega}=\omega} + \left.\frac{\partial U(\hat{\omega}, \omega, e(\hat{\omega}, \omega))}{\partial \omega}\right|_{\hat{\omega}=\omega} \\ &= \left.\frac{\partial U(\hat{\omega}, \omega, e(\hat{\omega}, \omega))}{\partial \omega}\right|_{\hat{\omega}=\omega} \text{ since } \left.\frac{\partial U(\hat{\omega}, \omega, e(\hat{\omega}, \omega))}{\partial \hat{\omega}}\right|_{\hat{\omega}=\omega} = 0 \\ &= p_{\omega}(e, \omega)[\Delta\beta(\omega) + \lambda(\mu)L]. \end{aligned} \quad (3.45)$$

Hence, $U(\hat{\omega}, \omega, e(\hat{\omega}, \omega))$ is increasing. Raising the share of the project's proceeds $\beta(\omega)$ of a type ω host increases the rents earned by all types more productive than type ω by an amount $p_\omega(e,\omega)\Delta$. Similarly, and more importantly, raising the amount of damages L borne by a type ω host increases the rents earned by all types more productive than type ω by an amount $p_\omega(e,\omega)\lambda(\mu)$.

Having established the set of incentive compatibility constraints, the solution to problem [AH] can now be obtained using control theoretic techniques. Proposition 9 describes the solution to the investor's problem under host liability.

Proposition 10. *Suppose that the scheme of liability holds the host strictly liable for project failure, the sorting condition holds and $\beta(\omega)$ is non-decreasing. Then the solution to program [AH], denoted by $\{\overline{\beta}(\omega), \overline{\kappa}(\omega)\}$, is characterized by*

$$\begin{aligned}
&[p_e(e(\omega),\omega)[\Delta + \lambda(\mu)L] - (1+r)]\frac{de}{d\beta} - \frac{(1-F(\omega))}{f(\omega)}p_\omega(e(\omega),\omega)\Delta \\
&\quad - \frac{(1-F(\omega))}{f(\omega)}p_{\omega e}(e(\omega),\omega)[\Delta\overline{\beta}(\omega) + \lambda(\mu)L]\frac{de}{d\beta} = 0,
\end{aligned} \tag{3.46}$$

and

$$\begin{aligned}
\kappa(\omega) &= \delta\left[[1 - p(e(\omega),\omega)]\lambda(\mu)L - p(e(\omega),\omega)\Delta\overline{\beta}(\omega)\right] - \mu + e \\
&\quad + \delta\int_{\underline{\omega}}^{\omega} p_\omega(e(\omega'),\omega')[\Delta\overline{\beta}(\omega') + \lambda(\mu)L]d\omega'
\end{aligned} \tag{3.47}$$

where

$\frac{de}{d\beta} = -\frac{p_e(e(\hat{\omega}),\omega)\Delta}{p_{ee}(e(\hat{\omega}),\omega)[\Delta\overline{\beta}(\hat{\omega})+\lambda(\mu)L]}$ and $\delta = \left(\frac{1}{1+r}\right)$.

Proof: See the appendix

An optimal contract must induce the host to undertake the appropriate level of investment as well as tell the truth about her type. Because of risk-neutrality, these two tasks can be separately accomplished by the linear contracts: The slope coefficient of the linear contract, β, provides proper incentives while the fixed component of the compensation takes care of truth-telling about type. Equation

(3.46) gives the condition for the optimal compensation coefficient or more precisely, the necessary condition to induce the optimal level of effort as defined by equation (3.42). Equation (3.47) gives the level of the fixed transfer from the investor to host.

From condition (3.47), we can see that the fixed part of the compensation package comprises two components: The first part is represented by the terms in the first line of expression 3.47. These guarantee the host her reservation utility. The second part is the integral term on the right hand side of (3.47)). This term has the smallest magnitude at the lowest host type, and is actually equal to zero when $\omega = \underline{\omega}$. For higher host types, this term is larger. Thus, the integral represents the host's information rent, the amount required to induce the host to reveal her true type. From (3.47), it is evident that the host will be offered a compensation package with fixed and variable components that are inversely related to each other. A host type with a higher bonus level (a higher incentive scheme) will receive a lower level of the fixed compensations and vise versa.

The intuitive idea behind (3.46) can be unravelled by considering the implication of combining adverse selection and moral hazard problems in the same context. If the level of effort were contractible and the host's information were common knowledge, then the full information levels of effort would satisfy $p_e(e(\omega),\omega)[\Delta + \lambda(\mu)L] = 1 + r$. Under pure moral hazard, the necessary condition for optimal effort is $[p_e(e(\omega),\omega)[\Delta + \lambda(\mu)L] - (1+r)]\frac{de}{d\beta} = 0$. Thus the second and the third terms in (3.46) derive from the host's private information. These two terms sum to zero for $\omega = \overline{\omega}$ since $F(\bar{\omega}) = 1$; that is, the host with the highest "absorptive capacity" works as hard as under full information conditions. For all host types below the upper end point, $\omega < \overline{\omega}$, however, $F(\omega) < 1$, and it is evident that the last two terms in equation (3.46) sum up to a negative value ($p_\omega(e(\hat{\omega}),\omega) > 0$ and $p_{\omega e}(e(\hat{\omega}),\omega) > 0$). The level of effort induced by the investor for these types will therefore be less than the pure moral hazard or full information level. As in McAfee and McMillan (1987), there is "no distortion at the top" but the incentive scheme for the low types is distort in order to capture the information rents.

An important consideration is the role played by the host's residual wealth (or her default potential) in determining the nature of the distortion in effort incentive that is optimally induced in this setting. When $\lambda(\mu)$ is near zero; that is, when μ is sufficiently small, the second distortion term decreases in significance, making the sum of the two terms less negative. Hence the overall level of distortion for $\lambda(\mu)=0$ is smaller in absolute magnitude than when $\lambda(\mu)$ is near one. Since $\lambda(\mu)$ is, by assumption, increasing in wealth, our model predicts that an increase in the host's level of wealth; that is, a decrease in the host's default potential, may actually compound the agency problem. The reason is that under host liability, the agent bears the liability risk in its entirely, and the costs of this risk are higher for a wealthy host than for a poor host. Since a wealthy host has more to lose in the event of project failure, he will accept to participate in the project only if he is promised a higher compensation to offset the severe downside threat he faces in the adverse state. In this sense, the host's participation constraint is tightened. A direct corollary from the foregoing is that the informational rent that must be paid for any implementable effort and the investor's incentive to distort effort are also increased following a rise in μ.

There is a positive side to a higher level of μ, however. When μ rises, the first term on the left-hand-side of equation (3.46) increases in significance. Since $\frac{de}{d\beta} > 0$, it follows that $p_e(e(\omega), \omega)$ must fall when μ rises; that is, e must increase as would be the case under full information. The reason for this is that a higher level of μ raises the severity of any punishment that the host is subjected to in the state of the world in which there is project failure. The host can cut his or her expected loss by reducing the failure probability. In other words, a higher level of wealth on the side of the host makes failure more costly, thereby making failure avoidance more attractive. Consequently, higher effort is supplied.

In sum, the effect of a higher level of μ on the size of the optimal effort incentives is ambiguous; it depends on the net balance of the adverse selection effects and the moral hazard effects. More precisely, it depends on the difference

$p_e(e(\omega),\omega) - \frac{(1-F(\omega))}{f(\omega)} p_{\omega e}(e(\omega),\omega)$. When $\frac{(1-F(\omega))}{f(\omega)} p_{\omega e}(e(\omega),\omega)$ is sufficiently large (i.e., when the expected marginal information rent more pronounced), the investor's incentive to mitigate the host's desire to understate his or her private information will dominate, and an increase in μ will reduce the level of effort incentives. Thus, our model makes a qualitative prediction that appears to contradict a pervasive perception, particularly in the labour economics literature, that the power of incentives afforded an agent should always increase with his or her wealth.[32] Here, an increase in the agent's wealth entails a decrease in his default potential which in turn increases the cost of adverse selection rent and the cost of any implementable effort. Thus, from (3.46) and (3.47), we further obtain:

Corollary 3. *If $p_{\omega e}(e(\omega),\omega)$ is sufficiently large, then the investor's incentive to distort the host's effort incentives increases in the host's level of wealth.*

Corollary 4. *In the optimal linear contract, the bonus term $\bar{\beta}(\omega)$ and the base term $\bar{\kappa}(\omega)$ are inversely related.*

Proof: Corollary 3 requires no formal proof. For proof of corollary 4, see the appendix.

3.6.2. Investor liability

With truthful reporting, the value of the investor's utility conditional on the hosts report, $\hat{\omega}$, becomes

$$\tilde{\pi} = p(e,\omega)[\Delta(1-\beta(\hat{\omega})) + L] - L - [1+r]\kappa(\hat{\omega}). \tag{3.48}$$

On the other hand, a host of type ω that reports type $\hat{\omega}$ has an expected utility

$$\tilde{U}(\hat{\omega},\omega) = p(e,\omega)\Delta\beta(\hat{\omega}) + [1+r][\mu + \kappa(\hat{\omega}) - e]. \tag{3.49}$$

[32] See, for example, Laffont and Matoussi (1995), and Legros and Newman (1996).

Equilibrium under investor liability in the presence of both moral hazard problem and adverse selection can be determined as a solution to the following optimization problem [AI]:

$$\max_{\beta,\,\kappa} \tilde{\pi} = \int_{\underline{\omega}}^{\overline{\omega}} [p(e,\omega)[\Delta(1-\beta(\hat{\omega})) + L] - L - (1+r)\kappa(\hat{\omega})]\, dF(\omega). \tag{3.50}$$

subject to

$$\tilde{U}(\omega,\omega) \geq 0 \quad \forall \omega \in \ [\underline{\omega}\ ,\overline{\omega}]\,; \tag{3.51}$$

$$\tilde{U}(\omega,\omega) \geq \tilde{U}(\hat{\omega},\omega) \quad \forall(\omega,\hat{\omega}) \in [\underline{\omega}\ ,\overline{\omega}]\,; \tag{3.52}$$

and

$$e \in \arg\max p(e,\omega)\Delta\beta(\hat{\omega}) + \kappa(\hat{\omega}) - e. \tag{3.53}$$

The following proposition describes the solution to the investor's problem [SI].

Proposition 11. *Suppose that the scheme of liability holds the investor strictly liable, the sorting condition holds and $\beta(\omega)$ is non-decreasing. Then the solution to problem [AI], denoted by $\{\tilde{\beta}(\omega), \tilde{\kappa}(\omega)\}$ is characterized by:*

$$\begin{aligned}[p_e(\tilde{e}(\omega),\omega)[\Delta + L] - (1+r)]\frac{de}{d\beta} - [\frac{1-F(\omega)}{f(\omega)}]p_\omega(\tilde{e}(\omega),\omega)\Delta \\ -[\frac{1-F(\omega)}{f(\omega)}]p_{\omega e}(\tilde{e}(\omega),\omega)\Delta\tilde{\beta}(\omega)\frac{de}{d\beta} = 0\end{aligned} \tag{3.54}$$

and

$$\tilde{\kappa}(\omega) = e - \mu - \delta p(e(\omega),\omega)\Delta\tilde{\beta}(\omega) + \delta \int_{\underline{\omega}}^{\omega} p_\omega(e(\omega'),\omega')\Delta\tilde{\beta}(\omega')d\omega' \tag{3.55}$$

where $\frac{de}{d\beta} = -\frac{p_e(\tilde{e}(\omega),\omega)}{p_{ee}(\tilde{e}(\omega),\omega)\Delta\tilde{\beta}(\omega)}$ and $\delta = \frac{1}{1+r}$.

Comparing equation (3.54) and (3.8) one can see that the optimal effort in the presence of both moral hazard and adverse selection, $\tilde{e}(\hat{\omega})$, coincides with the full information outcome for all types but $\overline{\omega}$. For all $\omega < \overline{\omega}$, the effect of the combination of adverse selection and moral hazard is not readily apparent. To see why, note that when ω and e are observable (and therefore contractible), the effort choice condition satisfies $p_e(e(\hat{\omega}),\omega)[\Delta + L] = 1 + r$ and at this level the host earns zero rent and cedes all her wealth. When e is observable but ω is unknown, the optimal effort satisfies condition $p_e(e(\hat{\omega}),\omega)\Delta = 1 + r$. Thus, $p_e(\tilde{e}(\omega),\omega)L\ de/\ d\beta$ and the last two terms of (3.54) represent the the effect of combining both moral hazard and adverse selection in the same context. The last two terms, which sum to a negative number in the investor's optimum, are the information rents to the host. They represent the distortion in the compensation scheme that is optimally induced in order to limit the ability of the host to command information rents. The term $p_e(\tilde{e}(\omega),\omega)L\ de/\ d\beta$ is positive and clearly tempers the investor's desire to shift effort away from the efficient level. If L were zero, then moral hazard and adverse selection would unambiguously induce a higher level of effort distortions than pure moral hazard

Recall that under pure moral hazard, the investor optimally sets $\beta = 1$, and in this way loses the ability to align the host's compensation with the project's outcome. In the presence of both moral hazard and adverse selection, however, β is conditioned on outcome. In this case, raising β increases the information rent to the host but induces an offsetting effect in that it results in a higher marginal return from effort in terms of avoided damages. In short, the effect of $p_e(\tilde{e}(\omega),\omega)L\ de/\ d\beta$ in the investor's optimum is to lessen the adverse selection consequences and reduce the cost of using high powered incentives. Thus, it is not possible to say, a *priori*, that effort incentives will be higher under pure moral hazard than under simultaneous moral hazard and adverse selection when the liability is installed on the investor.

3.6.3. Joint liability

Given the structure of contingent contracts as in (3.1) and the nature of joint liability, a host type ω that reports type $\hat{\omega}$ has an expected payoff $\breve{U}(\hat{\omega},\omega)$:

$$\breve{U}(\hat{\omega},\omega) = p(e,\omega)\Delta\beta(\hat{\omega}) + [1+r][\mu+\kappa(\omega)-e] - [1-p(e,\omega)]\lambda(\mu)\rho L. \quad (3.56)$$

The investor's expected payoff is similarly obtained as:

$$\breve{\pi} = p(e,\omega)\Delta[1-\beta(\hat{\omega})] - [1-p(e,\omega)][1-\rho\lambda(\mu)]L - (1+r)\kappa(\hat{\omega}). \quad (3.57)$$

Ex ante, the investor does not know the type of the host. Thus, the screening problem [AJ]is as follows:

$$\max_{\beta,\kappa} \pi = \int_{\underline{\omega}}^{\overline{\omega}} [p(e,\omega)\Delta[1-\beta(\hat{\omega})] \quad (3.58)$$
$$-[1-p(e,\omega)][1-\rho\lambda(\mu)]L - (1+r)\kappa(\hat{\omega})]\, dF(\omega)$$

subject to

$$\breve{U}(\omega,\omega) \geq 0 \quad \forall\omega \in [\underline{\omega}\ ,\overline{\omega}] \quad (3.59)$$

$$\breve{U}(\omega,\omega) \geq \breve{U}(\hat{\omega},\omega) \quad \forall(\hat{\omega},\omega) \in [\underline{\omega}\ ,\overline{\omega}] \quad (3.60)$$

$$e = \arg\max p(e,\omega)\Delta\beta(\hat{\omega}) + [1+r][\mu+\kappa(\hat{\omega})-e] - [1-p(e(\hat{\omega}),\omega)]\rho\lambda(\mu)L. \quad (3.61)$$

Applying the same control theoretic tools employed in the previous section, it is straightforward to show that the necessary condition for optimal effort as a function of private information satisfies,

$$[p_e(e(\omega),\omega)[\Delta + L] - (1+r)]\,\frac{de}{d\beta} - \frac{[1-F(\omega)]}{f(\omega)} p_\omega(e(\omega),\omega)\Delta \qquad (3.62)$$
$$-\frac{[1-F(\omega)]}{f(\omega)} p_{\omega e}(e(\omega),\omega)[\Delta\breve{\beta}(\omega) + \rho\lambda(\mu)L]\frac{de}{d\beta} = 0,$$

where $\frac{de}{d\beta} = -\frac{p_e(e(\hat{\omega}),\omega)\Delta}{p_{ee}(e(\hat{\omega}),\omega)[\Delta\breve{\beta}(\hat{\omega})+\rho\lambda(\mu)L]}$.

As with the case of the previous regime, we cannot say, a *priori*, whether effort incentives will be higher under pure moral hazard than under simultaneuos moral hazard and adverse selection. Raising β has adverse selection effects as represented by the last two terms in equation (3.62), but it also reduces the cost of using high-powered incentive schemes as captured by the term $p_e(e(\omega),\omega)L\frac{de}{d\beta}$.

We can obtain additional insight about the forces underlying the investor's optimal incentive provision by looking more closely at these terms. For instance, the second distortion term implies that an increase in the host's level of wealth or his share of the liability ρ will unambiguously exacerbate the agency problem. Unlike under host liability, there are no offsetting moral hazard effects in this setting. For any given level of μ, an increase in ρ implies an increase in the significance of the second distortion term, making the sum of the two terms more negative. Hence the overall level of distortion for any given λ is smaller in absolute magnitude when ρ is near zero than when ρ is near one. The reason is that a higher level of ρ tightens the host's participation constraint and increases the cost of the adverse selection rent that must be paid to induce truthtelling on the part of the host. In other words, an increase in ρ increases the cost of implementing any effort level, thereby increasing the cost of using highly powered incentive schemes.[33]

[33] It is standard to characterize the power of an incentive scheme in terms of the rate at which the agent's financial payoff increases as the surplus she creates increases (See, for example, McAfee and McMillan, 1987; and Lewis and Sappington, 2001)

3.6.4. Comparing the three schemes

The core conclusion from the preceding section is that the combination of moral hazard and adverse selection may exacerbate the agency problem. As equations (3.46), (3.54) and (3.62) show, the distortion term sums to a negative number in the investor's optimum under all the liability regimes considered, thereby inducing a shift away from the first-best or the pure moral hazard outcome. This result is consistent with, for example, McAfee and McMillan (1991) and Theilen (2003) who have examined the interaction between moral hazard and adverse selection in settings that, however, differ from ours.[34] But does the format of liability allocation affect the magnitude of distortions in effort incentives optimally implemented by the investor? Do qualitative differences emerge in the nature of optimal incentive provision when the sanctions are applied on the principal than when the sanctions are applied on the agent? As we argue below, the optimal level of distortions may depend crucially on whom the liability is assigned.

Host liability installs the financial burden on the agent and therefore implies a potential loss of wealth on the side of the host in the adverse state. Consequently, the host will accept to participate in the project only if he is promised a higher transfer payment to compensate for the severe downside risk that she faces in the event of failure. In other words, the installation of sanctions upon the host tightens her participation constraint and makes it harder to satisfy. Since the host is privately informed about her absorptive capacity which, along with his effort, influence project risk, the imposition of a financial burden on the host actually increases her ability to command informational rents. The reason for this is that the host with a higher absorptive capacity, for whom failure is less likely, can earn private financial gains from success not only in terms of his share of project output ($\frac{[1-F(\omega)]}{f(\omega)}p_{\omega e}(e(\omega),\omega)\Delta\beta(\omega)$) but also, most importantly, in terms of *avoided damages* ($\frac{[1-F(\omega)]}{f(\omega)}p_{\omega e}(e(\omega),\omega)\lambda(\mu)L$) by simply passing himself as a

[34] In McAfee and McMillan (1991), the moral hazard problem in team production is resolved by making the agents the residual claimant; the addition of adverse selection induces the principal to distort effort in a rationally attempt to limit the agents information rent. Theilen (2003) incorporates risk aversion and obtains similar result.

lower type. Hence, the critical need to mitigate the host's desire to understate his absorptive capacity is made more acute by the presence of these class of rents. Thus, a host liability system makes the adverse selection problem more severe but reduces the importance of moral hazard.

By contrast, under an investor liability, the principal absorbs all liability risk associated with the incentive schemes. In this setting, there are no rents in terms of *avoided damages* that can be appropriated by the host; the host's informational rent is limited to his share of the output $\frac{[1-F(\omega)]}{f(\omega)} p_{\omega e}(e(\omega), \omega)\Delta\beta(\omega)$. In essence, investor liability removes avoided damages from among the class of information rents that the host can command. This reduces the amount of rent required to induce the host to truthfully report his type, thereby making it less costly to achieve any implementable level of effort. Thus, starting from a setting in which the agent bears the sole responsibility for liability payment, a reallocation of liability to the principal will reduce the cost of using high powered incentive schemes and, therefore, the investor's incentive to distort effort.

It remains to determine the extent to which effort incentives are distorted under a joint liability scheme relative to the other two regimes. In the same vein as under a host liability scheme, joint liability tightens the participation constraint and increases the cost of adverse selection rent that must be paid to induce truthtelling. In this sense, joint liability makes it more costly to use high powered incentive, thereby inducing higher effort distortions relative to the situation where only pure moral hazard is present. However, the ability of the host to command these rents is tempered with by the share of the financial burden that the investor must bear in the bad state $(1-\rho)$. Thanks to the exogenously imposed sharing rule, the host's information rent in terms of avoided damages is now given by $\frac{[1-F(\omega)]}{f(\omega)} p_{\omega e}(e(\omega), \omega)\lambda(\mu)\rho L$. And the lower his share of the liability, the lower his ability to command these class of information rents and the lower is the investor's informational costs.

