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A Note on Organizational Design and the Optimal Allocation of Environmental Liability*

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Abstract

A multi-task principal-agent model is employed to derive optimal environmental liability rules for risk neutral managers under two alternative organizational structures: a functional organization and a product-based organization. For a product-based organization it is shown that efficiency is independent of whether the firm or managers are liable for environmental damages. In a functional organization it is optimal either to hold the firm liable for environmental damages or, equivalently, not to hold the production managers liable for environmental damages. We derive conditions to obtain the first-best solution for a given organizational structure. Finally, the organizational form that induces the highest environmental effort induces the lowest production effort and vice versa. This suggests that production and environmental protection are substitutes rather than complements.

Keywords: contracts, vicarious liability, multi-task, principal-agent, organizations
JEL classification: K3, L2, Q2

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1 Introduction

Corporations are becoming increasingly aware of the importance of corporate social responsibility (CSR) in maintaining and enhancing shareholder value. Within the array of CSR related activities, corporations' decision-making process towards environmental protection as a way of mitigating legal implications of environmental liability is a key issue (e.g., Kerr et al., 2009). From an organizational design perspective, the natural question that arises is how to optimally allocate environmental liability within the boundaries of a corporation. We address this question by examining the interaction between environmental liability and a corporation's organizational structure. By recognizing the importance of embedding environmental liability into a corporations' decision-making process, the aim of the paper is to shed light on this interaction. The paper demonstrates the tight interdependence between environmental liability and a corporation's organizational structure.

To investigate this interdependency, we employ a multi-task principal-agent (MTPA) framework, which serves as a natural way to study the interaction between incentives and behavior at corporate and managerial levels. In particular, we adopt and amend the model developed by Besanko et al. (2005), who make a distinction between a functional organization and a product-based organization. When a corporation is organized according to a functional design it consists of several *functional divisions*, such as production, research and development, marketing, finance, human resources, and environmental protection. In the case of a product-based design, the corporation is organized into *product lines*. To foster transparency, and without loss of generality, we assume that if a corporation has a functional design it features a simple two-divisional structure: one division taking care of production of the final good and the other division taking care of environmental protection. Both divisions affect the level of gross profits *and* the expected level of environmental damage.

We show that the choice of the organizational structure has implications for the optimal allocation of liability within the corporation. Following the case of risk averse managers, our analysis reveals that the allocation of liability between the firm and manager does not matter for efficiency in a product-based organization. The neutrality of the allocation of liability in a product-based organization is an extension of the neutrality proposition initially obtained by Kornhauser (1982) and Sykes (1984). This result is similar to the Coase (1960) theorem in the sense that in a world without transaction costs the initial allocation of property rights does not matter for inefficiency. Arlen and MacLeod (2005) have confirmed this in an applied analysis of care organizations. However, the neutrality proposition does not hold in a functional organization, implying that the allocation of liability *does* matter in the case of a firm organized into functional areas. We find that in a functional organization it is optimal either to hold the firm liable for environmental damages or, equivalently, not to hold the production managers liable for environmental damages.

Further, our analysis shows that there is a trade-off between environmental and production effort: the organizational set-up which induces the highest environmental effort induces the lowest production effort and vice versa. Thus, there is always a dominant function: either production or environmental protection. This implies that production effort and environmental effort are substitutes and do not interact in a complementary fashion.

The relevant literature in the environmental domain using a MTPA framework goes back to Gabel and Sinclair-Desgagné (1993, 1998). For instance, Gabel and Sinclair-Desgagné (1993) analyze the effect of monetary incentives on environmental risk-reducing activities within corporations. The emphasis of their analysis is twofold. First, they explicitly take into account that there are objective upper bounds to the amount of effort that can be undertaken by an individual agent. Second, they analyze how the accuracy of technology — used to monitor the effort levels — affects the optimal incentive schemes. We extend Gabel and Sinclair-Desgagné (1993) in two ways. First, we analyze the effects of environmental penalties on the organizational structure. Second, instead of incorporating the incentives exogenously into the model, we endogenously derive the incentives for environmental protection from the corporate's profit-maximizing behavior and assess how these incentives affect the corporation's functioning through the lens of the organizational structure.

A related strand of literature that use MTPA models assesses the relative efficiency of different penalty schemes; for example, civil liability of the corporation versus civil liability of individual managers, or criminal sanctions taken against individual managers. Seminal contributions in this tradition[1] are Kornhauser (1982) and Sykes (1984, 1988), whereas Segerson and Tietenberg (1992) offer a first application to the specific problem of environmental enforcement. MTPA has also been applied to job design issues (Holmstrom and Milgrom, 1991) and more recently to the study of incentives and allocation for teaching and research in universities (Gautier and Wauthy, 2007). Corts (2006) offers a more fundamental study examining the interplay between tasks and asset ownership. Further, the literature on vicar-

[1] See Kraakman (2000) for a review.

ious liability (Kornhauser, 1982, 1984) traditionally compares the efficiency of imposing civil liability on the principal rather than on the agent. Segerson and Tietenberg (1992) also consider the possibility of criminal sanctions imposed on managers. To foster transparency and clarity throughout the analysis, we concentrate here on the incentive structure and exclude the option of having criminal sanctions; we leave this as an area for further research.

Following Kornhauser (1982), we consider the case of strict liability and assume that in a product-based organization manager i pays a penalty that is equal to environmental damage caused by product i. In a functional organization, environmental damages are always a joint product of the environmental and the production manager's effort, even if there are no spillovers between product lines. If the legal system requires the courts to show *individual* causation in order to impose liability, then, of course, it is impossible to hold individual managers liable in a functional organization (see Kornhauser, 1982). However, as our purpose is to determine how different possible rules affect the organizational structure, we presume that in a functional organization all managers are held jointly liable. This means that, in our situation of two functional areas, each manager pays a fine that is proportional to total damage, with the sum of the fines equal to total environmental damage.[2] This exact allocation of liability between the two managers will be treated as exogenous in a first stage. However, we will show below that either this allocation does not matter or that the environmental manager should bear the *complete* burden of liability.

The structure of the paper is as follows. Section 2 outlines the basic model and examines the distinctive features of a product-based and a functional organization. In Section 3 we solve and analyze the model for both the functional and product-based organizational structure. Section 4 concludes.

2 The model

The basic setup of the underlying model is inspired by Besanko et al. (2005). Consider a firm that consists of a