In sum, a host liability makes the incentive problem in dealing with the host more acute; a joint liability outperforms a host liability in terms of effort distortion but evokes more distortion than investor liability. This result stands in stark contrast to a simple and spontaneous intuition, which would suggest that the problem of underincentive could be largely mitigated by imposing liability for underperformance on the party that directly controls the risk, since then the objective function of the shirking agent would be directly linked to the project outcome. The key point is that assigning liability to the host enhances his ability to command additional informational rents while the investor liability, by inoculating the host from any liability risk, limits his informational advantage in this respect. To the investor, these rents represent a cost, whilst to the host they constitute a benefit. So the host desires a higher effort level than does the investor. It is, therefore, plausible to assume that a shift in the balance of bargaining power towards the host may allow greater internalization of these rents, thereby evoking a higher level of effort on the part of the host.

It is important to stress that the foregoing result does not depend on the host's inability to pay. Limited wealth on the part of the host only heightens the moral hazard problem which in turn makes the adverse selection problem relatively less important for the investor. This implies that even if the host had adequate resources to pay off all her legal liability, the investor would still prefer that the host default more often so as to limit his potential gains from understating his absorptive capacity and the investor's information costs. Thus, a wealthy host may not necessarily be accorded the greatest opportunity to enjoy the financial success of the project.

3.6.5. Comparative statics

The analysis so far has resulted in expressions for the necessary conditions for an optimal sharing rate β as well the fixed transfer schedule. However, we can gain more insight to the economics of the problem by performing comparative statics. In this section, we construct a restricted functional form of the model, derive comparative statics and then analyze specific parameterization that illustrate the characteristic of the incentive scheme and the incentive for the host to undertake investment. Assume the following functional form for the probability function:

$$p(e, \omega) = \omega e^{\eta}, \text{ where } \eta < 1. \tag{3.63}$$

The comparative statics are summarized in table 1 below (see the appendix for derivations.) The parameters of interest are L, r and μ while the endogenous variable are e and β .

The table shows that the effect of changes in the level of liability on the scale of investment depends crucially on the liability rule in force. Under host and joint liability regimes, the effect of higher levels of L is ambiguous; it is the result of two countervailing forces: On the one hand, increases in L increase the host's liability risks exposure, which induces an increase in the scale of investment (moral hazard effect). At the same time, however, that increase indicate a higher marginal information rent that must be paid to implement any given effort level (adverse selection effect). This increases the cost of using high-powered incentives and reduces the scale of investment. Under investor liability regime, however, there is no ambiguity as to the effect of changes in L on the scale of investment: Since there are no countervailing adverse selection consequences, increases in L increase the scale of investment. This is because an increase in L increases the investor's loss in the state of the world in which there is project failure. The investor can cut his expected loss (and increase his net payoff) by reducing the failure probability. This is achieved by inducing a higher scale of investment on the part of the host. The foregoing argument is confirmed by the last three columns of table 1, which show that increases in L lead the investor use high-powered scheme less often under host and joint liability schemes ($\frac{\partial \bar{\beta}}{\partial L}$ and $\frac{\partial \breve{\beta}}{\partial L}$) but imply a higher incentive to use high-powered schemes under investor liability ($\frac{\partial \bar{\beta}}{\partial L}$).

Increase in	$\bar{e}$	$\tilde{e}$	$\breve{e}$	$\bar{\beta}$	$\tilde{\beta}$	$\breve{\beta}$
L	?	↑	?	↓	↑	↓
μ	?	-	?	↓	-	↓
r	↓	↓	↓	-	-	-

Table 1. Comparative statics

Now let us turn to μ. Under both host and joint liability schemes, the variable μ parametrizes the potential loss of wealth that the host can suffer in the event of project failure: An increase in μ increases the level of *ex-post* punishment that the host can be subjected to in the disaster state, thereby increasing the marginal return from investment and her ex-ante incentive to invest. At the same time, however, since the host's participation constraint must be satisfied, an increase in μ indicates a higher marginal information rent and increase in the cost of any implementable scale of investment. In a rational attempt to reduce the ability of the host of command these rents, the investor optimally reduces β; that is, diminishes the power of incentives.

The effect of changes in r on the scale of investment has no ambiguity at all. All other things being equal, an increase in r increases the marginal opportunity cost of undertaking investment, and it induces the host to divert funds away from the project and into private savings. That is, a higher degrees of moral hazard will be associated with a higher level of r.

3.6.6. Implications

We have used a highly stylized model to illustrate most clearly the interaction between liability allocation and the optimal provision of incentives in the presence of private information. Therefore, the framework cannot serve as a basis for comprehensive recommendation regarding the optimal design of technology transfer contracts or rules for liability allocation in an international system of trade in emissions credits. Nevertheless, the results of this paper can be applicable to the question of whom the responsibility should be assigned in the event that an offset activity fails and where there is a clear principal-agent relationship between the investor and the technology recipient.[35]

The conventional wisdom seems to be that, holding the host liable should be preferred because it enables the objective function of the shirking agent - who directly controls the risk - to be directly aligned with the project outcome.[36] However, the results here imply the contrary; they suggest that if a party that provides a clean technology to be utilized in a green house gas (GHG) reduction project can neither observe the level of effort exerted nor the recipient's absorptive capacity, then better supply of effort can be achieved by imposing the entire liability on the investor or on both parties rather than imposing the entire liability on the host. Overall, such policy could lead to a reduction in the frequency of project failure and enhance the credibility of an international system of trade in emissions reduction credits.

Conventional wisdom would also suggest that a wealthy hosts (or one with a reputation to protect) be assigned more financial responsibility than his or her relatively less endowed counterpart. Our model suggests that such a policy may well be counterproductive if the host's absorptive capacity is sufficiently large: Assigning more liability to a wealthy host who is also reasonably efficient in utilizing the technology may increase his or her ability to command informational rents, thereby increasing the investor's motive to engage in effort distortion. In this sense, assigning more responsibility to the wealthy host may actually lead to severe underinvestment in effort.

Our model predicts a positive relationship between an investor's stake in a project and the host's level of wealth. In a rational attempt to limit the host's ability to command information rents, the investor provides the least pronounced incentives to the wealthiest host. This finding suggests that foreign investors will tend to retain the most pronounced stakes when projects are undertaken in con-

[35] This requirement could be satisfied if, for instance, the investor were to establish a subsidiary in the host country.

[36] Investor liability can also be justified by appealing to the fact that the principal gains from the host's action and ability, and can, therefore, provide adequate incentives for the host to choose an appropriate level of effort.

junction with relatively wealthy hosts, and will acquire less pronounced stakes in projects undertaken jointly with poor hosts. This implies that investments in poor host countries will overwhelmingly take the form of *debt-like* arrangements. Clearly, this result has pessimistic implication for the participation poor host countries in climate change: The bias towards more debt-like financing arrangement may not endear climate change mitigation to third world countries in view of the crushing debt burdens under which they currently operate.

3.7. An extension: Host holds all the bargaining power

We have seen that allocating the liability to the host, either in part or in full, enhances her ability to command information rent. This would not have mattered were it not for the fact that the two parties hold diametrically opposed views about these rents: To the investor, these rents represent a cost, whilst to the host they constitute a benefit. So the host desires a higher effort level than does the investor. It is therefore natural to ask whether a shift in the balance bargaining power towards the host can change the nature of the distortions in effort that are optimally induced under the three liability regimes; that is, can an increase in the bargaining power of the host allow greater internalization of these class of rents?

In this section, we allow the balance of the bargaining power to swing in favour of the host and examine the properties of the corresponding solution. This assumption is consistent with a setting in which the host can dictate the terms of the contract, for example, where *ex-ante* competition among potential investors is particularly intense. For simplicity, we assume here that the host retains *all* the bargaining power in all circumstances. When the bargaining power is concentrated in the hands of the investor, the appropriate model must be one of screening by the investor. However, when the host has all the bargaining power, then we have a situation with an *informed principal*, to use the terminology of Maskin and Tirole (1992). In this case, the appropriate model must be one of signalling by the host.

Accordingly, we derive a signalling solution under each liability scheme based on Maskin and Tirole's (1992) concept of incentive-compatible Rothschild-Stiglitz-Wilson (RWS) allocation. When transplanted into our context, an allocation is said to be the RWS incentive compatible if it maximizes the payoff of each host type subject to the investor's reservation utility π^0 and the incentive-compatibility condition that the lower host type has no incentive to mimic the higher type. It is important to note that the RWS allocation is not necessarily the unique solution when the host can dictate the terms of the contract to the investor. However, Maskin and Tirole's (1992) have established a sufficient condition under which the RWS allocation represents the unique equilibrium to the signalling game. The condition is that the RWS be interim efficient for the *prior beliefs* of the investor; that is, there must exist no other incentive-compatible allocation that Pareto dominate the RSW allocation.

Suppose that the host has truthfully reported her type. Then given that the host's type is ω, the investor's expected payoff (indirect utility) under host liability, investor liability and joint liability can be written, respectively, as

$$\bar{\pi}(\omega) = p(e,\omega)[\Delta + \lambda(\mu)L] + [1+r][\mu - e] - \bar{U}(\omega) - \lambda(\mu)L = \bar{\pi}^0; \tag{3.64}$$

$$\tilde{\pi}(\omega) = p(e,\omega)[\Delta + L] + [1+r][\mu - e] - \tilde{U}(\omega) - L = \tilde{\pi}^0; \text{ and} \tag{3.65}$$

$$\breve{\pi}(\omega) = p(e,\omega)[\Delta + L] + [1+r][\mu - e] - \breve{U}(\omega) - L = \breve{\pi}^0 \tag{3.66}$$

where $\bar{U}(\omega) = p(e,\omega)\Delta\beta(\omega) + [1+r][\mu + \kappa(\omega) - e] - [1 - p(e,\omega)]\lambda(\mu)L$ is the host's payoff function when she truthfully reports her type and the rule in force holds her strictly liable, $\tilde{U}(\omega) = p(e,\omega)\Delta\beta(\omega) + [1+r][\mu + \kappa(\omega) - e]$ is the host's payoff function when she truthfully reports her type and the rule in force holds the investor strictly liable, and $\breve{U}(\omega,\omega) = p(e,\omega)\Delta\beta(\omega) + [1+r][\mu + \kappa(\omega) - e] -$

$[1-p(e,\omega)]\rho\lambda(r)L$ is the host's payoff function when she truthfully reports her type and the rule in force holds the two parties jointly responsible; $\bar{\pi}^0$, $\tilde{\pi}^0$ and $\breve{\pi}^0$ denote the investor's reservation payoff under each liability scheme. Assume that $\bar{\pi}^0 = \tilde{\pi}^0 = \breve{\pi}^0 = \pi^0$. The following proposition gives the necessary condition for an incentive-compatible RWS allocation under each alternative rule.

Proposition 12. *Suppose that the host has all the bargaining power and β is non-increasing and differentiable with respect to ω. Then for ω in the interior of $(\underline{\omega}, \overline{\omega})$, the incentive-compatible allocation will satisfy the following:*

(i) If the host is strictly liable, then

$$[p_e(e,\omega)[\Delta + \lambda(\mu)L] - (1+r)] \frac{de}{d\beta}\frac{d\beta}{d\omega} - p_\omega(e,\omega)[\Delta\beta(\omega) + \lambda(\mu)L] = 0; \quad (3.67)$$

(ii) If the investor is strictly liable, then

$$[p_e(e,\omega)[\Delta + L] - (1+r)] \frac{de}{d\beta}\frac{d\beta}{d\omega} - p_\omega(e,\omega)\Delta\beta(\omega) = 0; \quad (3.68)$$

(ii) If both parties are jointly liable, then

$$[p_e(e,\omega)[\Delta + L] - (1+r)] \frac{de}{d\beta}\frac{d\beta}{d\omega} - p_\omega(e,\omega)[\Delta\beta(\omega) + \rho\lambda(\mu)L] = 0. \quad (3.69)$$

Proof: The proof follows immediately from totally differentiating 3.64 - 3.66 with respect to ω.■

The effect of private information in this signalling framework is represented by the distortion terms $p_\omega(e,\omega)[\Delta\beta(\omega)+\lambda(\mu)L]$, under host liability; $p_\omega(e,\omega)\Delta\beta(\omega)$,under investor liability; and $p_\omega(e,\omega)[\Delta\beta(\omega) + \rho\lambda(r)L]$, under joint liability. Since $\frac{d\beta}{d\omega} \leq 0$, the effect of shifting the balance of the bargaining power in favour of the host is to decrease $p_e(e,\omega)$ relative to the case where only moral hazard is present; that is, there is more effort in the RWS mechanism compared with the pure moral hazard.

This result reflect the standard conclusion in signalling settings that the activities of the most productive type are distorted upward in order to distinguish themselves from the low types. In our context, the high type host distinguishes herself from the low type by prescribing a higher variable component and low fixed component of the compensation package than the low type. Absent such a feature in the compensation package, low type hosts, for whom success is less likely, may falsely report that their types are higher in order to earn a higher share of the project's proceeds. To preclude this incentive, the signalling contract prescribes a high bonus component for the high type and a low bonus component for the low type. Since success is realized less often by the low type, the low type finds it too costly to pass herself off as a high type.

Does it matter, for effort distortion, who bears the burden of project failure? Comparing the three distortion terms in equations 3.67 - 3.69, it is immediate that the host's incentive to oversupply effort is more pronounced under host liability than it is under either joint liability or investor liability. Intuitively, when the host is held strictly liable, then each time the project succeeds she gets not only the bonus payment but also manages to avoid liability payment; under joint liability, the avoided loss is only a fraction ρ of the expected liability; under investor liability, however, no gain accrues to the host in terms of avoided damages. In short, the balance of the bargaining power can fundamentally change the prediction regarding the pattern of effort distortions.

3.8. Conclusion

The motive for writing this paper was to rank alternative concepts of liability by examining how the allocation of liability can affect the nature of contractual agreement between the investor and the host and the induced level of effort under asymmetric information.

Consistent with common perception, we find that the first-best outcome of full efficiency in effort is achievable when contracting takes place between a risk neutral principal and a risk-neutral agent in the presence of pure moral hazard. Contrary to conventional wisdom, however, this analysis shows that a regime of liability that installs responsibility solely on the host -who directly controls the risk- yields a lower level of effort than that which installs the entire liability on the investor if the host's absorptive capacity is privileged information. The reason for this is that assigning liability to the host enhances his ability to command additional informational rents while assigning the burden to the investor inoculates the host from any liability risk, thereby limiting his informational advantage. To the investor, these rents represent a cost, whilst to the host they constitute a benefit. To induce truthtelling, the investor intentionally distorts effort away from the full information level. But because the host commands a higher level of rent under host liability than under investor liability, the investor's motive to distort effort is much stronger under the former regime than under the latter.

These results are obtained through a number of simplifying assumptions, which could be extended in a variety of ways. Our model assumes that both the investor and the host are risk neutral. Risk neutrality for the investor is questionable in this context, however, because individual investor's seeking low-cost abatement options are unlikely to possess a portfolio of similar projects spread across the developing world. The same can be said of the host's risk preferences. Thus, a deeper exploration of the impact of liability allocation might involve an examination of the effects of risk preferences. Second, we assumed throughout that only the host's effort matters for the project's success. Most often, however, the success of technology transfer depend on the input of both the host and the technology supplier. Third, our model assumes that financial penalties are imposed whenever a project fails regardless of the actions undertaken by the parties to the contract. A possible extension might admit a scheme of liability based on negligence. These lines of thought are beyond the scope of this study and are left for further research.

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4. Paper 3: Technology transfer, project failure and liability allocation under double moral hazard and private knowledge of wealth

4.1. Introduction

The second paper abstracted from any direct contributions that the investor might make toward enhancing the success of the technological transfer. In that paper, the foreign investor was presumed to be a purely passive actor with no role beyond providing the required investment funds. This depiction neglects to consider that the foreign investor may undertake actions that may substantially affect the project's outcome; for example, the investor may provide basic input necessary for the effective transmissions of the technology and supply other support functions to maintain and improve the value of investment in the technology.

In this paper we incorporates two features that have not been examined in the extant literature. First, we explicitly allow for the investor to directly intervene in the project by supplying personally costly effort.[37] The investor's intervention is assumed to enhance the likelihood of the project's success. Second, we permit the host to be privately informed about her wealth and, therefore, her probability of having a loss. In short, there exists a double-sided moral hazard problem as well an adverse selection issue. It is well known that when a principal in an agency relationship has a choice variable which can affect the project outcome, but whose value cannot be assessed *ex-ante*, the optimal contract must take into account the "principal's incentive provision as well as the agent's own incentive provision."[38]

Our prime concern here is to determine whether the liability rule in place can imply qualitative differences in the nature of incentive provision when only bilateral moral hazard is present, and when both two-sided moral hazard and adverse

[37] Choi (2001) is, perhaps, a notable exception in this regard. As we show below, this work does not incorporate adverse selection, and is not concerned with the issue of liability allocation, however.

[38] See, for example, Bhattacharyya and Lafontaine (1995) and Kim and Wang (1998).

selection are present simultaneously. It turns out that the nature of distortions in the levels of input supplied by the two parties depends critically on whom the liability is installed and the nature of information sets held by the two parties. When the investor is held strictly liable, the optimal contract yields an incentive to underinvest in effort by the two parties under pure moral hazard; under simultaneous moral hazard and adverse selection, the incentive scheme exhibits bunching of types and a shift away from host's effort and towards investor's effort. When liability is installed on the host (in part or in full), the optimal contract continues to induce underinvestment under pure moral hazard; however, once both moral hazard and adverse selection are incorporated in the same context, the resulting rent-efficiency trade-off yields an incentive to overburden the host with too much effort relative to the pure moral hazard situation.

What drives these results is the manner in which the host's private information enters the investor's payoff. Under host liability, the investor induces truthtelling by imposing a financial disclosure requirement on the host. In this case, the host has an incentive to overstate her wealth endowment (understate her payoff) and her private loss in the event of project failure in order to convince the investor that a more generous fixed compensation is in order. The investor best mitigates the host's incentive to misrepresent her wealth by offering a high-powered incentive scheme (a lower fixed component of the compensation package) when she claims to be wealthy. This induces a shift away from investor's effort and toward host's effort relative to the case where only pure moral hazard is present. Under investor liability, however, the host faces no external sanctions from the IEA when the project underperforms and has, therefore, no incentives to take into account the costs of project failure despite the fact that she controls the project's failure risk. The investor optimally aligns the host's effort incentives by requiring her to post up-front a non-refundable cash bond. To mitigate the host's incentive to *understate* her wealth, it is best to promise her a higher share of the project's proceeds when she posts a higher bond. However, offering the host a more generous output sharing arrangement to compensate for the larger wealth that she forfeits has countervailing effects in that its dulls the investor's incentive to undertake productive investment. Because the optimal contract must also induce appropriate effort incentives on the part of the investor and because of diminishing returns from effort, the investor optimally cedes rent to the host when her wealth is sufficiently high. Consequently, the incentive scheme exhibits bunching in some regions of the type space.

As for policy, we show that the introduction of an input-based subsidy or a reduction in foreign ownership cap to encourage foreign investment may reduce the incentive for the investor to overburden the host with too much investment. The results of the model presented in this paper can also advise on the problem of equity, which has often been inextricably linked to climate change negotiations.[39] According to this study, the goal of equity can be best served by requiring donor countries to assume increased responsibility for project failure. Installing damages on host entities in the presence of private information appears to worsen the equity problem in that it shifts the burden of investment actions to the host and reduces the scale investment undertaken by the investor.

This work is in the same spirit as previous studies that have examined the problem of international technology transfer. A truncated list include works by Gallini and Wright (1990), Beggs (1992) and more recently Tao and Wang (1998) and Choi (2001). Gallini and Wright (1990) and Beggs (1992) examine the characteristics of licensing when the royalty rate in the contract acts as a signaling device for the party who has better information about the value of the licensed technology. Tao and Wang (1998) focus on contractual joint ventures between multinationals and local firms in an environment characterized by weak enforcement of binding contracts. Choi (2001) is perhaps closest to this study in that it develops a formal model of technology transfer in the presence of double moral-hazard. By coupling a double-sided moral hazard problem with an adverse selection problem, the present study extends the aforementioned studies.

[39] One of the UNFCCC principles is that climate change protection must have an "equitable" basis and that developed countries should take the lead in combating climate change.

Also closely related are those studies that have documented the effects of exogenous wealth constraints on agency relationships. Che and Gale (2000) is perhaps the most influential in this regard. Che and Gale (2000) analyse an adverse selection model in which buyers have private information about their willingness and ability to pay for a good. They show that when a buyer has private information about both her valuation of a good and her budget constraint, the optimal selling mechanism involves price discrimination where a single price would have been optimal in the absence of private information. Lewis and Sappington (2001) examine the optimal design of contracts when an agent is privately informed about his wealth, his ability and his effort supply. In this two-dimensional adverse selection and moral hazard framework, an agent's wealth and ability act as perfect complements in determining the power of the incentive scheme in which an operates. More precisely, an agent requires both high ability and greater wealth to secure a more powerful incentive scheme: ability alone is not sufficient. Lewis and Sappington (2000b) examine how a project owner selects a project operator when the potential operators are privately informed about their wealth and effort is not contractible. They show that truthful revelation is induced by promising a higher probability of operation or a greater share of the realized profit, the larger the bond that a potential operator posts. Lewis and Sappington (2000a) incorporates private information about wealth on the part of the agent but abstracts from private knowledge of ability.

The rest of this paper is organized as follows. The next section develops the basic model. Section 3.3 characterizes the optimal contract under full information. Section 3.4 introduces limited information and examines pure double moral hazard, and simultaneous moral hazard and adverse selection to explore the magnitude of distortion in the supply of productive input in the context of alternative rules of liability allocation. In section 3.5, we provide some concluding remarks.

4.2. Basic model

There are three players in the model: a risk-neutral firm that is eligible to host a GHG reduction project (call her the host), a risk-neutral foreign investor (hereafter, the investor) and an international environmental authority (IEA). An important feature that distinguishes this paper from the previous paper is that rather than provide the funds, it will be assumed that the foreign investor directly supplies the energy efficient technology. This assumption eliminates the possibility of the host diverting part of the investment capital to finance her perquisite consumption, a possibility that spawned the moral hazard problem in the second paper. To fix things, we assume that the foreign investor acquires the host firm, and thereby obtains title to all project proceeds. This effectively transforms the host into a manager of a wholly owned subsidiary.

The nature of the production technology is as follows: After the energy saving equipment has been installed, the host commits resources, whose monetary costs are given by e, to develop the capacity to adapt and use foreign technology. The investor's direct involvement in the project does not, however, end with the equipment transfer. In addition to providing the technology, the investor may exercise control and makes decisions over the implementation of the GHG project that are costly to verify, but which enhance the value of the technology; he may bring to the project managerial and organizational skills, which cannot be contracted upon; he may supply essential inputs (e.g., effort) to the project. We will denote by i the productive input supplied by the investor beyond providing the equipment/technology.

As before, a successful project generates Δ in emissions reduction credits, while an unsuccessful project generates no net emissions credits. The probability that the project is successful is a function of the effort supplied by the host in the acquisition and assimilation of the technological capacity and the amount of resources invested by the investor, and is described by $p(e, i)$. The probability function is assumed to be continuously differentiable with the following properties:

$$p_e(e,i) > 0, \quad p_{ee}(e,i) < 0, \quad p_i(e,i) > 0, \; p_{ii}(e,i) < 0, \; p_{ei}(e,i) = p_{ie}(e,i) = 0. \tag{4.1}$$

The first four conditions are standard assumptions in the literature. They simply say that there are diminishing returns to inputs. The assumption on $p_{ei}(e,i)$ has been imposed for analytical simplicity, but most importantly, to underscore the fact that the investor's input supplements the host's effort e and is not absolutely essential for project success.[40]

The significant assumption of the model relates to how the host's wealth endowment and the regime of liability allocation interact to affect the optimal provision of incentives. Since the investor always wants the host to undertake the project, he must guarantee that the host will accept the contract by paying her at least her outside opportunity payoff. For example, in an environment where the host must bear responsibility for project failure either in part or in whole, an important element of her costs is her expected liability payment. We assume that when liability is installed upon the host, the fraction of the damage that is actually indemnified is constrained by the host's ability or willingness to pay. This feature is captured formally by assuming that any liability levied on the host is paid off only with probability $\lambda(w)$. The parameter $\lambda(w)$ affects the investor's payoff, at least indirectly, since it determines the class of contracts that the host will accept. To see why, note that a wealthy host faces a potentially high expected penalty and must therefore be afforded a higher level of compensation in order to accept any contract. Conversely, a host with more limited wealth faces only a small potential loss of wealth in the adverse state and will therefore demand less compensation as a precondition to accepting any contracts. However, if the host is privately informed about her default potential $\lambda(w)$, she might intentionally overstate her endowment (or understate her expected payoff) in

[40]This assumption is easily satisfied by a probability function of the form $p(e,i) = e^{\gamma} + i^{\alpha}$, where $\gamma, \alpha \in (0,1)$.

order to earn rent, thereby reducing the investor's net payoff.[41] And the incentive to overstate wealth (understate her expected payoff) is greater for the host with a lower wealth endowment. An optimal contract must therefore prevent the host from exaggerating her potential loss with impunity. This is the major source of contractual friction in the model.

The model features bilateral moral hazard and adverse selection. There is double moral hazard because both the investor and the host choose unobservable actions that determine the ultimate success of the project. There is adverse selection in the sense that the host knows her wealth $w \in [\underline{w}, \overline{w}]$ and while the investor knows only that w is a random variable with a cumulative distribution function $F(w)$ and density function $f(w)$. Denote by $\underline{w}$ the least level of wealth possible for the host.

Before emissions reduction activities can be undertaken and carbon credits generated, the host and the investor must negotiate a contract specifying how the host will be compensated. Such a contract must be based on variables that are verifiable by the sponsor or a third party. Therefore, we will assume (except under full information) that the contract is written on Δ and on the host's announcement of her wealth (type) represented by $\hat{w}$. We will focus on a contract C of the following form:

$$C(\Delta, \hat{w}; \beta(\hat{w}), \kappa(\hat{w})) = \begin{cases} \Delta\beta(\hat{w}) & +\kappa(\hat{w}) \text{ if } \Delta > 0 \\ 0 & +\kappa(\hat{w}) \text{ if } \Delta = 0 \end{cases} \quad (4.2)$$

where $\beta(\hat{w}) \geq 0$, but $\kappa(\hat{w})$ can take on any value depending on whether it is a transfer from the investor to the host or *vice versa.* If $\kappa(\hat{w}) > 0$, then this scheme can be interpreted as a bonus contract in which the host is promised a base salary $\kappa(\hat{w})$ plus a share of the output $\beta(\hat{w})$ only when the project is successful. When $\kappa(\hat{w}) < 0$, then 4.2 can be perceived as a formal approximation of a situation where the investor implements a "bond" contract: In this case, the host selects

[41] It may be costly, if not impossible, for a foreign investor to monitor the host's cash flows or the use of the available funds. Gale and Hellwig (1985) highlight this problem in the context of domestic investment.

a penalty for underprovision by posting up-front a non-refundable bond in the amount of $\kappa(\hat{w})$ and is rewarded with a share of the output only when the project successful.[42]

We will assume initially that the host has no equity interest in the project. Subsequently, we will introduce equity participation on the part of the host in order to examine the impact of foreign ownership equity caps as a host-government policy measure directed toward attracting foreign investment.

The sequence of events is as follows: In the first stage, the investor offers a compensation package. In stage 2, the IEA publicly announces the liability rule and the size of liability, L. Throughout, we take L as a fixed parameter and not to be determined in the model. In the fourth stage, the investor and the host simultaneously choose their levels of effort to supply in order to maximize their returns given $C(\Delta, \hat{w}; \beta(\hat{w}), \kappa(\hat{w}))$ and the liability rule. Final project output is observed and distributed according to the contract selected by the host in the third stage.

4.3. Full information solution

Before proceeding to characterize the contracts that would be written between the investor and the host, it is instructive to consider the social problem. Assuming that it costs a total of X dollars to restore GHG accumulation to where they would be if the project had succeed, the expected damage borne by the society as a result of project failure is given by $[1 - p(e,i)]X$. The host has an expected payoff of $U(\beta, \kappa, e, i) = p(e,i)\beta\Delta + \kappa - e$, while the investor's expected utility $\Pi(e, i, \beta, \kappa) = p(e,i)\Delta(1-\beta) - \kappa - i$. Thus, the expected social value of the project is $W(e,i,\beta) = U + \Pi - [1 - p(e,i)]X = p(e,i)[\Delta + X] - X - i - e$. Note that β and κ drop out of this total and are therefore indeterminate. The problem of maximizing the expected social value of the project is $\max_{\{e,i\}} W(e,i)$, which yields

[42] Che and Gale (2000) and Lewis and Sappington (2000a) have made similar approximation.

$$p_e(e^s, i^s)[\Delta + X] - 1 = 0 \tag{4.3}$$

and

$$p_i(e^s, i^s)[\Delta + X] - 1 = 0 \tag{4.4}$$

as the socially optimal levels of effort exerted by the investor and the host, respectively.[43]

The solution to the social problem identifies the optimal levels of investment in productive inputs where the incremental expected benefit of the project defined as the sum of the reduction in accumulation of carbon (increase in clean air) and avoided damages just offset the marginal disutility of effort. We will label this outcome the social optimum.

4.3.1. The investor's optimum: no damages

Now consider a setting where no adverse selection or moral hazard problem arises because both effort and wealth are known to the investor, but the optimal incentive contracts and effort choices are determined through private interaction between the two parties. Under full information, an efficient contract must necessarily maximize the expected total surplus from the project: $\Pi + U = p(e,i)\Delta - i - e$. The first order conditions with respect to e and i are, respectively, $p_e(e,i)\Delta - 1 = 0$ and $p_i(e,i)\Delta - 1 = 0$.

Notice that the investor's problem differs importantly from the social problem. Whereas the social problem takes into account all the externalities associated with project failure, the investor, acting in his own best interest does not do so. Thus, the absence of damage liability entails lower levels of effort and investment than under the social optimum. This is because in the absence of monetary sanctions, effort and investment are rewarded according to the investor's private gains only, which are lower than the social returns. Given that the absence of damages would entail lower investment by both parties than is socially desirable,

[43]Throughout, subscripts will denote partial derivatives.

it is reasonable to expect that a provision in support of damage liability can rectify this underincentive problem.

4.3.2. Introducing damages

We now present the investor's problem in an environment where either monetary sanctions are imposed by the IEA according to some predetermined rules of liability allocation or the two parties incur non-pecuniary cost in the event of project failure. As before, we abstract from the problem of liability determination and therefore take L as given.

Host liability. Before analyzing the conditions when host-only liability is in place, we need to first point out that the host may be financially constrained and may therefore not feasibly indemnify the liability in the event of project failure. This may also be construed as a situation in which the host has limited reputation concerns. We capture the effect of the host's limited wealth and ability to pay (or limited reputation concerns) by assuming that an eventual penalty of L is paid only with probability $\lambda(w)$, where $\lambda'(w) > 0, \lim_{w \to \infty} \lambda(w) \leq 1$and $\lambda(0) = 0$. Where necessary, we will invoke the following assumption with respect to $\lambda(w)$: $\lambda''(w) \geq 0$. The host's expected utility, given contract $\{\beta, \kappa\}$, can be expressed as: $\bar{U}(e, i, \beta, \kappa) = p(e, i)\Delta\beta + \kappa - [1 - p(e, i)]\lambda(w)L - e$. Given the liability rule in force, the investor's problem in this full information environment reads:

$$\max_{e,i} p(e, i)[\Delta + \lambda(w)L] - \lambda(w)L - e - i \tag{4.5}$$

An optimal contract $\bar{C}^* = \{\bar{e}^*, \bar{\imath}^*\}$ is therefore identified by the following conditions:

$$p_e(e, i)[\Delta + \lambda(w)L] - 1 = 0 \tag{4.6}$$

and

$$p_i(e, i)[\Delta + \lambda(w)L] - 1 = 0. \tag{4.7}$$

The last two conditions are the effort selection efficiency conditions. Since effort is observable, the investor simply prescribes the level of effort that maximizes the expected total surplus. This requires that the marginal return from effort, which accrues in terms of an increase in expected output and expected avoided liability, be equated to the marginal disutility of effort. Note that the optimal level of effort prescribed by the investor depends on the host's default potential. More precisely, the optimal contract prescribes a higher level of effort for both parties when the host has more wealth than when she has meager wealth. The full information solution then suggests that the less wealthy host should reach a smaller effort level than her wealthy counterpart. Note that combining 4.6 and 4.7 yields the relationship $p_e(e,i)[\Delta + \lambda(w)L] = p_i(e,i)[\Delta + \lambda(w)L]$. This says that the marginal return of effort for the two parties are perfectly equalized.

Investor liability. Now, suppose that the liability scheme in place holds the investor strictly liable in the event of a bad outcome. The basic difference between host liability and investor liability is that while the former admits the possibility of a wedge between the damage L and actual compensation, the latter assumes that the liability is always fully indemnified. There are three reasons why this assumption is plausible in the situation represented here. First, the question of enforcement of liability is essentially a question about the scale of the payment obligation L relative to the willingness of the party upon whom the sanctions are imposed to meet her legal obligation. In this study, we assume that the investor has sufficient assets to meet all of his legal liabilities. The host, on the other hand, is wealth constrained in the sense that her wealth endowment may be inadequate to pay her portion of damages arising from project failure.[44] Second, it is plausible that the investor has a greater level of concern for building and maintaining his reputation than the host. Consequently, the *non-* pecuniary costs of reneging on his legal obligations, which can occur in terms damaged reputation, might be significantly higher for the investor than the host. Third,

[44] Note also that the host may be able to deliberately hide her wealth in order to evade her legal obligation

we can justify this assumption by appealing to the fact that the investor may be faced with binding emissions reduction requirements in the current period while the host may not be under such obligations. Thus, while project failure might imply a breach on the part of the investor, the same need not be true for the host.

The host's expected payoff from the project is given by $\tilde{U}(e, i, \beta, \kappa) = p(e, i)\beta\Delta + \kappa - e$, while the investor's expected payoff is $\tilde{\pi} = p(e, i)[(1-\beta)\Delta + L] - L - \kappa - i$.[45] Hence, the investor solves the following program:

$$\max_{e,i} p(e, i)[(1 - \beta)\Delta + L] - L - \kappa - i. \tag{4.8}$$

The solution to problem 4.8 yields the full-information first-best (or efficient) effort levels which we will denote by $\tilde{C}^* = \{\tilde{e}^*, , \tilde{\imath}^*\}$ and which satisfies

$$p_e(\tilde{e}^*, \tilde{\imath}^*)][\Delta + L] - 1 = 0 \tag{4.9}$$

$$p_i(\tilde{e}^*, \tilde{\imath}^*)][\Delta + L] - 1 = 0. \tag{4.10}$$

These conditions are almost a replica of those given earlier by equations 4.6 and 4.7. The only difference is that the host's wealth no longer features in the optimal determination of effort. Interpreted, these conditions suggest that at the optimum, the host and the investor necessarily exert effort levels that maximize the total surplus. Because of the investor's unbounded wealth and his monopoly bargaining power, the liability is fully internalized.

Joint Liability We conclude this section by considering a hybrid regime in which both parties are jointly held liable for the entire liability amount L should the project return no emissions credits. Since, the host's expected liability is limited to her residual wealth and the investor is obliged to take care of any

[45] Throughout, the investor's and the host's return under investor liability are denoted by tildes to distinguish them from those under host liability.

residual liability, the host's expected payoff can be written as

$$\breve{U}(e,i,\beta,\kappa) = p(e,i)[\Delta\beta + \rho\lambda(w)L] - \kappa - \rho\lambda(w))L - e, \quad (4.11)$$

where $\rho \in (0,1)$ represents the fraction of the liability burden that is installed upon the host in the event of failure. The investor's expected return from the project is given by

$$\breve{\Pi}(e,i,\beta,\kappa) = p(e,i)[\Delta(1-\beta) + (1-\rho\lambda(w))L] - (1-\rho\lambda(w))L - \kappa - i, \quad (4.12)$$

and his problem reads as follows:

$$\max_{\beta,\kappa,e,i} p(e,i)[\Delta(1-\beta) + (1-\rho\lambda(w))L] \quad (4.13)$$
$$-(1-\rho\lambda(w))L - \kappa - i$$

subject to $\breve{U}(e,i,\beta,\kappa) \geq 0$. For future reference, we record here the conditions for an optimal contract $\breve{C}^* = \{\breve{e}^*, \breve{\imath}^*\}$:

$$p_e(\breve{e}^*, \breve{\imath}^*)[\Delta + L] - 1 = 0 \quad (4.14)$$

$$p_i(\breve{e}^*, \breve{\imath}^*)[\Delta + L] - 1 = 0. \quad (4.15)$$

Again, it is clear that since the investor can observe the host's effort, he can demand an effort level by designing a forcing contract. He optimally assigns the host an effort level that maximizes the total surplus and the risk-neutral host finds it preferable to deliver this level of effort since she is guaranteed her outside opportunity payoff. The investor's expenditure on effort similarly maximizes their joint surplus. Consequently, there is no uncompensated liability, and the efforts exerted are socially optimal. In short, the threat to make the investor liable for any residual damages coupled with his unlimited wealth induces the investor to fully internalize the externality generated by project failure. Note also that the effort level prescribed for the host and the optimal expenditure of i remains the same regardless of the host's level of wealth suggesting that the host's default potential is immaterial to the determination of the optimal contract when the investor must compensate any residual damages.

The results of the foregoing discussion are summarized in proposition 12 below.

Proposition 13. *Suppose that* $\lambda(w) = 1 - \exp -(\sigma w)$, *where* $\sigma > 0$. *Then, as* w *gets infinitely large,* $\bar{e}^* = \tilde{e} = \breve{e} = e^s$ *and* $\bar{\imath}^* = \tilde{\imath} = \breve{\imath} = i^s$; *when* w *is more limited, then* $\bar{e}^* < \tilde{e} = \breve{e} = e^s$ *and* $\bar{\imath}^* < \breve{\imath} = \tilde{\imath} = i^s$.

Proof: See the appendix

The intuition for this result is as follows. The optimal contract under full information necessarily maximize the total surplus. Hence, the portion of liability that is internalized under any optimal contract between the investor and the host depends on the level of liability that is actually indemnified. Investor-only liability and joint liability schemes results in no uncompensated liability since the investor has sufficient wealth to meet all her obligations as well any residual liability resulting from the host's failure to pay. In either case, the total surplus is reduced by the full amount L. Consequently, the marginal benefit of effort in terms of avoided liability takes into account the entire expected liability amount imposed by the IEA in the event of failure. Under host liability, however, the fraction of the damage that is actually internalized depends on the size of w, which is a measure of the host susceptibility to monetary sanctions as embodied in $\lambda(w)$. When w is sufficiently large there is no problem of uncompensated liability. In this case, the host is forced to deliver the socially optimal level of effort. When w is more limited such that $\lambda(w) < 1$, however, there is a wedge between the actual level of damages and the actual compensation. Intuitively, the host's meager wealth leads the investor to understate the potential reduction in the expected total surplus, thereby reducing the expected marginal return from effort in terms of avoided damages. Accordingly, the levels of effort prescribed by the investor are too little with respect to the social optimum.

4.4. Limited information solution

We now discuss the optimal incentive contract under informational asymmetry. More precisely, we assume that the host's effort e is neither observable nor verifiable by the investor. This assumption is a reasonable one since the host is likely to be endowed with country-specific knowledge or inputs that cannot be contracted upon. If, therefore, the project outcome turns out to be bad, the investor would not be able to determine whether this was simply due to random events or because the host withheld her effort.

In addition to taking care of the host's incentive to shirk, the optimal contract must also handle a moral hazard incentive for the investor; that is, the investor's expenditure on productive inputs i is unobservable. The assumption of nonobservability of i is a natural one given that technology recipients often cannot assess the value of the technology *ex-ante*. Finally, we allow for adverse selection on the part of the host's ability to pay; that is, we assume the host possesses an informational advantage about her default potential. To sum up, there exists both a double-sided moral hazard problem and an adverse selection problem. Thus, any optimal compensation scheme must simultaneously provide *two* sets of incentives; one for the host and the other for the investor.

The following discussion is organized in two parts. In the first part, we abstract from the adverse selection problem and discuss the solution to the investor's problem under pure bilateral moral hazard. This outcome is then compared, in the subsequent part, to the situation that develops when both bilateral moral hazard and adverse selection are simultaneously present.

4.4.1. Pure double moral hazard

In a standard single moral hazard framework, the only additional constraint on the investor under limited information relative to full information is that the host be at an optimum with regard to her level of effort given the incentive scheme. Under double moral hazard, however, the investor provides unobservable input into the project, and any optimal contract must also address his own incentive provision.

Host liability. The investor's problem under host liability and pure moral hazard can be stated as follows:

$$\max_{\beta,\kappa} p(e,i)\Delta(1-\beta) - \kappa - i \tag{4.16}$$

subject to

$$\bar{U}(e,i,\beta,\kappa) \geq 0 \tag{4.17}$$

$$e(\beta) = \arg\max_{e} p(e,i)[\Delta\beta + \lambda(w)L] + \kappa - e - \lambda(w)L \tag{4.18}$$

and

$$i(\beta) = \arg\max_{i} p(e,i)\Delta(1-\beta) - \kappa - i. \tag{4.19}$$

Constraint 4.17 carries over from the full information setting; it is the individual rationality (participation) constraint. The only difference between the full information problem and limited information problem results from the *additional* constraints 4.18 and 4.19. These say that under bilateral moral hazard, both parties must also be at the optimum with regard their effort given the incentive scheme.

Note that since the investor's payoff is decreasing in κ, participation constraint 4.17 is necessarily binding. The proof of this statement is straightforward.

Suppose $\{\beta,\ \kappa\}$ is the optimal contract such that $\bar{U} > 0$. Now, replace this contract with a new contract $\{\beta,\ \kappa - \varepsilon\}$ where $\varepsilon > 0$. This new contract still satisfies the participation constraint and the the double incentive constraints. But this would mean that the new contract is superior to $\{\beta,\ \kappa\}$. It follows that the contract $\{\beta,\ \kappa\}$ could not have been optimal in the first place. Because 4.17 is binding, the problem described by 4.16 -4.19 can be reformulated in the following convenient form. By employing κ from the binding participation constraint 4.17 and substituting into equation 4.16 we can rewrite the problem as follows:

$$\max_{\beta} p(e,i)[\Delta + \lambda(w)L] - \lambda(r)L - e - i - \bar{U}. \tag{4.20}$$

subject 4.18 and 4.19.

The optimal effort levels undertaken by the two parties are defined by 4.18 and 4.19. The first-order conditions for optimal efforts derived from 4.18 and 4.19, are respectively,

$$p_e(e,i)[\Delta\beta + \lambda(w)L] - 1 = 0 \tag{4.21}$$

and

$$p_i(e,i)\Delta(1-\beta) - 1 = 0. \tag{4.22}$$

The concavity of $p(e,i)$ in e and i ensures that these conditions are also sufficient. As before, the compensation coefficient β positively affects the host's incentive to exert effort. The converse is true for the investor; the larger the level of β, the greater the return to e and the more pronounced is the host's incentive to apply herself more diligently to the project.

Proposition 13 below describes the solution to the investor's problem under host liability and in the presence of pure moral hazard.

Proposition 14. *Under moral hazard and host liability, the solution to the in-*

vestor's program defined by 4.16- 4.19 is characterized by

$$\kappa = e + [1 - p(e,i)]\lambda(w)L - p(e,i)\Delta\beta, \text{ and} \tag{4.23}$$

$$[p_e(e,i)[\Delta + \lambda(w)L] - 1]\frac{de}{d\beta} + [p_i(e,i)[\Delta + \lambda(w)L] - 1]\frac{di}{d\beta} = 0, \tag{4.24}$$

where $\frac{de}{d\beta} = -\frac{p_e(e,i)\Delta}{p_{ee}(e,i)[\Delta\beta + \lambda(w)L]} > 0$ *and* $\frac{di}{d\beta} = \frac{p_i(e,i)}{p_{ii}(e,i)(1-\beta)\Delta} < 0$ *derive from 4.21 and 4.22.*

Proof. maximization of 4.20 with respect to β, where e and i are defined by 4.18 and 4.19, gives the first order condition for an interior maximum equation 4.24. Equation 4.23 is derived from the binding participation constraint.■

Equation 4.23 gives the fixed component of the transfer payment. It has several sub-components: The first two terms guarantees the host a compensation for effort and expected liability. The third term is the negative of the host's expected share of project output. In sum, these three payments ensure that at the optimum, the host participates and is held to her reservation utility.

Equation 4.24 gives the necessary condition for an optimal expenditure on e and i. By structuring the variable component of the contract in the manner described by 4.24, the optimal contract provides the host and the investor with the appropriate incentives to choose effort levels described by equations 4.21 and 4.22. The first term of 4.24 derives from the moral-hazard problem on the part of the host, while the second term represents moral-hazard problem on the part of the investor. Thus, absent moral hazard on the side of the investor, the second term would drop out of equation 4.24 and the necessary condition for optimal effort would reduce to $p_e(e,i)[\Delta + \lambda(w)L] - 1 = 0$, which is the full information level of effort.

In general, expression 4.24 cannot be rearranged to express the share value

β as an explicit function of the parameters of the model. However, it is still possible to infer the important properties of the implied function and the induced level of effort by comparing 4.24 with 4.3 and 4.4. From these three equations one can see that the optimal levels of e and i are not the same under moral hazard as under full information even though the agent portrays risk neutral preferences. If the host's and the investor's inputs were observable and therefore contractible, the optimal incentive scheme would have required the maximization of 4.20 only, which would have given the marginal conditions $p_e(e,i)[\Delta+\lambda(w)L]-1=0$ and $p_i(e,i)[\Delta+\lambda(w)L]-1=0$. Under bilateral moral hazard, however, $p_e(e,i)[\Delta+\lambda(w)L]-1>0$ and $p_i(e,i)[\Delta+\lambda(w)L]-1>0$. It must therefore be the case that both $p_e(e,i)$ and $p_i(e,i)$ have all increased relative to the full information situation. Since $p(e,i)$ is concave in its arguments, there must have been a decrease in the level of effort exerted by the two parties relative to the full information situation; that is, too little effort is exerted under bilateral moral hazard relative to the first-best outcome.

To learn more about this result, recall that under a standard single moral hazard setting, the investor can attain the full information solution by making the risk-neutral host the residual claimant; that is, by allocating all the incentives to the host. Under bilateral moral-hazard situation, however, the optimal contract must satisfy the incentives for *both* parties. Consequently, implementing a contract that makes the host the residual claimant cannot be optimal. To see why this is the case, consider a limiting case in which the host becomes the residual claimant for the project's revenue stream, i.e., $\beta=1$.[46] Clearly, such a contract would afford the host the maximum possible reward. However, it would leave the investor with no incentive to expend effort i beyond committing his sunk investment K. Such an outcome would not be optimal. The proof of this is straightforward: Suppose that $\beta=1$ is the optimal sharing rule. Then subject

[46]It is a well known fact that in single moral hazard setting, the principal can readily implement the full information solution when the agent is risk-neutral by simply selling the entreprise to the agent in return for a fixed fee.This is what we characterize as a "buy out" contract. See Demski and Sappington (1991), among others.

to incentive and participation constraints, $p(e,0)[\Delta+\lambda(w)L]-\lambda(r)L-e$ must be the investor's expected payoff given that $\beta = 1$. If the investor now modifies the contract by marginally reducing β below unity, his expected payoff would change by the amount

$$
\begin{aligned}
&-[p_e(e,0)[\Delta+\lambda(w)L]-1]\frac{de}{d\beta} \\
&-p_i(e,0)[\Delta+\lambda(w)L]\frac{di}{d\beta}
\end{aligned}
\tag{4.25}
$$

since $\frac{de}{d\beta} > 0$ and $\frac{di}{d\beta} < 0$. The first term in the parenthesis is zero. The second is positive. Thus, by marginally reducing β below unity, the investor attains a higher expected payoff than he does when $\beta = 1$. It follows that a compensation package with $\beta = 1$ could not have been optimal in the first place. To sum up, the investor finds it in his best interest to optimally distort the efforts incentives of *both* parties' away from their full information level in order to simultaneously satisfy the incentives for *both* parties.

Investor liability. Consider, now, the other extreme in which the investor can be held strictly liable in the event of project failure. Obviously, the host is not exposed to dramatic penalties in the event of project failure in this setting. When the investor must bear the full financial burden associated with project failure regardless of her behavior, she faces an expected penalty of $[1-p(e,i)]L$. This represents an additional cost which the investor must take into account in designing the incentive contracts. Investor-only liability effectively imposes an external claim on the investor's expected surplus in the adverse state. Since the failure risk is in part influenced by the host's unobservable effort level, it is clear that such a liability regime fails to properly align effort incentives to project outcome. In short, there is no direct mapping between the damages and the payoffs of the economic agents that are responsible for the damages.

To properly align the host effort incentives, the principal can pursue two strategies. The first strategy would be for the investor to commit to monitoring the host's effort. It is well known that monitoring can attenuate moral hazard problems that arise between individual actions affecting the wellbeing of other; that is, effort monitoring can allow the principal to observe the agent's effort and to force the agent to supply a level of effort that exceeds the level that would be supplied if effort were unobservable. When transplanted into our context, effort monitoring can increase the level of effort exerted by the host's and the project's success probability. The second strategy could involve implementing a contract that requires the host to select a penalty for underprovision by posting up-front a non-refundable bond, and is rewarded with a share of the output only when the project is successful.

Assuming that the investor imposes a bond requirement on the part of the host, the her problem reads:

$$\max_{\beta,\kappa} p(e,i)\Delta(1-\beta) - i - [1-p(e,i)]L + \kappa \tag{4.26}$$

subject to

$$\tilde{U}(e,i,\beta,T) = p(e,i)\Delta\beta - e - \kappa \geq 0, \tag{4.27}$$

$$e(\beta) = \arg\max_{e} p(e,i)\Delta\beta - \kappa - e, \tag{4.28}$$

$$i(\beta) = \arg\max_{i} p(e,i)\Delta(1-\beta) - [1-p(e,i)]L + \kappa - i. \tag{4.29}$$

and

$$w - \kappa \geq 0. \tag{4.30}$$

Expression 4.26 states that the investor's objective is to maximize his expected return, which is the difference between his expected profit from the project minus bond revenues. Equations 4.27 ensures the host's participation by guaranteeing her nonnegative rent. Equations 4.28 and 4.29 identify, respectively, $e(\beta)$ and $i(\beta)$ as the optimal levels of effort that the two parties will select given the incentive scheme. Equation 4.30 says that the host can post a bond that is no more than her wealth endowment; it captures the fact that the host is wealth constrained.

The first-order conditions associated with (4.28) and (4.29) are, respectively

$$p_e(e,\omega)\Delta\beta - 1 = 0 \tag{4.31}$$

and

$$p_i(e,i)[\Delta(1-\beta)+L] - 1 = 0. \tag{4.32}$$

Let λ_0 and γ_0 be the Lagrange multipliers corresponding to (4.27) and (4.30), respectively. Solving (4.31) and (4.32) for $e(\beta)$ and $i(\beta)$ and substituting in the objective function, the first-order conditions (together with the associated complementary slackness condition) is given by:

$$\beta: \quad -[1-\lambda_0]p(e,i)\Delta + p_e(e,i)[\Delta(1-\beta)+L]\frac{de}{d\beta} = 0, \tag{4.33}$$

$$\kappa: \quad [1-\lambda_0-\gamma_0] = 0$$

Note that the wealth constraint must be binding somewhere. If it was not, then the investor could either reduce his transfers to the host uniformly by a small amount and/or require the host to post a larger bond thus obtain larger revenues, while still satisfying the wealth constraint. Since wealth is observable in this setting, the investor simply asks the host to deliver her entire wealth as a bond up-front. Thus, constraints 4.30 always binds,$\gamma_0 > 0$. We now consider the following exhaustive and mutually exclusive cases depending on whether the participation constraints bind or not.

Case I. The participation constraint does not bind. In this case, $\lambda_0 = 0$ and $\gamma_0 = 1$. Equation (4.33) can be rewritten as $[p_e(e,i)[\Delta+L]-1]\frac{de}{d\beta}$-$p(e,i)\Delta$ =0 which implies that $p_e(e,i)[\Delta+L]-1>0$. Also (4.32) implies that $p_i(e,i)[\Delta+L]-1>0$. There is no contradiction. Thus individual effort is distorted away from its full information level.

Case II. The participation constraint binds. In this case $\lambda_0 = [1 - \gamma_0] > 0$. Equation (4.33) can be rewritten as $[p_e(e,i)[\Delta + L] - 1]\frac{de}{d\beta}$-[1-$\lambda_0$]$p(e,i)\Delta$ =0. This implies that $p_e(e,i)[\Delta + L] - 1 > 0$ since [1-λ_0] $= \gamma_0 > 0$ by assumption. Equation (4.32) also implies that $p_i(e,i)[\Delta + L] - 1 > 0$. Again, effort incentives are distorted away from their first-best levels.

The following proposition summarizes the solution to the investor's problem under investor liability.

Proposition 15. *Under pure moral hazard, the optimal supply of e and i are distorted from their full information level; that is* $p_e(e,i)[\Delta + L] - 1 > 0$ *and* $p_i(e,i)[\Delta + L] - 1 > 0$

Under pure moral hazard, the investor must provide himself with adequate incentives to undertake the appropriate level of investment; at the same time, he must motivate the risk-neutral host by conditioning her compensation on project outcome. As explained earlier, these twin objectives can only be achieved by intentionally inducing deviations from the full information solution.

Joint liability. We conclude this section by considering a situation in which a bilateral moral-hazard problem is present and the regime of liability assigns joint responsibility to both parties with the investor absorbing any residual damages. Since both parties have to share responsibility in the event of failure and both directly influence the project's outcome through their own investment, it is plausible to assume that the investor may not require the host to post a bond. Accordingly, the investor will solve the following problem:

$$\max_{\beta,\kappa} p(e,i)\Delta(1-\beta) - [1-p(e,i)][1-\lambda(w)\rho L] - i \tag{4.34}$$

subject to

$$\breve{U}(e,i,\beta,\kappa) \geq 0, \tag{4.35}$$

$$i \in \arg\max_{i} p(e,i)\Delta(1-\beta) - [1-p(e,i)][1-\lambda(w)\rho L] - i, \tag{4.36}$$

$$e \in \arg\max_{e} p(e,i)[\Delta\beta + \lambda(w)\rho L] + \kappa - e - \lambda(w)\rho L \tag{4.37}$$

and

$$w - \kappa \geq 0. \tag{4.38}$$

Using the same procedure as under investor, it can be shown that effort choice decisions under joint liability will yield the following:

$$p_e(e,i)[\Delta + L] - 1 > 0 \text{ and } p_i(e,i)[\Delta + L] - 1 > 0. \tag{4.39}$$

Equation 4.39 shows, once more, that relative to the case of full information, the two efforts are optimally distorted to provide appropriate incentives to the two parties. These results are summarized by proposition 15 below

Proposition 16. *Suppose effort is unobservable and both the host and the investor are held liable. Then, the optimal level of effort is characterized by (4.39).*

4.4.2. Simultaneous double moral-hazard and adverse selection

This section builds on the previous one by incorporating both adverse selection and moral hazard into the same context. The contract design problem is analyzed within a mechanism design framework and formulated as a direct revelation game in which the mechanism is defined in terms of the host's report on her type rather than a selection from a family of contracts. By the revelation principle, it is known that the choice of the host from a menu of contracts may also be represented by a direct revelation mechanism in which the host reports on her level of wealth (type). We assume that the investor offers a standard screening contract $\{\beta(\hat{w}), \kappa(\hat{w}) : \hat{w} \in [\underline{w}\ , \overline{w}]$, that stipulates a variable and fixed transfer conditional upon the host's report on her type. Following standard practice, we assume that the investor can credibly commit not to renegotiate the contract.

Host liability. Recall that the actual level of liability indemnified by the host is dependent on her level of residual wealth. When the host is privately informed about her wealth endowment (and her default probability), a particular contracting friction emerges.[47] This is because for the host to participate in the project, she must be guaranteed at least her outside opportunity payoff. A host with a higher level of w faces a potentially high expected penalty in the failure state and will consequently demand a higher level of compensation in order to accept any contract. Conversely, a host with limited wealth faces only a small potential loss of wealth in the adverse state and will therefore demand less compensation. Since the host is privately informed about her endowment, however, she might find it attractive to intentionally exaggerate her wealth in order to earn information rent. Thus, an optimal contract must not only induce an appropriate effort choice decision on the part of the two parties, but it must also preclude the host from misrepresenting her true level of wealth with impunity.

As a first step to determining the optimal contract, we need to establish the incentive compatibility constraints for both players. If the host declares her type as $\hat{w}$ when her true type is w, she gets an expected utility $\bar{U}(\hat{w}, w)$:

$$\begin{aligned} \bar{U}(\hat{w}, w, e(\hat{w}, w)) &= p(e,i)[\Delta\beta(\hat{w}) + \lambda(w)L] + \kappa(\hat{w}) - e - \lambda(w)L \\ &\forall \quad \hat{w}, w \in [\underline{w}, \overline{w}]. \end{aligned} \tag{4.40}$$

If $\hat{w} = w$ is the best report of host w, then we can write

$$\begin{aligned} \bar{U}(w, w, e(w, w)) &\equiv \bar{U}(w) = p(e,i)[\Delta\beta(w) + \lambda(w)L] + \kappa(w) - e - \lambda(w)L \\ &\forall \quad w \in [\underline{w}, \overline{w}], \end{aligned} \tag{4.41}$$

and the following first-order condition necessarily holds: $\frac{\partial \bar{U}(w)}{\partial w} = -[1-p(e,i)]\lambda'(w)L = 0$. The investor knows that the host will choose e to maximize her objective function as follows:

[47]It is well known that assets of individaul entities may be difficult to track due to factors such as bank secrecy laws, money laundering and other clandestine activities (See, for example, Lewis and Sappington [2000], and Lane [1999]). The recent corporate accounting scandals also serve to illustrate the inherent difficulty in determining the true asset value of a firm.

$$e(\beta(\hat{w}), \kappa(\hat{w}), w) = \arg\max_e p(e,i)[\Delta\beta(\hat{w}) + \lambda(w)L] + \kappa(\hat{w}) - e - \lambda(w)L. \quad (4.42)$$

Similarly, the host knows that the investor will choose i to maximize his objective function

$$i(\beta(\hat{w}), \kappa(\hat{w}), w) = \arg\max_i p(e,i)\Delta(1-\beta(\hat{w})) - \kappa(w) - i. \quad (4.43)$$

Note that 4.42 and 4.43 can be interpreted as the constraints involving the host's and the investor's optimal choice of effort. From these conditions, we obtain, respectively

$$p_e(e(\beta(w), w), i)[\Delta\beta(w) + \lambda(w)L] - 1 = 0 \quad (4.44)$$

and

$$p_i(e(\beta(w), w), i)\Delta[1-\beta(w)] - 1 = 0, \quad (4.45)$$

which define the optimal effort levels $e(\beta(w), w)$ and $i(\beta(w), w)$. Equations 4.44 and 4.45 simply state that at the margin both parties would invest in effort to the extent that the return on effort invested just equaled the marginal cost of effort. Since $p(e,i)$ is concave in e and i, there always exists a unique optimal choice of effort combination $(e,\ i)$.

Of interest is the question of how the host's choice of e and the investor's expenditure of i will change in response to changes in the bonus part of the compensation package $\beta(w)$; that is, what are the signs of $\frac{de}{d\beta(w)}$ and $\frac{di}{d\beta(w)}$? The answer to this question requires the total differentiation of the first order conditions given by 4.44 and 4.45. By totally differentiating these equations, and upon rearrangement of terms, we obtain, $\frac{de}{d\beta(w)} = -\frac{p_e(e,i)\Delta}{\overline{SOC}} > 0$ and $\frac{di}{d\beta(w)} = \frac{p_{ii}(e,i)\Delta}{\overline{SOC}} < 0$ where $\overline{SOC}_e = p_{ee}(e,i)[\Delta\beta(w) + \lambda(w)L] < 0$ and $\overline{SOC}_i = p_{ii}(e,i)\Delta(1-\beta(w))$

< 0 are the second-order conditions associated with 4.44 and 4.45 respectively. These expressions record the diametrically opposed impact of the host's stake on the optimal expenditure on effort. On the one hand, the higher the host's share of the project's proceeds, the higher is the host's reward in the event of success and the more intense is her incentive to exert effort. At the same time, a higher stake for the host implies a lower reward to the investor's effort in the event of success. This dulls the investor's incentive to apply himself diligently for the sake of the project.

In the presence of adverse selection, the mechanism offered by the principal must be incentive compatible and satisfy the participation constraint of the privately informed agent. Thus, the investor's problem can be written as follows:

$$\max_{\{\beta,\kappa\}} \int_{\underline{w}}^{\overline{w}} [p(e,i)\Delta(1-\beta(w)) - \kappa(w) - i]\, dF(w) \tag{4.46}$$

subject to,

$$\bar{U}(w,w) \geq 0 \quad \forall w \in [\underline{w}, \overline{w}] \tag{4.47}$$

$$\bar{U}(w,w) \geq \bar{U}(\hat{w},w), \quad \forall \;\; \hat{w}, w \in [\underline{w}, \overline{w}] \tag{4.48}$$

$$e = e(\beta(\hat{w}), \kappa(\hat{w}), w) \text{ as defined by 4.44, and} \tag{4.49}$$

$$i = i(\beta(\hat{w}), \kappa(\hat{w}), w) \text{ as defined by 4.45.} \tag{4.50}$$

Equation 4.47 is the host's individual rationality constraint while constraint 4.48 ensures that the host truthfully reveals her type (the incentive compatibility constraint). When the investor can prevent the host from exaggerating her wealth, he can offer a compensation that depends on the host's reported type. Substituting for $\kappa(w)$ in the investor's objective function using (4.41), the investor's objective function can be rewritten as

$$\max_{\beta} \int_{\underline{w}}^{\overline{w}} \left[p(e,i)[\Delta + \lambda(w)L] - \lambda(w)L - e - i - \bar{U}\right] dF(w) \tag{4.51}$$

As shown in the appendix, the solution to the modified problem can be obtained through a control theoretic formulation where $\bar{U}(w)$ (the rent left to the host) is designated as the state variable and $\beta(w)$ is the control variable. Proposition 16 describes the solution.

Proposition 17. *Suppose that* $\left[p_e(e,i)\frac{de}{d\beta(w)} + p_i(e,i)\frac{di}{d\beta(w)}\right]\lambda'(w)L < 0$ *and* $\beta(w)$ *is nonincreasing. Then the solution to the problem described by 4.46-4.50 denoted by* $\{\bar{\kappa}(w), \bar{\beta}(w)\}$ *is characterized as*

$$\begin{aligned} \bar{\kappa}(w) &= [1 - p(e,i)]\lambda(w)L + e - p(e,i)\Delta\beta(w) \\ &\quad + [1 - p(e,i)]L \int_{w}^{\overline{w}} \lambda'(w')dw'; \text{ and} \end{aligned} \tag{4.52}$$

$$[p_e(e,i)[\Delta + \lambda(w)L] - 1]\frac{de}{d\beta(w)} + [p_i(e,i)[\Delta + \lambda(w)L] - 1]\frac{di}{d\beta} - \delta(w) \tag{4.53}$$

where $\delta(w)$ *is a distortion term defined as*

$$\delta(w) = \frac{F(w)}{f(w)}\left[p_e(e,i)\frac{de}{d\beta(w)} + p_i(e,i)\frac{di}{d\beta(w)}\right]\lambda'(w)L = 0. \tag{4.54}$$

Proof: See the appendix.

Equation 4.52 gives the level of the fixed component of the compensation package. The first two terms in this expression ensure that the host is compensated for the cost of her effort and the expected legal liability. The third term reduces the host's fixed transfer with the variable portion of her compensation. The final term gives the amount required to induce the host to truthfully report her type. Since it is only advantageous for the less wealthy type to misreport her true type, all host types except the wealthiest (i.e., type $\overline{w}$) have their fixed transfer enhanced by this term. In essence, κ is designed to prevent the host from exaggerating her level of wealth with impunity.

Equation 4.53 is the core of the analysis, for it determines the necessary condition for an optimal investment in e and i. In order to understand the implications of this condition recall that if the investor's level of investment and the host's expenditure on effort were observable and therefore contractible, then the full information solution would satisfy $p_e(e,i)[\Delta+\lambda(w)L] = 1$ and $p_i(e,i)[\Delta+\lambda(w)L] = 1$. Under bilateral moral hazard, but without adverse selection, the necessary condition for optimal effort is given by equation 4.24. Thus, the first two terms in 4.53 derive from double sided moral hazard, while the third term comes from the host's private information. The third term equals zero for $w = \underline{w}$ since by definition $F(\underline{w}) = 0$. This implies that the host type with the least amount of wealth exerts as much effort as under pure moral hazard; that is, there is no distortion at the "bottom". Similarly, the investor's effort decision is the same under limited information as it is under double moral hazard when $w = \underline{w}$.

For all wealth levels $w > \underline{w}$, however, the distortion term is strictly negative and it therefore enters positively in the investor's optimum. This requires that the first two terms in equation 4.54 sum to a negative value in the investor's optimum. Consequently, it must be the case that $p_e(e,i)$ has decreased (since $\frac{de}{d\beta} > 0$) and $p_i(e,i)$ has gone up (since $\frac{di}{d\beta} < 0$) relative to the situation where only moral hazard is present. Since $p(e,i)$ is concave in its arguments, there must have been an increase in the level of effort exerted by the host and a decrease in the level of investment undertaken by the investor compared with the pure bilateral moral hazard case.

The optimal incentive scheme has the familiar form of incentive schemes in the single-principal, single-agent, adverse selection model. Only the best agent (type $w = \underline{w}$) undertakes the optimal level of investment. All other types undertake less than the efficient scale of investment. Introducing distortion for $w > \underline{w}$ allows a reduction in the information rents paid to the less wealthy type who has the greatest incentive to exaggerate her endowment. The explanation for this result is as follows: Since the host bears the burden of project failure in its entirety, any optimal contract must compensate her for both her cost of exerting effort and expected liability payment. The investor knows that the host with a higher level of wealth is endowed with only limited default ability and therefore faces a more severe asset loss in the event of failure. Hence, the value of exerting effort will be greater the higher her level of wealth. This implies that a host with a great deal of wealth to loose will require only minimal incentives. Accordingly, the set of contracts in the absence of adverse selection will offer low-powered incentive schemes (with higher fixed components) for the the wealthy host but prescribe a high-powered incentive packages for the one with meager resources. In other words, the host's wealth obviates the need to employ a powerful incentive scheme. However, the use of such contracts in the presence of hidden information implies that a host who knows that her wealth is *low* will intentionally misreport her true level of wealth in order to receive a high fixed transfer and a lower level of the variable payment β.[48] Knowing the host's incentive to misreport, the investor optimally lowers the attractiveness of the compensation contract designed for hosts with *higher* level of wealth. This is done by lowering the fixed component of compensation and raising the power of incentives. Consequently, there is over investment by the host and underinvestment by the investor relative to the pure moral hazard case for all wealth levels $w > \underline{w}$.

We can shed some light on the character of effort distortion by learning a little more about the distortion term $\delta(w)$. For instance,

$$\begin{aligned}\delta'(w) &= \left[\frac{\partial}{\partial w}\left(\frac{F(w)}{f(w)}\right)\right]\left[p_e(e,i)\frac{de}{d\beta(w)} + p_i(e,i)\frac{di}{d\beta(w)}\right]\lambda'(w)L \quad (4.55)\\ &+ \left[\frac{F(w)}{f(w)}\right]\left[p_e(e,i)\frac{de}{d\beta(w)} + p_i(e,i)\frac{di}{d\beta(w)}\right]\lambda''(w)L.\end{aligned}$$

From the classic Monotonic Hazard Rate condition, we know that f/F is a decreasing function. Therefore, it must be the case that $\frac{\partial}{\partial w}\left[\frac{F(w)}{f(w)}\right] > 0$. Given that

[48]Note that lying is advantageous for the low type host.

$p_e(e,i)\frac{de}{d\beta(w)} + p_i(e,i)\frac{di}{d\beta(w)} < 0$ and $\lambda''(w) \geq 0$ by assumption, it immediately follows that $\delta'(w) < 0$. Since $\delta(w)$ is negative, an increase in w makes the distortion term more significant; the tendency to overburden the host with personally costly action will be more pronounced the *higher* is the host's level of wealth. In sum, the information rent increases and effort distortion decreases as the host's type gets closer to the lower end point. Thus, our model suggests that we should expect a host to be afforded a relatively low share of the realized returns if she is less wealthy and a greater share of the project's output (more powerful incentive schemes) if she is wealthy.

The aforementioned varying rent and effort distortions profiles distinguish our results from those by Lewis and Sappington (2000a). In that study, the contracting friction is spawned by the desire by the agent to conceal/understate some of her wealth. To preclude this incentive, the principal reduces the share of profits afforded the agent by just enough to offset the smaller bond she posts as her wealth decreases. This compensating variation results in a constant rent profile for the agent. Since our framework does not afford the investor the ability to impose a bond under investor-only liability, however, the host with meager wealth can only be precluded from overstating her wealth (potential loss) by raising the bonus part and lowering the salary component of the compensation package depending on how far the host's wealth is from the lowest end point $\underline{w}$. Consequently, a uniform rent profile and effort distortion is not optimal.

Investor liability. Recall that the distinguishing feature of investor-only liability relates to the ability of the investor's unbounded wealth to ensure that there are no uncompensated liability. Suppose that a host of type w reports that her wealth is $\hat{w}$ to the investor. Then given mechanism $(\beta(\hat{w}), \kappa(\hat{w})$, her expected rent $\tilde{U}(w, \hat{w})$ is given by

$$\tilde{U}(w, \hat{w}, e(\hat{w}, w)) = p(e,i)\Delta\beta(\hat{w}) - e - \kappa(\hat{w}). \tag{4.56}$$

Let $\tilde{U}(w, w, e(w, w)) \equiv \tilde{U}(w)$ be the indirect payoff function, or information rent (i.e., the net payoff made by host w when she truthfully reports her type to the investor). Hence, the investor's problem reads:

$$\max_{\beta(w),T(w)} \int_{\underline{w}}^{\overline{w}} [p(e,i)\Delta(1-\beta(w)) - [1-p(e,i)]L + \kappa(w)]\, dF(w) \tag{4.57}$$

subject to

$$\tilde{U}(w, w) \geq 0 \tag{4.58}$$

$$\tilde{U}(w, w) \geq \tilde{U}(w, \hat{w}) \; \forall w, \hat{w} \in [\underline{w}, \overline{w}] \tag{4.59}$$

$$e(\beta(\hat{w}), \kappa(\hat{w}), w) = \arg\max_{e} p(e,i)\Delta\beta(\hat{w}) - e - \kappa(\hat{w}) \tag{4.60}$$

$$i(\beta(\hat{w}), \kappa(\hat{w}), w) = \arg\max_{i} p(e,i)\Delta(1-\beta(\hat{w})) - [1-p(e,i)]L + \kappa(\hat{w}) - i \tag{4.61}$$

and

$$w - \kappa(\hat{w}) \geq 0. \tag{4.62}$$

The only difference between the program described by the system of equations 4.57 - 4.62 and that described by system 4.26 - 4.30 is the additional constraint 4.59. This is the truthtelling condition, and it says that the host truthfully reports her wealth in equilibrium. We can transform the problem before deriving the characteristics of the optimal solution. First, note that constraint 4.62 can be rewritten in the following convenient form: From (4.56) we obtain $\kappa(w) = p(e,i)[\Delta\beta(w) - e - \tilde{U}(w)$. Substituting for $\kappa(w)$ in the investor's objective function 4.57 and feasibility constraint 4.62, we now obtain the following modified problem:

$$\max_{\beta(w)} \int_{\underline{w}}^{\overline{w}} \left[p(e,i)(\Delta + L) - e - i - \tilde{U}\right] dF(w) \tag{4.63}$$

subject to 4.58 - 4.61 and $\left[\tilde{U} - \{p(e,i)\Delta\beta(w) - e - w\}\right] \geq 0$.

In this modified program, $\tilde{U}(.)$ can be viewed as the state variable and $\beta(.)$ as the control variable. As before, we can apply the Pontryagin's Principle to this optimal control problem. The following proposition summarizes the central features of the solution to this problem. The proof has be relegated to the appendix.

Proposition 18. *Suppose that investor-only liability rule is in force and the host is privately informed about her wealth. Then there exists a critical wealth threshold* $w^* \in [\underline{w}, \overline{w}\,]$ *such that*

$$\begin{aligned} &[p_e(e,i)[\Delta + L] - 1]\frac{de}{d\beta(w)} \\ &+ [p_i(e,i)[\Delta + L] - 1]\frac{di}{d\beta(w)} \begin{cases} = 0 \;\forall\; w \in (w^*, \overline{w}] \\ > 0 \;\forall\; w \in [\underline{w}, w^*] \end{cases}. \end{aligned} \tag{4.64}$$

Proof: See the appendix.

Condition 4.64 suggests that the incentive scheme under investor-only liability exhibits bunching in region $w \in [w^*, \overline{w}]$ of the host's type space. Significantly, the level of effort that is optimally induced for this pool of types is the same as under pure moral hazard. Types outside the pooling zone have their effort distorted away from the pure moral hazard solution. More precisely, the host is induced to deliver her entire wealth whenever her effort supply is below its pure moral hazard level. Types that supply effort levels that are consistent with the pure moral level are ceded a rent. Recall that under pure moral hazard, the necessary condition for an optimal expenditure on e and i is $[p_e(e,i)(\Delta + L)$ $-1]\frac{de}{d\beta w)} + [p_i(e,i)(\Delta + L) - 1]\frac{di}{d\beta(w)}$. Equation 4.64 suggests that for types in the

$[\underline{w}, w^*)$ region, $p_e(e,i)$ must increase while $p_i(e,i)$ must decrease relative to the case where only pure moral hazard is present. Thus, there is a shift away from host's effort and towards investor's effort relative to the case where only pure moral hazard is present. In other words, types that are less endowed deliver less wealth and are offered less powerful incentive schemes. This requirement gives the investor too much investment incentives relative to the case where there is no hidden information. The foregoing analysis imply that the functions $\beta(w), \kappa(w)$ have a jump discontinuity at w^* and thus are not monotone.

The logic behind this result is as follows: When the host's wealth is high, the only way the investor can prevent the host from understating her wealth is by promising her a higher reward when she posts a higher bond. However, the more generous the output sharing arrangement the host is offered to compensate for the larger wealth that she delivers up-front, the lower the investor's incentive to undertake productive investment. Thus, when designing an incentive scheme, the investor must balance the two incentive effects which clearly work at cross purposes. As the host becomes more wealthy, diminishing returns to output sharing sets in since $\frac{d}{d\beta}\left[\frac{de}{d\beta(w)}\right] = \frac{p_e(e,i)}{p_{ee}(e,i)} < 0$; further increase in β increases the host's rents, but reduces the investor's incentive more than it increases the total surplus. Consequently, the investor leaves rent to the host when her wealth is sufficiently high, and as shown in the appendix, the rent that is ceded is the same regardless of the host's level of wealth.

Joint liability. We now conclude this section by considering the investor's optimum under joint liability. Given contract $\{\beta, \kappa\}$, the host's effort supply is determined by

$$p_e(e,i)[\Delta\beta(w) + \rho\lambda(w)L] - 1 = 0. \tag{4.65}$$

Similarly, the investor's effort supply function is determined by

$$p_i(e,i)[\Delta(1-\beta(w)) + (1-\rho\lambda(w))L] - 1 = 0 \tag{4.66}$$

Equations (4.65) and (4.66) define the host's effort $e(\beta, w)$ and the investor's effort $i(\beta, w)$ as functions of the host's stake in the project as well her own level of residual wealth. The investor's problem is

$$\max_{\beta,\kappa} \int_{\underline{w}}^{\overline{w}} [p(e,i)[\Delta(1-\beta)+[1-\rho\lambda(w)]L] \tag{4.67}$$
$$-\kappa-[1-\rho\lambda(w)]L-i]\,dF(w)$$

subject to

$$\check{U}(w,w) \geq 0 \tag{4.68}$$

$$\check{U}(w,w) = \check{U}(\hat{w},w) \;\; \forall \quad \hat{w}, w \in [\underline{w}, \overline{w}] \tag{4.69}$$

$$e = e(\beta(\hat{w}), \kappa(\hat{w}), w) \text{ as defined by 4.65;} \tag{4.70}$$

and

$$i = i(\beta(\hat{w}), \kappa(\hat{w}), w) \text{ as defined by 4.66.} \tag{4.71}$$

The proposition below summarizes the solution to the investor's problem under joint liability. Its proof involves applying similar control theoretic techniques as those employed for the problem described by equations 4.46 - 4.50 and is therefore omitted.

Proposition 19. *Suppose that* $\left[p_e(e,i)\frac{de}{d\beta}+p_i(e,i)\frac{di}{d\beta}\right]\rho\lambda'(w)L < 0$ *and* $\beta(w)$ *is nonincreasing. Then the solution to the program described by 4.67 -4.71 is characterized as*

$$\kappa(w) \;=\; [1-p(e,i)]\rho\lambda(w)L + e - p(e,i)\Delta\beta(\hat{w}) \tag{4.72}$$
$$+[1-p(e,i)]L\rho\int_{\overline{w}}^{w}\lambda'(w')dw'.$$

$$[p_e(e,i)[\Delta + L] - 1]\frac{de}{d\beta} + [p_i(e,i)[\Delta + L] - 1]\frac{di}{d\beta} \tag{4.73}$$
$$- \left[\frac{F(w)}{f(w)}\right]\left[p_e(e,i)\frac{de}{d\beta} + p_i(e,i)\frac{di}{d\beta}\right]\rho\lambda'(w)L = 0.$$

An interpretation analogous to the interpretation of proposition 16 applies here. The optimal levels of effort in the presence of private knowledge of wealth and unobservable effort differs from those under pure moral hazard for all levels of wealth but $w = \underline{w}$. This is because the distortion term in equation 4.73 vanishes when $w = \underline{w}$ since $F(\underline{w}) = 0$ but takes a negative value for all $w > \underline{w}$. Thus, proposition 18 suggests that for all $w > \underline{w}$, the first two terms must sum to a negative in the investor's optimum. This means that $p_e(e,i)$ must have decreased and $p_i(e,i)$ increased relative to the pure moral hazard situation. That is, hidden information induces a shift away from i and toward e relative to the case of pure moral hazard.

An interesting implications is provided by examining the nature of the distortion term in 4.73 as a function of the host's share of the liability, ρ. An increase in ρ unambiguously increases the magnitude of the distortion term; that is, an increase in ρ increases the burden of productive investment undertaken by the host. Therefore, increasing the share of the liability that is allocated to the host may actually exacerbate the agency problem. This is because an increases in ρ effectively increase the host's expected liability and her *ex-ante* loss of wealth in the failure state. This gives her a greater incentive to report her wealth as higher in an attempt to earn rent, thereby necessitating an increase in the share component of compensation package in the investor's optimum.

4.5. Host-government policy

The flow of technology-laden foreign investment of the kind described in this study is often accompanied by other benefits such as transfers of *modern* technologies and more competitive markets. Not surprisingly, most host governments, particularly those of economies in transition, have pursued active policies to attract foreign investment and induce technological diffusion (See, for example, Reitzes and Grawe,1999; Saggi, 1999; Fumagall, 2003; and Broll et al., 2003). The set-up examined so far has precluded any role for host government policy. It might be argued that this is not realistic. Thus, an interesting question is wether the main conclusions from the previous sections continue to hold if we introduce host-government policies targeted toward attracting clean technology transfer. In this section, we extend our analysis by explicitly taking into account host-government domestic investment incentives designed to stimulate the successful transfer and assimilation of the foreign technology into the local economy.

There is a fairly long list of measures that a host country can employ in order to attract foreign investment. These include fiscal incentives such as lower taxes for foreign investors, financial incentives such as subsidies, strong economic fundamentals and removal/reduction of foreign equity caps (Reitzes and Grawe,1999; OECD, 2000.) In this section, however, we confine ourselves to only two types of incentives that appear to have attracted significant attention; namely, an investment subsidy directed toward the foreign investor and foreign ownership equity caps. The subsidy considered here is assumed to be a financial incentive (such as a discount on inputs costs, compensation for adverse changes in the exchange rate, and favourable financing) issued to the investor on an on-going basis, and therefore excludes up-front fiscal incentives, which lower the cost of the initial sunk investment.

Formally, let $s \in (0, 1)$ be the subsidy applied to each unit of expenditure on effort undertaken by the investor. To capture the role of foreign ownership equity cap most simply, we assume that the foreign investor has equity (ownership) interest denoted by ϕ over the host firm. However, his equity stake is restricted by host government policy. We capture the effect of government restrictions on foreign ownership claims by assuming that $\phi<1$. Throughout, we take s and ϕ as given, not to be determined in the model. Negotiations instead apply to β and κ.

Suppose that the regime of liability in place holds the host strictly liable and that both moral hazard and adverse selection are present. The expected profit from the project is $p(e,i)[\ \Delta - \Delta\beta - \kappa - i(1-s)] - [1-p(e,i)][\kappa + i(1-s)]$ or simply $p(e,i)\ \Delta(1-\beta) - \kappa - i(1-s)$. The net payoff to the host is equal to the compensation plus the net value of the equity held less the disutility of effort. Thus, the host's net payoff, $\overline{U}'$ is given by

$$\begin{aligned} \overline{U}' &= \phi\left[p(e,i)\Delta(1-\beta) - \kappa - i(1-s)\right] + p(e,i)\Delta\beta(w) + \kappa(w) \quad (4.74) \\ &\quad -e - [1-p(e,i)]\lambda(w)L \\ &= p(e,i)[\phi\Delta + (1-\gamma)\Delta\beta(w) + \lambda(w)L] + (1-\phi)\kappa(w) \\ &\quad -e - \phi i(1-s) - \lambda(w)L. \end{aligned}$$

Similarly, the investor's net payoff is

$$\overline{\pi}' = (1-\phi)\left[p(e,i)\Delta(1-\beta) - \kappa(w) - i(1-s)\right]. \quad (4.75)$$

The investor's problem in the presence of host government incentives [G] can now be rewritten as

$$\max_{\beta} \int_{\underline{w}}^{\overline{w}} (1-\phi)\left[p(e,i)\Delta(1-\beta) - \kappa(w) - i(1-s)\right] dF(w) \quad (4.76)$$

subject to, for all $w, \hat{w} \in [\underline{w}, \overline{w}]$

$$\overline{U}'(w,w) \geq 0; \quad (4.77)$$

$$\overline{U}'(w,w) \geq \overline{\overline{U}}'(w,\hat{w}); \quad (4.78)$$

$$\begin{aligned} e(\beta(\hat{w}),\kappa(\hat{w}),w,) &\equiv \arg\max_{i} p(e,i)[\phi\Delta + (1-\phi)\Delta\beta(w) + \lambda(w)L] + (1-\phi)\kappa(w) \quad (4.79) \\ &\quad -e - \phi i(1-s) - \lambda(w)L; \end{aligned}$$

and

$$i(\beta(\hat{w}), \kappa(\hat{w}), w) \equiv \arg\max(1-\phi)\left[p(e,i)\Delta(1-\beta) - \kappa(w) - i(1-s)\right]. \quad (4.80)$$

Totally differentiating the first order condition given by equation 4.79, we obtain $\frac{di}{ds} = -\frac{\phi}{p_{ii}(e,i)\Delta(1-\beta(w))} > 0$ and $\frac{di}{d\phi} = \frac{(1-s)}{p_{ii}(e,i)\Delta(1-\beta(w))} < 0$. Not surprisingly, the investors's effort is an increasing function of the input subsidy and a decreasing function foreign equity cap.

Our principal objective here, however, is to determine whether the introduction of an investment subsidy or a reduction in foreign equity caps implies qualitative differences in the nature of incentive provision when only bilateral moral hazard is present, and when both two-sided moral hazard and adverse selection are present. To address this issue we must obtain the solution to problem [G]. Equation 4.81 below gives the investor's optimum under this new setting. It shows that the introduction of an inward investment subsidy does indeed affect the nature of incentive provision.

$$\begin{aligned} &[p_e(e,i)[\Delta + \lambda(w)L] - 1]\frac{de}{d\beta(w)} \quad (4.81)\\ &+ [p_i(e,i)[\Delta + \lambda(w)L] - 1]\frac{di}{d\beta(w)} - \delta(w) + (1-\phi)s\frac{di}{d\beta(w)} = 0. \end{aligned}$$

In the above expression, $\delta(w)$ is a distortion term defined by 4.54. It follows immediately that $\delta(w)$ is not a function of ϕ or s. Hence, the introduction or changes in ϕ or s will have no adverse selection consequences.

But how do changes in ϕ and s affect the optimal provision of incentives? Under the no-subsidy setting, the first three terms in equation 4.81 must sum to zero in the investor's optimum. With the introduction of the subsidy, however, equation 4.81 indicates that the first three terms must now sum to a positive number in order to maintain the required equality. It must therefore be the case that $p_e(e,i)$ has increased (since $\frac{de}{d\beta} > 0$) and $p_i(e,i)$ has decreased (since $\frac{di}{d\beta} > 0$) relative to the situation where there is no subsidy. Since $p(e,i)$ is concave in its arguments, there must have been a decrease in the level of effort exerted by the host and an increase in the level of effort undertaken by the investor compared with the case without subsidy. An analogous interpretation applies to the effect of a reduction in ϕ.

While the effect of the subsidy on the investor's effort incentive is not surprising, its diminution of the host's effort incentives is not entirely a *priori* obvious. Intuitively, it could be argued that since an input subsidy directly reduces the investor's cost of undertaking effort, his incentive to exert more effort should increase. However, this still does not tell us why there is less distortion in the host's effort in the aftermath of the introduction of a subsidy. To see the logic behind the above result more clearly, one must realize that the presence of moral hazard and adverse selection imply that the marginal cost of effort as perceived by the investor is higher as it must include the marginal informational rents paid to the host. A subsidy reduces the marginal cost of any implementable effort, and therefore it reduces the investor's incentive to distort effort. To sum up, the introduction of an input-based subsidy to encourage direct foreign investment may dull the incentive for the investor to overburden the host with too much investment.

Paradoxically, this result has pessimistic implication for domestic investment: It suggests that while a subsidy may ultimately encourage foreign investment, it has the potential to crowd out domestic investment. This outcome is in consonance with a section of empirical studies that have examined the impact of foreign direct investment on investment by domestic firms. In these studies, however, foreign direct investment leads to a decrease in domestic investment when foreign firms borrow heavily from the domestic capital market, thereby exacerbating the domestic firms' financial constraints (See, for example, Harrison and McMillan, 2001.)

We end this section by the deriving the solution to the investor's problem under joint liability. In this environment, the project's profit and the net value of equity is reduced by the investor's share of the liability. Hence, the project's expected profit is $p(e,i)[\Delta(1-\beta)+(1-\rho\lambda(w))L] - \kappa - i(1-s)$. Given the structure of the compensation $(\beta(\hat{w}), \kappa(\hat{w}))$, the host's expected payoff is

$$\begin{aligned} \breve{U}'(w,\hat{w}) &= [1-\phi]\left[p(e,i)[\Delta(1-\beta(\hat{w}))+(1-\rho\lambda(w))L]-\kappa(\hat{w})-i(1-s)\right] \qquad (4.82) \\ &\quad +p(e,i)\Delta\beta(\hat{w})+\kappa(\hat{w})-[1-p(e,i)]\rho\lambda(w)L-e. \end{aligned}$$

It can be shown (the proof is similar to the proof of proposition 15) that the solution to the investor's problem includes

$$\begin{aligned} &[p_e(e,i)[\Delta+L]-1]\frac{de}{d\beta(w)} \qquad (4.83) \\ &+[p_i(e,i)[\Delta+L]-1]\frac{di}{d\beta(w)}-\breve{\delta}(w)+(1-\phi)s\frac{di}{d\beta(w)}=0 \end{aligned}$$

where $\breve{\delta}(w)$ is a distortion term defined by

$$\breve{\delta}(w)=\frac{F(w)}{f(w)}\left[p_e(e,i)\frac{de}{d\beta}+p_i(e,i)\frac{di}{d\beta}\right]\phi\rho\lambda'(w)L. \qquad (4.84)$$

By contrast with the host liability framework, joint liability shows that the distortion term is influenced by foreign ownership restrictions. When ϕ is near zero, that is, when the degree of foreign ownership restriction is more limited, the distortion term is less positive and therefore less significant. Hence, the overall level of distortion is increasing in ϕ. Thus, our model predicts that an enhanced foreign ownership implied by a reduction in foreign equity cap may actually moderate the incentive for the foreign investor to distort effort incentives. Finally, note that because there are no adverse selection consequences under investor liability, ϕ will not affect the overall level of effort distortion under this scheme.

4.6. Conclusion

The main focus of this paper was to explore the interaction between liability allocation, informational asymmetry and the optimal investment in project implementation by the investor and the host, respectively, in the context of international technology transfer. The framework incorporated both double-sided moral hazard and adverse selection. The results indicate that the nature of the distortions in effort depends critically on whom the liability is installed and the nature of the information problem. More precisely, when the investor is strictly liable, the optimal contract may yield the same incentive structure under both pure moral hazard, and simultaneous moral hazard and adverse selection. On the other, when liability is installed on the host, the optimal contract induces too little efforts (relative to the first-best) by both parties under pure moral hazard; however, once moral hazard and adverse selection are incorporated in the same context, the resulting rent-efficiency trade-off yields an incentive for the investor to optimally reduce his investment and to overburden the host with too much investment. And the incentive to overburden the host is more pronounced, the greater the host's wealth endowment. The model, therefore, suggests that equity is better served by installing liability more on the investor than by exacting damages on the host.

The model also gives an interesting prediction regarding the impact of the host's share of the liability and inward investment subsidy on the overall magnitude of effort distortion. An increase in host's share of the liability unambiguously increases the magnitude of the distortion optimally introduced by the investor to limit the information rent accrued to the host; that is, an increase in the host's share of liability increases the host's effort relative to that of the investor. This implies that increasing the host's share of the liability may actually worsen the agency problem. An increase in the rate of investment subsidy induces lower levels of effort incentives on the part of the host.

Although this analysis focused on the nature of contracts under project-based mechanisms for emissions reduction, this should not mask the strong applicability of the model to other economic situations characterized by externalities. For example, the framework developed herein can be used to shed some light on the problem of extending liability to third parties with whom a firm interacts, and who may have exercised operational control on the firm. Conditions that make the analysis here relevant exist in the case of extended liability. For example, e in our framework would be synonymous with the firm's level of care while i would be the third party's level of productive investment/monitoring.

In closing, we can point to some possible refinements to the model that can be usefully explored in the future. It was assumed throughout that liability is exogenously determined. A complete analysis would therefore include an explicit treatment of the IEA's determination of the optimal level of damages. The study also assumed a one-short game. In repeated game context, however, signals may be revealed for wealth and effort. Thus, another possible extension would be to consider the optimal allocation in a multi-period framework.

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5. General Discussion and Conclusions

This body of research applied the theory of incentives to examine critical environmental issues that challenge contemporary society. The main focus was to explore the interaction between *ex-post* liability rules designed to internalize environmental damages, informational asymmetry and the nature of optimal contracts in settings where there is asymmetries of information *after* the signing of a contract.

The first paper considered the relevance of extended liability for a firm's capital structure, the level of precautionary incentives and the firm's prospects for insolvency in bilateral-moral hazard situation where the lender's action along with the borrower's investment in precaution influence the distribution of damage realizations. The key observation is that when the borrower's assets bounds are exceedingly tight relative to the highest possible damage realization, then the lender's deep pockets help increase firm incentives for care, and extending liability to the creditor decreases the level of social damages. In general, this result tends to support those found by Balkenborg (2001), Lewis and Sappington (2001), Heyes (1999) and Dionne and Spaeter (2003), and conforms to the spirit of CERCLA. The main feature that sets this study apart, however, is with regard to the channel through which extended liability affects optimal incentive provisions. In Lewis and Sappington (2001), the lender's deep pockets enables the lender to improve the firm's incentives for care by adopting an extreme reward structure when the firm's assets are small. In Heyes (1999), extended liability gives the lender the incentive to gatekeep more stringently, thus inducing high risk borrowers to drop out of the market. In Dionne and Spaeter (2003), extended liability works by altering the face value of debt, which has two offsetting effects on prevention, however. In that paper, extended liability will increase prevention if and only if an increase in the face value of debt increases precaution. In our model, extended liability unambiguously increases prevention. The intuitive idea behind this result is that when extended liability increase the face value of debt, the lender is optimally afforded lower control rights over the firm while the manager's ownership claims are simultaneously increased. This gives both parties the incentive to undertake more precaution - the borrower because of the increased ownership claims and the lender because of the higher expected returns in the state of the world in which the firm is solvent. These effects have not been stressed in the literature.

One shortcoming with the first essay is that it presumes that the agent, to whom the contract is proposed, has no relevant private information at the (*ex-ante)* contracting stage. This assumption is too restrictive. In the second essay, we abandon this restriction, and assume instead that the agent's private information is an argument in the principals objective function. Accordingly, a model structure that admits two classes of asymmetry of information simultaneously is developed to examine the relevance of liability allocation and information asymmetry in the context of international transfer of energy efficient technologies.

We obtain two sets of results. On the one hand, if the investor is endowed with all the bargaining power, then installing the damages on the host - who directly controls the failure risk - induces more effort distortion than assigning the liability to the investor. Intuitively, installing sanctions on the host enhances her ability to command information rent, which occurs in terms of avoided damages. To limit the agent's ability to command these rents, she must be afforded low-powered incentives. Thus, agent (host) liability intensifies the private information (adverse selection) aspects of the agency problem, thereby, increasing the cost of using high-powered incentive schemes. On the other hand, if the host is allocated all the bargaining power, host-only liability enables the host to internalize the information rents and increases her incentives to labour diligently for the project; there are no adverse selection considerations. Consequently, host-only liability outperforms investor-only liability in terms of effort incentives.

Comparing the first two essays, one can see that the interaction of liability allocation and incentive provisions depends crucially on the elements within the two parties' information sets. When the source of uncertainty is pure moral hazard, bargaining power is clearly inessential for incentive provisions, and allocating the liability to the party that directly controls the environmental risk may be dominated by extended liability. In the presence of both moral hazard and adverse selection, however, the balance of bargaining power is essential in determining the intensity of incentive provisions. In this case, allocating the liability to the party that directly controls the environmental risk yields a higher level of effort incentives if that party is endowed with all the bargaining power. The converse is true if the party without control over the environmental risk has the monopoly over the bargaining power.

In the third essay, we broaden the two parties' information sets by (a) explicitly allowing the principal (investor) to have some input into the technology transfer process, and (b) admitting the possibility of private knowledge of wealth (expected payoff) on the part of the host. When the investor is held strictly liable, the optimal contract indicates a shift towards more effort by the investor. On the other hand, when the liability is installed on the host, the rent-efficiency trade off arising yields an incentive to overburden the host with too much investment. And the tendency to overburden the host is more significant the higher the host's wealth endowment.

The analysis presented in this dissertation has been purely positive, examining the implications of *ex-post* liability rules to deal with environmental externalities for capital structure, compensation contracts and care incentives both at the international level and at the national level. We have not been able to make any claim as to whether we should want the liability to be imposed on the party that directly controls an environmental risk or on the party that finances a potentially damaging economic activity. By adopting a purely positive approach, we have side-stepped a number of interesting questions that can be usefully explored in the future. First, it was assumed throughout that liability is exogenously determined. A complete analysis could therefore introduce the regulator as an active participant and include an explicit treatment of the determination of the optimal level of damages. The situation could then be plausibly examined using a standard common agency framework (see, e.g. Bernheim and Whinstin, 1986; Biglaiser and Mezzeti, 1993; and Bond and Gresik, 1997). The study also assumed a one-short game. In a repeated game context, however, signals may be revealed for wealth, type and effort, and the parties may not commit themselves not to renegotiate.

All our models assume that the contracting parties are all risk neutral. Risk neutrality for the investor, for example, may be questionable, however, because individual investor's seeking low-cost abatement options are unlikely to possess a portfolio of similar projects spread across the developing world. The same can be said of the host's or the borrower's risk preferences. If the borrower is risk averse, for example, then in designing the contract that is best for him, she will trade-off risk sharing concerns against moral hazard. Hence, her incentive to raise the face value of debt κ in response to extended liability may be tempered by her desire to limit the risk from stochastic damages. Thus, a deeper exploration of the impact of liability allocation might involve an examination of the effects of risk preferences.

Despite these limitations, we believe that the analysis presented makes a useful contribution to the literature. We have emphasized that the size of environmental damages relative to an injurer's asset base, the allocation of bargaining power and alternative information asymmetries may well affect the *ex-ante* incentive to exercise care/effort. The analysis suggests that a particular liability rule may have markedly different effects depending on the parties involved and their information sets. This suggest that it would be prudent to adopt a case-by-case approach to environmental legal liability, both at the international level and national level, rather than adopting a general rule.

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6. Appendices

6.1. Appendix to paper 1

6.1.1. The social problem

The first-order conditions associated with the social problem are given by

$$\int_0^{l^*(\kappa)} [v-l]\, f_e(l/e,a)dl + \int_{l^*(\kappa)}^{\min\{v,L\}} [v-l]\, f_e(l/e,a)dl - 1 = 0 \qquad (6.1)$$

and

$$\int_0^{l^*(\kappa)} [v-l]\, f_e(l/e,a)dl + \int_{l^*(\kappa)}^{\min\{v,L\}} [v-l]\, f_e(l/e,a)dl - 1 = 0, \qquad (6.2)$$

respectively. Now, integrating the last two equations by parts, making use of $F_a(L/e,a) = F_a(0/e,a) = 0$, eliminating and rearranging terms, we obtain $\int_0^{\min\{v,L\}} F_e(l/e,a)dl - 1 = 0$ and $\int_0^{\min\{v,L\}} F_a(l/e,a)dl - 1 = 0$, from which it immediately follows that $\int_0^{\min\{v,L\}} F_e(l/e,a)dl = \int_0^{\min\{v,L\}} F_a(l/e,a)dl = 1$.■

6.1.2. Proof of proposition 1

There are two cases to consider:

Case 1. $v \geq L$. In this case $\min\{v,L\} = \min\{L, v+\rho(L-v)\} = L$. A direct comparison of (2.4), (2.5), (2.6) and (2.7) yield $e^s = \bar{e} = \tilde{e} = \breve{e}$ and $a^s = \bar{a} = \tilde{a} = \breve{a}$.

Case 2. $v < L$. In this case $\min\{v,L\} = v$ and $\min\{L, v+\rho(L-v)\} = v+\rho(L-v)$. From (2.4) and (2.6) we have $\int_0^L F_e(l/e^s,a^s)dl = \int_0^L F_e(l/\tilde{e}^*,\tilde{a}^*)dl = 1, \Longrightarrow \tilde{e}^* = e^s$. Similarly, $\int_0^L F_a(l/e^s,a^s)dl = \int_0^L F_a(l/\tilde{e}^*,\tilde{a}^*)dl = 1 \Longrightarrow \tilde{a}^* = a^s$. From (2.4) and (2.5 we have $\int_0^v F_e(l/e^s,a^s)dl + \int_v^L F_e(l/e^s,a^s)dl = 1$ and $\int_0^v F_e(l/\bar{e}^*,\bar{a}^*)dl = 1$,which imply that

$$\int_0^v F_e(l/e^s,a^s)dl - \int_0^v F_e(l/\bar{e}^*,\bar{a}^*)dl = -\int_v^L F_e(l/e^s,a^s)dl \qquad (6.3)$$

By assumption, the RHS of 6.3 is negative whilst the LHS of 6.3 is negative if and only if $\int_0^v F_e(l/e^s, a^s)dl < \int_0^v F_e(l/\bar{e}^*, \bar{a}^*)dl$ or $\bar{e}^* < e^s$. From (2.7) and (2.5) we have $\int_0^v F_e(l/\breve{e}^*, \breve{a}^*)dl + \int_v^{v+\rho(L-v)} F_e(l/\breve{e}^*, \breve{a}^*)dl = 1$ and $\int_0^v F_e(l/\bar{e}^*, \bar{a}^*)dl = 1$, which imply that

$$\int_0^v F_e(l/\breve{e}^*, \breve{a}^*)dl - \int_0^v F_e(l/\bar{e}^*, \bar{a}^*)dl = -\int_v^{v+\rho(L-v)} F_e(l/\breve{e}^*, \breve{a}^*)dl. \tag{6.4}$$

Again, the LHS is negative if and only if $\bar{e}^* < \breve{e}^*$. Proceeding in a similar manner, it can be shown that

$$\int_0^v F_e(l/\tilde{e}^*, \tilde{a}^*)dl - \int_0^{v+\rho(L-v)} F_e(l/\breve{e}^*, \breve{a}^*)dl = -\int_v^L F_a(l/\tilde{e}^*, \tilde{a}^*)dl \tag{6.5}$$

which implies that $\breve{e}^* < \tilde{e}^*$. Combining the last three steps now show that when $v < L$, then $e^s = \tilde{e}^* > \breve{e}^* > \bar{e}^*$. The proof for a^* is analogous, and is therefore omitted.■

6.1.3. Proof of proposition 2

Partially differentiate (2.21) with respect β to obtain

$$\int_0^{\min\{v,L\}} [v-l]\, f_e(l/e,a)\frac{de}{d\beta}dl + \int_0^{\min\{v,L\}} [v-l]\, f_a(l/e,a)\frac{da}{d\beta}dl - \frac{de}{d\beta} - \frac{da}{d\beta} = 0. \tag{6.6}$$

Integrating the latter most expression by parts, making use of $F_e(0/e,a)$ =0 and $[v-l]\, F_e(\min\{v,L\}/e,a) = 0$ and rearranging, we obtain

$$\left[\int_0^{\min\{v,L\}} F_e(l/e,a)dl - 1\right]\frac{de}{d\beta} + \left[\int_0^{\min\{v,L\}} F_a(l/e,a)dl - 1\right]\frac{da}{d\beta} = 0 \tag{6.7}$$

which is equation (2.22) of proposition 2. Similarly, partially differentiating (??) with respect κ we obtain

$$\int_0^{\min\{v,L\}} [v-l]\, f_e(l/e,a)\frac{de}{d\kappa}dl + [v-l^*]\, f(l^*/e,a)\frac{\partial l^*}{\kappa} \tag{6.8}$$
$$+\int_0^{\min\{v,L\}} [v-l]\, f_a(l/e,a)\frac{da}{d\kappa}dl - [v-l^*]\, f(l^*/e,a)\frac{\partial l^*}{\kappa} - \frac{de}{d\kappa} - \frac{da}{d\kappa} = 0.$$

which is equation (2.23) of proposition 2. Recall that the firm's insolvency condition is given by as

$$v - \kappa - l^* = 0. \tag{6.9}$$

It follows, therefore, that

$$\frac{\partial l^*}{\partial \kappa} = -1. \tag{6.10}$$

Integrating equation (6.8) by parts, making use of the fact that $F_e(0/e,a)$ =0 and $[v-l]\, F_e(l/e,a)|_{l=\min\{v,L\}}$=0 and rearranging, equation (6.8) simplifies to

$$\left[\int_0^{\min\{v,L\}} F_e(l/e,a)dl - 1\right]\frac{de}{d\kappa} + \left[\int_0^{\min\{v,L\}} F_a(l/e,a)dl - 1\right]\frac{da}{d\kappa} = 0. \tag{6.11}$$

Dividing equation (6.7) by (6.11) we obtain

$$\frac{de}{d\beta}\frac{da}{d\kappa} = \frac{da}{d\beta}\frac{de}{d\kappa}. \tag{6.12}$$

Making use of (??), (??), (2.15) and (2.16), the last expression can be rewritten as

$$\frac{\int_0^{l^*(\kappa)} F_e(l/e,a)dl}{\overline{SOC}_e}\frac{\beta F_a(l^*/e,a)}{\overline{SOC}_a} = \frac{\int_0^{l^*(\kappa)} F_a(l/e,a)dl}{\overline{SOC}_a}\frac{\beta F_e(l^*/e,a)}{\overline{SOC}_e}, \tag{6.13}$$

which simplifies to

$$F_e(l^*/e,a)/\, F_a(l^*/e,a) = \int_0^{l^*(\kappa)} F_e(l/e,a)dl \Big/ \int_0^{l^*(\kappa)} F_a(l/e,a)dl. \qquad (6.14)$$

Now, using the last equation and the first order conditions (2.11) and (2.14), we obtain

$$\frac{F_e(l^*/e,a)}{F_a(l^*/e,a)} = \frac{(1-\beta)}{\beta}\frac{1}{\nabla_0} \qquad (6.15)$$

which is equation (2.24)of proposition 1. Equation (2.25) follows immediately from the binding participation constraint (2.20).■

6.1.4. Proof of proposition 4

The first-order associated with (2.38) is given by

$$(1-\beta)\int_0^{l^*(\kappa)} F_a(l/e,a)dl + \int_{l^*(\kappa)}^{\min\{L,v+\rho(L-v)\}} F_a(l/e,a)dl - 1 = 0. \qquad (6.16)$$

The manager's unconstrained problem is

$$\max_{\{\beta,\kappa\}} \int_0^{l^*(\kappa)} [v-l]\, f(l/e,a)dl + \int_{l^*(\kappa)}^{\min\{L,v+\rho(L-v)\}} [v-l]\,(l/e,a)]dl - rK - a - e - U^B, \qquad (6.17)$$

subject to (2.29) and (2.38). Partially differentiate (6.17) with respect β, applying assumptions $F_e(0/e,a) = F_e(L/e,a)$ and $F_a(0/e,a) = F_a(L/e,a) = 0$ we obtain

$$\left[\int_0^{\min\{L,v+\rho(L-v)\}} F_e(l/e,a)dl - 1\right]\frac{de}{d\beta} \qquad (6.18)$$
$$+\left[\int_0^{\min\{L,v+\rho(L-v)\}} F_a(l/e,a)dl - 1\right]\frac{da}{d\beta} = 0.$$

Similarly, partially differentiating (6.17) with respect κ we obtain

$$\left[\int_0^{l^*(\kappa)} F_e(l/e,a)dl + \int_{l^*(\kappa)}^{\min\{L,v+\rho(L-v)\}} F_e(l/e,a)dl - 1\right]\frac{de}{d\kappa} \tag{6.19}$$
$$+\left[\int_0^{l^*(\kappa)} F_a(l/e,a)dl + \int_{l^*(\kappa)}^{\min\{L,v+\rho(L-v)\}} F_a(l/e,a)dl - 1\right]\frac{da}{d\kappa} = 0,$$

Manipulation of (6.18), (6.19) and the first-order conditions (2.11) and (6.16) yields $\frac{(1-\beta)}{\beta} = \frac{F_e(l^*/e,a)}{F_a(l^*/e,a)}\left[1 - \int_{l^*(\kappa)}^{\min\{L,v+\rho(L-v)\}}\right]$, which is equation (2.42) of proposition 3.■

6.1.5. Proof of corollary 1

We prove this corollary by first establishing the following. Under no liability, the lender's effort choice decision is given by (2.14). Substituting for β in (2.14) using (2.24) we obtain

$$\bar{U}_a^B(\bar{a},\bar{e}) = \int_0^{l^*(\kappa)} F_a(l/\bar{a},\bar{e})dl + \int_{l^*(\bar{\kappa})}^{l^m} F_a(l/\bar{a},\bar{e})dl$$
$$-\frac{F_a(l^*(\kappa)/\bar{a},\bar{e})\int_0^{l^*(\bar{\kappa})} F_a(l/\bar{a},\bar{e})dl}{F_a(l^*/\bar{a},\bar{e}) + F_e(l^*/\bar{a},\bar{e})\left[1 - \int_{l^*(\bar{\kappa})}^{l^m} F_a(l/\bar{a},\bar{e})dl\right]} - 1 = 0$$

where $l^m = \min\{v, L\}$. Now, compute the partial derivative

$$\frac{\partial \bar{U}_a^B(\bar{a},\bar{e})}{\partial l^m} = F_a(l^m/e,a)\left[1 - \frac{F_a(l^*/e,a)F_e(l^*/e,a)}{\Omega^2}\int_0^{l^*(\kappa)} F_a(l/e,a)dl\right],$$

where $\Omega = F_a(l^*/e,a) + F_e(l^*/e,a)\left[1 - \int_{l^*(\kappa)}^{l^m} F_a(l/e,a)dl\right]$. It is straightforward to show that $\frac{F_a(l^*/e,a)F_e(l^*/e,a)}{\Omega^2} \in (0,1)$. Thus, a necessary and sufficient condition for $\frac{\partial U_a^B(\bar{a},\bar{e})}{\partial l^m} > 0$ is that $\int_0^{l^*(\kappa)} F_a(l/e,a)dl \in (0,1)$. From (2.14), we have

$(1-\beta) = 1 - \int_{l^*(\kappa)}^{l^m} F_a(l/e,a)dl \Big/ \int_0^{l^*(\kappa)} F_a(l/e,a)dl$

$\Longrightarrow \int_0^{l^*(\kappa)} F_a(l/e,a)dl > 1 - \int_{l^*(\kappa)}^{l^m} F_a(l/e,a)dl$ since $(1-\beta) \in (0,1)$

$\Longrightarrow \int_{l^*(\kappa)}^{l^m} F_a(l/e,a)dl > 1 - \int_0^{l^*(\kappa)} F_a(l/e,a)dl$

$\Longrightarrow \int_0^{l^*(\kappa)} F_a(l/e,a)dl < 1.$

Hence $\frac{\partial U_a^B(\bar{a},\bar{e})}{\partial l^m} > 0$. The proof that $\frac{\partial U_e^o(\bar{a},\bar{e})}{\partial l^m} > 0$ is analogous, and we therefore omit it. We now consider two cases.

Case 1: $L \leq v$ such that $\min\{v, L\} = L$ and $\min\{L, v+\rho(L-v)\} = L$. Then the effort choice condition under each regime is given by

$$\tilde{U}_a^B(\tilde{a},\tilde{e}) = \int_0^{l^*(\kappa)} F_a(l/\tilde{a},\tilde{e})dl + \int_{l^*(\kappa)}^{L} F_a(l/\tilde{a},\tilde{e})dl \tag{6.20}$$
$$-\frac{F_a(l^*/\tilde{a},\tilde{e}) \int_0^{l^*(\kappa)} F_a(l/\tilde{a},\tilde{e})dl}{F_a(l^*/\tilde{a},\tilde{e}) + F_e(l^*/\tilde{a},\tilde{e})\left[1 - \int_{l^*(\kappa)}^{L} F_a(l/\tilde{a},\tilde{e})dl\right]} - 1 = 0,$$

$$\breve{U}_a^B(\breve{a},\breve{e}) = \int_0^{l^*(\kappa)} F_a(l/\breve{a},\breve{e})dl + \int_{l^*(\kappa)}^{L} F_a(l/\breve{a},\breve{e})dl \tag{6.21}$$
$$-\frac{F_a(l^*/\breve{a},\breve{e}) \int_0^{l^*(\kappa)} F_a(l/\breve{a},\breve{e})dl}{F_a(l^*/\breve{a},\breve{e}) + F_e(l^*/\breve{a},\breve{e})\left[1 - \int_{l^*(\kappa)}^{L} F_a(l/\breve{a},\breve{e})dl\right]} - 1 = 0$$

and

$$U_a^B(\bar{a},\bar{e}) = \int_0^{l^*(\kappa)} F_a(l/e,a)dl + \int_{l^*(\kappa)}^{L} F_a(l/e,a)dl \tag{6.22}$$
$$-\frac{F_a(l^*/e,a) \int_0^{l^*(\kappa)} F_a(l/e,a)dl}{F_a(l^*/e,a) + F_e(l^*/e,a)\left[1 - \int_{l^*(\kappa)}^{L} F_a(l/e,a)dl\right]} - 1 = 0.$$

A direct comparison of the last three expressions yields $\breve{a} = \bar{a} = \tilde{a}$. Arguing in a similar manner, one can show that $\tilde{e} = \bar{e} = \breve{e}$. Since effort incentives are identical across the three regimes, it follows trivially that the optimal contracts must be the same; that is, $\bar{\beta} = \tilde{\beta} = \breve{\beta}$ and $\breve{\kappa} = \bar{\kappa} = \tilde{\kappa}$.

Case 2: $v < L$. This means $\min\{v, L\} = v$ and $\min\{L, v + \rho(L - v)\} = v + \rho(L - v)$. Note that $v + \rho(L - v) = v(1 - \rho) + \rho L > v$. The lender's effort choice under full lender liability satisfies

$$\bar{U}_a^B(\tilde{a},\tilde{e}) = \int_0^{l^*(\kappa)} F_a(l/\tilde{a},\tilde{e})dl + \int_{l^*(\kappa)}^{L} F_a(l/\tilde{a},\tilde{e})dl \tag{6.23}$$
$$-\frac{F_a(l^*/\tilde{a},\tilde{e})\int_0^{l^*(\kappa)} F_a(l/\tilde{a},\tilde{e})dl}{F_a(l^*/\tilde{a},\tilde{e}) + F_e(l^*/\tilde{a},\tilde{e})\left[1-\int_{l^*(\kappa)}^{L} F_a(l/\tilde{a},\tilde{e})dl\right]} - 1 = 0.$$

The effort selection condition under no lender liability setting is given by

$$\bar{U}_a^B(\bar{a},\bar{e}) = \int_0^{l^*(\kappa)} F_a(l/e,a)dl + \int_{l^*(\kappa)}^{v} F_a(l/e,a)dl \tag{6.24}$$
$$-\frac{F_a(l^*/e,a)\int_0^{l^*(\kappa)} F_a(l/e,a)dl}{F_a(l^*/e,a) + F_e(l^*/e,a)\left[1-\int_{l^*(\kappa)}^{v} F_a(l/e,a)dl\right]} - 1 = 0.$$

The corresponding condition under partial lender liability is

$$\breve{U}_a^B(\breve{a},\breve{e}) = \int_0^{l^*(\kappa)} F_a(l/\breve{a},\breve{e})dl + \int_{l^*(\kappa)}^{\min\{L,v+\rho(L-v)\}} F_a(l/\breve{a},\breve{e})dl \tag{6.25}$$
$$-\frac{F_a(l^*/\breve{a},\breve{e})\int_0^{l^*(\kappa)} F_a(l/\breve{a},\breve{e})dl}{F_a(l^*/\breve{a},\breve{e}) + F_e(l^*/\breve{a},\breve{e})\left[1-\int_{l^*(\kappa)}^{\min\{L,v+\rho(L-v)\}} F_a(l/\breve{a},\breve{e})dl\right]} - 1 < 0.$$

Evaluating $\bar{U}_a^B(\tilde{a},\tilde{e},\bar{\kappa})$, we obtain

$$\bar{U}_a^B(\tilde{a},\tilde{e}) = \int_0^{l^*(\kappa)} F_a(l/\tilde{a},\tilde{e})dl + \int_{l^*(\bar{\kappa})}^{v} F_a(l/\tilde{a},\tilde{e})dl \tag{6.26}$$
$$-\frac{F_a(l^*/\tilde{a},\tilde{e})\int_0^{l^*(\kappa)} F_a(l/\tilde{a},\tilde{e})dl}{F_a(l^*/\tilde{a},\tilde{e}) + F_e(l^*/\tilde{a},\tilde{e})\left[1-\int_{l^*(\bar{\kappa})}^{v} F_a(l/\tilde{a},\tilde{e})dl\right]} - 1 < 0.$$

since $v < L$. Since $\bar{U}^B$ is concave in a, it follows that $\tilde{a} > \bar{a}$; the lender has more incentives to exercise precaution under full lender liability than under no lender liability. Now, evaluating $\bar{U}_a^B(\breve{a},\breve{e},\bar{\kappa})$, we obtain

$$\bar{U}_a^B(\breve{a},\breve{e}) = \int_0^{l^*(\kappa)} F_a(l/\breve{a},\breve{e})dl + \int_{l^*(\bar{\kappa})}^{v} F_a(l/\breve{a},\breve{e})dl \tag{6.27}$$
$$-\frac{F_a(l^*/\breve{a},\breve{e})\int_0^{l^*(\kappa)} F_a(l/\breve{a},\breve{e})dl}{F_a(l^*/\breve{a},\breve{e}) + F_e(l^*/e,a)\left[1-\int_{l^*(\bar{\kappa})}^{v} F_a(l/\breve{a},\breve{e})dl\right]} - 1 < 0$$

since $v < v + \rho(L - v)$. Again, since $\bar{U}^B$ is concave in a, it follows that $\breve{a} > \bar{a}$. We now compare $\breve{a}$ with $\tilde{a}$. Evaluating $\tilde{U}_a^B(\breve{a}, \breve{e}, \breve{\kappa})$ it can be seen that

$$\tilde{U}_a^B(\breve{a}, \breve{e}) = \int_0^{l^*(\kappa)} F_a(l/\breve{a}, \breve{e})dl + \int_{l^*(\kappa)}^{L} F_a(l/\breve{a}, \breve{e})dl \tag{6.28}$$

$$-\frac{F_a(l^*/\breve{a}, \breve{e}) \int_0^{l^*(\kappa)} F_a(l/\breve{a}, \breve{e})dl}{F_a(l^*/\breve{a}, \breve{e}) + F_e(l^*/\breve{a}, \breve{e}) \left[1 - \int_{l^*(\kappa)}^{L} F_a(l/\breve{a}, \breve{e})dl\right]} - 1 > 0.$$

since $L > v + \rho(L - v)$. It follows that $\breve{a} < \tilde{a}$ and $\tilde{a} > \breve{a} > \bar{a}$. Proceeding in the same manner, one can show that $\tilde{e} > \breve{e} > \bar{e}$. In sum, both the lender and the manager are afforded the highest level of incentives under full lender liability; no lender liability yields the least incentives for both parties. This outcome is possible if and only if $\tilde{\kappa} > \breve{\kappa} > \bar{\kappa}$ and $\tilde{\beta} > \breve{\beta} > \bar{\beta}$. ■

6.2. Appendix to paper 2

6.2.1. Proof of Proposition 5

Part (i): It suffices to show that the investor will be indifferent between the two regimes. Because the investor has all the bargaining power, he need only satisfy the host's participation constraint. The level of fixed transfer payments κ that achieves this are given by $\kappa = [\mu - e] - \frac{1}{[1+r]}p(e,\omega)\Delta\beta$ under investor liability and $\kappa = [\mu - e] - \frac{1}{[1+r]}p(e,\omega)\Delta\beta + \frac{1}{[1+r]}[1 - p(e,\omega)]\rho\lambda(\mu)L$ under joint liability, respectively. These transfers yield the same expected payoff of $p(e,\omega)[\Delta + L] + [1+r][\mu - e] - L$ for the investor. Hence, the two liability regimes are equivalent from the investor's perspective, and the investor finds it optimal to assign the same level of effort.

Part (ii): It is straightforward to show that the investor's *ex-ante* payoff under host liability is $p(e,\omega)[\Delta+\lambda(\mu)L]+[1+r][\mu+\kappa-e]-\lambda(\mu)L$. This implies an effort supply function defined by $p_e(\bar{e},\omega)[\Delta + \lambda(\mu)L] = 1 + r$. We know that the effort choice under joint liability or investor liability is given by $p_e(\tilde{e},\omega)[\Delta + L] = 1 + r$. It follows that $p_e(\tilde{e},\omega) = p_e(\bar{e},\omega)\frac{[\Delta+\lambda(\mu)L]}{[\Delta+L]}$. Using lemma 2, we can now state the following: If $\lambda(\mu) = 1$, $p_e(\tilde{e},\omega) = p_e(\bar{e},\omega) \Longrightarrow \tilde{e} = \bar{e}$ since $p(e,\omega)$ is concave in e. For $\lambda(\mu) < 1$, $p_e(\bar{e},\omega) > p_e(\tilde{e},\omega)$, which by concavity of $p(e,\omega)$ in e implies that $\tilde{e} > \bar{e}$.■

6.2.2. Proof of Proposition 6

Let $\overline{\pi}^*(\omega)$, $\tilde{\pi}^*(\omega)$, and $\breve{\pi}^*(\omega)$ denote the expected maximal investor welfare under host, investor, and joint liability regimes, respectively. Then we have:

$$\overline{\pi}^*(\omega) = p(\bar{e}^*,\omega)[\Delta + \lambda(\mu)L] + [1+r][\mu - \bar{e}^*] - \lambda(\mu)L; \qquad (6.29)$$

$$\tilde{\pi}^*(\omega) = p(\bar{\tilde{e}}^*,\omega)[\Delta + L] + [1+r][\mu - \tilde{e}^*] - L; \qquad (6.30)$$

and

$$\breve{\pi}^*(\omega) = p(\breve{e}^*, \omega)[\Delta + L] + [1 + r][\mu - \breve{e}^*] - L. \tag{6.31}$$

The effects of changes in L or r on the investor's optimal welfare can now be obtained from the envelope theorem as follows:

$$\frac{d\overline{\pi}^*(\omega)}{dL} = \frac{\partial \overline{\pi}^*(\omega)}{\partial L} = \underbrace{[p_e(\overline{e}^*, \omega)[\Delta + \lambda(\mu)L] - (1+r)] \frac{d\overline{e}^*}{dL}}_{\text{effort incentive effect}} - \underbrace{[1 - p_e(\overline{e}^*, \omega)]\lambda(\mu)}_{\text{revenue effect}} \tag{6.32}$$

$$= -[1 - p_e(\overline{e}^*, \omega)]\lambda(\mu) < 0;$$

$$\frac{d\tilde{\pi}(\omega)}{dL} = \underbrace{[p_e(\tilde{e}^*, \omega)[\Delta + L] - (1+r)] \frac{d\tilde{e}^*}{dL}}_{\text{effort incentive effect}} - \underbrace{[1 - p_e(\tilde{e}^*, \omega)]\lambda(\mu)}_{\text{revenue effect}} \tag{6.33}$$

$$= -[1 - p_e(\tilde{e}^*, \omega)] < 0;$$

and

$$\frac{d\breve{\pi}(\omega)}{dL} = \underbrace{[p_e(\breve{e}^*, \omega)[\Delta + L] - 1] \frac{d\breve{e}^*}{dL}}_{\text{effort incentive effect}} - \underbrace{[1 - p_e(\breve{e}^*, \omega)]\lambda(\mu)}_{\text{revenue effect}} \tag{6.34}$$

$$= -[1 - p(\breve{e}^*, \omega)] < 0$$

since $p_e(\overline{e}^*, \omega)[\Delta + \lambda(\mu)L] - (1+r) = 0$, $p_e(\tilde{e}^*, \omega)[\Delta + \lambda(\mu)L] - (1+r) = 0$, $p_e(\breve{e}^*, \omega)[\Delta + \lambda(\mu)L] - (1+r) = 0$, and $\frac{de^*}{dL} > 0$ for all regimes.■

6.2.3. Proof of proposition 9

The investor's problem [AH] as defined by equations (3.38) - (3.41) in the text can be reformulated in the following convenient form. From (3.35) we obtain:

$$\kappa(\omega) = [U(\omega,\omega) - p(e,\omega)[\Delta\beta(\omega) + \lambda(r)L] - [1+r][\mu - e] + \lambda(r)L]/[1+r]. \quad (6.35)$$

Substituting for $\kappa(\omega)$ in the objective function (3.38) using

$$U(\omega,\omega,e(\omega,\omega)) = p(e,\omega)\Delta\beta(\omega) + [1+r][\mu+\kappa(\omega)-e] - [1-p(e,\omega)]\lambda(\mu)L \quad (6.36)$$

yields

$$\int_{\underline{\omega}}^{\overline{\omega}} [p(e,\omega)[\Delta + \lambda(\mu)L] - U - \lambda(\mu)L + (1+r)(\mu - e)]\, dF(\omega). \quad (6.37)$$

The solution to the modified problem can now be obtained using control theoretic techniques with ω being treated in the same manner as a time index in an optimal control program. Note that since $p_\omega(e,\omega) > 0$, the right-hand side of (3.45) is positive. Thus, $U(\omega)$ increases with ω. As a result, we only need to require the participation constraint to be satisfied at the lower end point $\omega = \underline{\omega}$. The control problem can be stated as

$$\max_{\{\beta(\omega)\}} \int_{\underline{\omega}}^{\overline{\omega}} [p(e,\omega)[\Delta + \lambda(r)L] - U - \lambda(r)L + (1+r)(\mu - e)]\, f(\omega)d\omega) \quad (6.38)$$

subject to (3.45) and

$$U(\underline{\omega}) = 0 \quad U(\overline{\omega}) \text{ free} \quad (\underline{\omega}, \overline{\omega} \text{ given}). \quad (6.39)$$

We take U as the state variable with trajectory determined by lemma (3.45), and β as the control variable (See Chiang, 1992). The Hamiltonian can be written as

$$H_1(\beta(\omega), U, \omega, \gamma) = [p(e,\omega)[\Delta + \lambda(r)L] - U - \lambda(r)L + (1+r)(\mu - e) \quad (6.40)$$
$$+ \frac{\gamma(\omega)\,[p_\omega(e,\omega)[\Delta\beta(\omega) + \lambda(\mu)L]]}{f(\omega)}\Bigg] f(\omega).$$

Assuming an interior solution for $\beta(\omega)$, the maximum-principle conditions include:

$$\frac{\partial H}{\partial \beta(\omega)} = 0 \quad \text{[maximizing the Hamiltonian]} \tag{6.41}$$

$$\frac{d\gamma}{d\omega} = -\frac{\partial H}{\partial U} \quad \text{[equation of motion for } \gamma\text{]} \tag{6.42}$$

$$\frac{dU}{d\omega} = p_\omega(e,\omega)[\Delta\beta(\omega) + \lambda(\mu)L] = \frac{\partial H}{\partial \gamma} \quad \text{[equation of motion for } U\text{]} \tag{6.43}$$

and

$$\gamma(\overline{\omega}) = 0. \quad \text{[transversality condition]} \tag{6.44}$$

Notice that because the participation constraint will bind only at the lower bound, the co-state variable, $\gamma(\omega)$, will be zero at the upper end point, $\overline{\omega}$. The solution for the control variable $\beta(\hat{\omega})$ is

$$\begin{aligned} &[p_e(e(\omega),\omega)[\Delta + \lambda(\mu)L] - (1+r)]\frac{de}{d\beta} - \frac{\gamma(\omega)}{f(\omega)}p_\omega(e(\omega),\omega)\Delta \\ &-\frac{\gamma(\omega)}{f(\omega)}p_{\omega e}(e(\omega),\omega)[\Delta\beta(\omega) + \lambda(\mu)L]\frac{de}{d\beta} = 0. \end{aligned} \tag{6.45}$$

Since (6.45) expresses $\beta(\omega)$ in terms of $\gamma(\omega)$, we must look for a solution for $\gamma(\omega)$. We resort to the equation of motion for the co-state variable. Equation $\frac{d\gamma(\omega)}{d\omega} = -\frac{\partial H}{\partial U}$ is a differential equation which can be solved by separating the variables. Now write

$$\frac{d\gamma(\omega)}{d\omega} = -\frac{\partial H}{\partial U} = f(\omega) \Longrightarrow d\gamma(\omega) = f(\omega)d\omega. \tag{6.46}$$

Integrating both sides of (6.46) yields $\int d\gamma(\omega) = \int f(\omega)d\omega$ or $\gamma(\omega) = F(\omega) + c$

(c arbitrary constant).We now make use of the fact that $F(\overline{\omega}) = 1$ and the transversality condition $\gamma(\overline{\omega}) = 0$ to definitize the constant c. Thus, $\gamma(\overline{\omega}) = F(\overline{\omega}) + c$, implying that the constant $c = -1$. This yields the following value for the co-state variable, $\gamma(\omega)$:

$$\gamma(\omega) = -[1 - F(\omega)] < 0. \tag{6.47}$$

Substituting back into the first order condition on $\beta(\hat{\omega})$ yields equation (3.46) of proposition 9. From (3.45)), we can write $dU(\omega) = p_\omega(e, \omega)[\Delta\beta(\omega) + \lambda(\mu)L]d\omega$. Integrating both sides of this equation and making use of the fact that $U(\underline{\omega}) = 0$, we obtain

$$U(\omega) = \int_{\underline{\omega}}^{\omega} p_\omega(e, \omega')[\Delta\beta(\omega') + \lambda(\mu)L]d\omega'. \tag{6.48}$$

Substituting back into (6.35) yields equation (3.47) of proposition 9. ■

6.2.4. Proof of corollary 4

From the definition of $\kappa(\omega)$ (equation 3.47), and using the *Leibniz rule* for differentiating an integral, we have

$$\frac{\partial\bar{\kappa}(\omega)}{\partial\beta(\omega)} = -\delta p(\bar{e}(\omega), \omega)\Delta + \delta \int_{\underline{\omega}}^{\omega} \left(\frac{\partial}{\partial\beta} \left[p_\omega(\bar{e}(\omega'), \omega')[\Delta\overline{\beta}(\omega') + \lambda(r)L] \right] \right) d\omega' \tag{6.49}$$

$$= -\delta p(\bar{e}(\omega), \omega)\Delta + \delta \int_{\underline{\omega}}^{\omega} p_\omega(\bar{e}(\omega'), \omega')\Delta d\omega' < 0, \text{ where } \delta = 1/(1+r). ■$$

6.2.5. Comparative statics

Step 1: Let $\phi = \frac{[1-F(\omega)]}{f(\omega)}$. Then given $p(e, \omega) = \omega e^{\eta}$, we can solve explicitly for the optimal value of β under each scheme of liability to obtain the following:

$$\bar{\beta}(\omega) = \frac{\eta\omega[\Delta + \lambda(\mu)L] - (1+r)\bar{e}(\omega)^{(1-\eta)} - \phi\lambda(\mu)L}{\phi\Delta} \quad (6.50)$$

$$\tilde{\beta}(\omega) = \frac{\eta\omega[\Delta + L] - (1+r)\tilde{e}(\omega)^{(1-\eta)}}{\phi\Delta} \quad (6.51)$$

and

$$\breve{\beta}(\omega) = \frac{\eta\omega[\Delta + L] - (1+r)\breve{e}(\omega)^{(1-\eta)} - \phi\rho\lambda(r)L}{\phi\Delta}. \quad (6.52)$$

Step 2: From the first-order condition for optimal investment under each scheme, we can solve explicitly for the optimal level of investment to obtain:

$$\bar{e}(\omega) = \left[\frac{\eta\omega(\Delta\beta + \lambda(\mu)L)}{1+r}\right]^{\frac{1}{1-\eta}}; \quad (6.53)$$

$$\tilde{e}(\omega) = \left[\frac{\eta\omega\Delta\beta}{1+r}\right]^{\frac{1}{1-\eta}}; \text{ and} \quad (6.54)$$

$$\breve{e}(\omega) = \left[\frac{\eta\omega(\Delta\beta + \rho\lambda(\mu)L)}{1+r}\right]^{\frac{1}{1-\eta}}. \quad (6.55)$$

Step 3: Substitute for e in equations 6.50 - 6.52 using equations 6.53 - 6.55 to obtain

$$\bar{\beta}(\omega) = \frac{\eta\omega\Delta - \phi\lambda(\mu)L}{[\eta\omega + \phi]\,\Delta}; \quad (6.56)$$

$$\tilde{\beta}(\omega) = \frac{\eta\omega[\Delta + L]}{[\eta\omega + \phi]\,\Delta}; \quad (6.57)$$

and

$$\breve{\beta}(\omega) = \frac{\eta\omega[\Delta + L] - \phi\rho\lambda(\mu)L}{[\eta\omega + \phi]\,\Delta}. \quad (6.58)$$

We can now derive the following:

$\frac{\partial\bar{\beta}(\omega)}{\partial L} = \frac{-\phi\lambda(r)}{[\eta\omega+\phi]\Delta} < 0,\ \frac{\partial\bar{\beta}(\omega)}{\partial\mu} = -\frac{\phi\lambda'(\mu)L}{[\eta\omega+\phi]\Delta} < 0,\ \frac{\partial\bar{\beta}(\omega)}{\partial r} = 0;$

$\frac{\partial\tilde{\beta}(\omega)}{\partial L} = \frac{\eta\omega}{[\eta\omega+\phi]\Delta} > 0,\ \frac{\partial\tilde{\beta}(\omega)}{\partial\mu} = 0,\ \frac{\partial\tilde{\beta}(\omega)}{\partial r} = 0;$

$\frac{\partial\breve{\beta}(\omega)}{\partial L} = \frac{\eta\omega-\rho\lambda(\mu)\phi}{[\eta\omega+\phi]\Delta} =?\ \frac{\partial\breve{\beta}(\omega)}{\partial\mu} = -\frac{\eta\omega\phi\rho\lambda'(\mu)L}{[\eta\omega+\phi]\Delta} < 0,\ \frac{\partial\breve{\beta}(\omega)}{\partial r} = 0.$

Similarly, from equations 6.50 - 6.52, we obtain

$\frac{\partial\bar{e}(\omega)}{\partial L} = \left[\frac{\eta\omega[\Delta\beta+\lambda(\mu)L]}{\eta\omega+\phi}\right]^{\frac{\eta}{1-\eta}} \frac{\eta\omega}{(1+r)} \left[\Delta\frac{\partial\bar{\beta}(\omega)}{\partial L} + \lambda(\mu)\right] =?$ since $\Delta\frac{\partial\bar{\beta}(\omega)}{\partial L} < 0;$

$\frac{\partial\bar{e}(\omega)}{\partial\mu} = \left[\frac{\eta\omega[\Delta\beta+\lambda(\mu)L]}{\eta\omega+\phi}\right]^{\frac{\eta}{1-\eta}} \frac{\eta\omega}{(1+r)} \left[\Delta\frac{\partial\bar{\beta}(\omega)}{\partial\mu} + \lambda'(\mu)L\right] =?$ since $\Delta\frac{\partial\bar{\beta}(\omega)}{\partial\mu}<0;$

$\frac{\partial\bar{e}(\omega)}{\partial r} = -\left[\frac{\eta\omega(\Delta\beta+\lambda(\mu)L)}{1+r}\right]^{\frac{\eta}{1-\eta}} \left[\frac{\eta\omega(\Delta\beta+\lambda(\mu)L)}{(1+r)^2}\right] < 0;$

$\frac{\partial\tilde{e}(\omega)}{\partial L} = \left[\frac{\eta\omega\Delta\beta}{1+r}\right]^{\frac{\eta}{1-\eta}} \frac{\eta\omega\Delta}{(1+r)}\frac{\partial\tilde{\beta}(\omega)}{\partial L} > 0;\ \frac{\partial\tilde{e}(\omega)}{\partial\mu} = \left[\frac{\eta\omega\Delta\beta}{1+r}\right]^{\frac{\eta}{1-\eta}} \frac{\eta\omega\Delta}{(1+r)}\frac{\partial\tilde{\beta}(\omega)}{\partial\mu} = 0;$

$\frac{\partial\tilde{e}(\omega)}{\partial r} = -\left[\frac{\eta\omega\Delta\beta}{1+r}\right]^{\frac{\eta}{1-\eta}} \frac{\eta\omega\Delta\beta}{(1+r)^2} < 0;$

$\frac{\partial\breve{e}(\omega)}{\partial L} = \left[\frac{\eta\omega(\Delta\beta+\rho\lambda(\mu)L)}{1+r}\right]^{\frac{\eta}{1-\eta}} \frac{1}{(1+r)} \left[\eta\omega\Delta\frac{\partial\breve{\beta}(\omega)}{\partial L} + \rho\lambda(\mu)\right] =?$

$\frac{\partial\breve{e}(\omega)}{\partial\mu} = \left[\frac{\eta\omega(\Delta\beta+\rho\lambda(\mu)L)}{1+r}\right]^{\frac{\eta}{1-\eta}} \frac{1}{(1+r)} \left[\eta\omega\Delta\frac{\partial\breve{\beta}(\omega)}{\partial\mu} + \rho\lambda'(\mu)L\right] =?$

$\frac{\partial\breve{e}(\omega)}{\partial r} = -\left[\frac{\eta\omega(\Delta\beta+\rho\lambda(\mu)L)}{1+r}\right]^{\frac{\eta}{1-\eta}} \left[\frac{\eta\omega(\Delta\beta+\rho\lambda(\mu)L)}{(1+r)^2}\right] < 0.\blacksquare$

6.3. Appendix to paper 3

6.3.1. Proof of Proposition 12

The Lagrangian to the investor's problem under host liability is

$$\ell = p(e,i)[\Delta + \lambda(w)L] - i - e - \lambda(w)L. \tag{6.59}$$

The Kuhn-Tucker conditions are

$$\frac{\partial \ell}{\partial e} = \ell_e = p_e(e,i)[\Delta + \lambda(w)L] - 1 \leq 0,\ e \geq 0,\ \ell_e\ e = 0 \tag{6.60}$$

$$\frac{\partial \ell}{\partial i} = \ell_i = p_i(e,i)[\Delta + \lambda(w)L] - 1 \leq 0,\ i \geq 0,\ \ell_i\ i = 0 \tag{6.61}$$

together with the participation constraint. Assume the solution involves positive e and i. Then $\ell_e = \ell_i = 0$, which implies that

$$p_e(\bar{e}^*, \bar{\imath}^*)[\Delta + \lambda(w)L] - 1 = 0 \tag{6.62}$$

$$p_i(\bar{e}^*, \bar{\imath}^*)[\Delta + \lambda(w)L] - 1 = 0 \tag{6.63}$$

Proceeding is a similar manner as above and assuming an interior equilibrium, it can be shown that the optimal levels of effort under investor liability will be given by

$$p_e(\tilde{e}^*, \tilde{\imath}^*)[\Delta + L] - 1 = 0 \tag{6.64}$$

and

$$p_i(\tilde{e}^*, \tilde{\imath}^*)[\Delta + L] - 1 = 0. \tag{6.65}$$

The corresponding conditions under joint liability are

$$p_e(\breve{e}^*, \breve{\imath}^*)[\Delta + L] - 1 = 0 \tag{6.66}$$

and

$$p_i(\breve{e}^*, \breve{\imath}^*)[\Delta + L] - 1 = 0. \tag{6.67}$$

Since $p(e,i)$ is concave in e and i, it follows immediately from 6.64 - 6.67 that $\tilde{e}^* = \breve{e}^*$ and $\tilde{\imath}^* = \breve{\imath}^*$. It now remains to compare $\tilde{e}^*$and $\tilde{\imath}^*$ with $\bar{e}^*$ and $\bar{\imath}^*$. To do this, we put more structure on function $\lambda(w)$. Suppose $\lambda(w)$ takes the following functional form: $1 - \exp -\phi w$. Then, as $w \longrightarrow \infty$, $\lambda(w)$ tends toward unity, which implies that 6.62 and 6.63 collapse to 6.64 and 6.65 respectively. In this case, $\bar{e}^* = \tilde{e}^* = \breve{e}^*$ and $\bar{\imath}^* = \tilde{\imath}^* = \breve{\imath}^*$. Now consider $w \longrightarrow 0$. In this case, $\lambda(w)$ tends toward zero. This implies that the left-hand side of 6.62 will exceed the left-hand side of 6.64; that is, $p_e(\bar{e}, \bar{\imath}) > p_e(\tilde{e}, \tilde{\imath})$. Since $p(e,i)$ is concave in e, it follows that $\bar{e}^* < \tilde{e}^* = \breve{e}^*$. Reasoning in a similar manner, it is straightforward to show that as $w \longrightarrow 0$, $\bar{\imath}^* < \tilde{\imath}^* = \breve{\imath}^*$. The rest of the results then follow immediately.■

6.3.2. Proof of Proposition 16

Let $\bar{U}(w) \equiv \bar{U}(w,w)$ denote the host's expected payoff when she reports her true level of wealth. The sorting condition is defined by

$$\frac{\partial}{\partial w}\frac{\partial \bar{U}(w)/\partial \beta}{\partial \bar{U}(w)/\partial \kappa} = \left[p_e(e,i)\frac{de}{d\beta(w)} + p_i(e,i)\frac{di}{d\beta(w)}\right]\lambda'(w)L \tag{6.68}$$

A necessary condition for implementability of an indirect mechanism as a direct mechanism is that

$$\frac{\partial}{\partial \omega}\frac{\partial \bar{U}(w)/\partial \beta}{\partial \bar{U}(w)/\partial \kappa}\frac{\partial \beta}{\partial \omega} \geq 0. \tag{6.69}$$

Suppose that $\beta(\hat{w})$ is non-increasing, then in this case, the *Spence-Mirrlees* (sorting) *condition* would be given by

$$\frac{\partial}{\partial w}\left(\frac{\partial \bar{U}(w,w)/\partial \beta}{\partial \bar{U}(w,w)/\partial \kappa}\right) < 0. \tag{6.70}$$

The incentive compatibility condition, can be obtained from the envelope theorem as follows:

$$\frac{d\bar{U}(w)}{dw} = \frac{\partial\bar{U}(w)}{\partial w} = -[1-p(e,i)]\lambda'(w)L. \tag{6.71}$$

The problem defined by equations 4.46-4.48, 4.42 and 4.43 can be reformulated in the following convenient form. By employing $\kappa(w)$ from the definition of 4.40 we obtain:

$$\begin{aligned} \kappa(w) &= \bar{U}(w,w) + [1-p(e,i)]\lambda(w)L + e \\ &\quad -p(e,i)\Delta\beta(w). \end{aligned} \tag{6.72}$$

This is substituted into 4.46 to yield

$$\int_{\underline{w}}^{\overline{w}} \left[p(e,i)[\Delta + \lambda(w)L] - \bar{U} - L - e - i\right] dF(\omega). \tag{6.73}$$

We take $\bar{U}$ as the state variable with trajectory determined by 6.71, and β as the control variable. Note that since $\bar{U}(w)$ is decreasing in w, the right hand side of ?? is negative. As a result we only need to require the participation constraint to be satisfied at the highest end point, i.e., $\bar{U}(\overline{w},\overline{w}) = \bar{U}(\overline{w}) = 0$. This implies that the adjoint variable, μ, will be zero at the lower end point, $\underline{w}$. Hence, the optimal contract is characterized by the solution to the following control program:

$$\max_{\beta(w)} \int_{\underline{w}}^{\overline{w}} \left[p(e,i)[\Delta + \lambda(w)L] - \bar{U} - L - e - i\right] dF(\omega). \tag{6.74}$$

subject to 6.71 and

$$\bar{U}(\overline{w}) = 0 \; U(\underline{\omega}) \text{ free} \quad (\underline{\omega}, \overline{\omega} \text{ given}).$$

The Hamiltonian can be written as

$$H = \left[p(e,i)[\Delta + \lambda(w)L] - \lambda(w)L - \bar{U} - e - i - \frac{\mu[1-p(e,i)]\lambda'(w)L}{F'(\omega)}\right] F'(\omega). \tag{6.75}$$

Maximization of 6.75 with respect to β gives the following first order condition for an interior maximum:

$$[p_e(e,i)[\Delta + \lambda(w)L] - 1]\frac{de}{d\beta(w)} + [p_i(e,i)[\Delta + \lambda(w)L] - 1]\frac{di}{d\beta} - \frac{\mu}{f(\omega)}\left[p_e(e,i)\frac{de}{d\beta(w)} + p_i(e,i)\frac{di}{d\beta(w)}\right]\lambda'(w)L = 0, \tag{6.76}$$

where we have made use of $F'(\omega) = f(\omega)$. From the equation of motion $\frac{d\mu(w)}{dw} = -\frac{\partial H}{\partial U} = f(w)$, we obtain

$$d\mu(\omega) = f(w)dw \tag{6.77}$$

Integrating both sides of (6.77) yields $\int d\mu(w) = \int f(w)dw$ or $\mu(w) = F(w) + c$

(c arbitrary constant).We now make use of the fact that $F(\underline{w}) = 0$ and the transversality condition $\mu(\underline{w}) = 0$ to definitize the constant c. Thus, $\mu(\underline{w}) = F(\underline{w}) + c$, implying that $c = 0$. This yields the following value for the co-state variable, $\mu(w)$:

$$\mu(w) = F(\omega) > 0. \tag{6.78}$$

Substituting back into the first order condition on $\beta(\hat{w})$ yields equation 4.54 of proposition 16. From 6.71, we can write $d\bar{U}(w) = -[1 - p(e,i)]\lambda'(w)Ldw$. Integrating both sides of this equation we have $\bar{U}(\overline{w}) - \bar{U}(\underline{w}) = -[1-p(e,i)]L\int_{\underline{w}}^{\overline{w}} \lambda'(w)dw$. Now making use of the fact that $U(\overline{w}) = 0$, we obtain

$$\bar{U}(w) = [1 - p(e,i)]L\int_{w}^{\overline{w}} \lambda'(w')Ldw'. \tag{6.79}$$

Substituting back into 6.72 yields equation 4.52 of proposition 16.■

6.3.3. Proof of proposition 17

Assume that $d\tilde{U}(w)/dw = \dot{\tilde{U}}(w) \geq 0$. We can justify this assumption by appealing to the fact that a greater level of wealth may afford the host a larger choice set under any optimal contract. Thus, we can replace 4.59 with $\dot{\tilde{U}}(w) \geq 0$. The system 4.57 - 4.62 can now be formulated as an optimal control program with the following Hamiltonian:

$$\begin{aligned} H_2 &= \left\{p(e,i)[\Delta + L] - \tilde{U} - e - i - L\right\} f(w) \qquad (6.80) \\ &+U(\bar{w})\left[\Lambda(\bar{w}) - 1\right] + \xi(w)\dot{\tilde{U}} + \Lambda(w)\dot{\tilde{U}} + \vartheta(w)\left[\tilde{U} - \{p(e,i)\Delta\beta(w) - e - w\}\right]. \end{aligned}$$

In this formulation $\tilde{U}$ can be viewed as the state variable and $\xi(w)$ as the costate variable associated with U; $\beta(w)$ is the control variable; $\Lambda(w)$ is the Langrange multiplier associated with the host's participation constraint. The Hamiltonian necessary conditions include:

$$\begin{aligned} &[p_e(e,i)[\Delta + L] - 1]\frac{de}{d\beta(w)} + [p_i(e,i)[\Delta + L] - 1]\frac{di}{d\beta(w)} \qquad (6.81) \\ &-\frac{\vartheta(w)}{f(w)}\left\{p_i(e,i)\Delta\frac{di}{d\beta(w)} + p(e,i)\Delta\right\} = 0. \end{aligned}$$

$$\dot{\xi}(w) = f(w) - \vartheta(w) \qquad (6.82)$$

$$\xi(w)\dot{\tilde{U}} = 0 \qquad \dot{\tilde{U}} \geq 0 \qquad \xi(w) \geq 0 \qquad (6.83)$$

$$\vartheta(w)\left[\tilde{U} - \{p(e,i)\Delta\beta(w) - e - w\}\right] = 0 \; \tilde{U} - \{p(e,i)\Delta\beta(w) - e - w\} \geq 0 \; \vartheta(w) \geq 0 \qquad (6.84)$$

$$U(\bar{w})\Lambda(\bar{w}) = 0 \; U(\underline{w})\Lambda(\underline{w}) = 0 \; \Lambda(\underline{w}) \geq 0 \; U(\underline{w}) \geq 0. \qquad (6.85)$$

The solution to this problem takes one of two forms. If $\vartheta(w) > 0$, then

$\tilde{U} - \{p(e,i)\Delta\beta(w) - e - w\} = 0$ or $w - T(w) = 0$, which by 6.83 implies that $\dot{\tilde{U}} = 0$ and $\xi(w) > 0$ since $\tilde{U} = 0$. If $\vartheta(w) = 0$ instead, then the solution is identical the one derived under pure moral hazard. In this case, $\tilde{U} - \{p(e,i)\Delta\beta(w) - e - w\} > 0$, $w - T(w) > 0$ and $\tilde{U} > 0$. Conditions 6.82 and 6.83 reveal that we must have $\dot{\tilde{U}}$ =0 and $\xi(w) > 0$. Suppose not; that is, suppose $\vartheta(w) = 0$, but $\dot{\tilde{U}}$ >0, then 6.83 would require that $\xi(w) = 0$ and $\dot{\xi}(w) = 0$. But 6.82 would require that $\dot{\xi}(w) > 0$ implying that $\dot{\tilde{U}} = 0$, which contradicts the earlier assertion. Either way, it is optimal to induce $\dot{\tilde{U}} = 0$. Now, let $w^* \in [\underline{w}, \overline{w}]$ be some wealth threshold at which the wealth constraint binds; that is $w - T(w) \leq 0$. Then a straightforward intermediate value argument reveals that

$$[p_e(e,i)[\Delta + L] - 1] \frac{de}{d\beta(w)} + [p_i(e,i)[\Delta + L] - 1] \frac{di}{d\beta(w)} = 0 \; \forall \; w \in (w^*, \overline{w} \tag{6.86}$$

and

$$[p_e(e,i)[\Delta + L] - 1] \frac{de}{d\beta(w)} + [p_i(e,i)[\Delta + L] - 1] \frac{di}{d\beta(w)} - \frac{\vartheta(w)}{f(w)} \left\{ p_i(e,i)\Delta \frac{di}{d\beta(w)} + p(e,i)\Delta \right\} = 0 \; \forall \; w \in [\underline{w}, w^*].$$

The results of proposition 17 now follow immediately.■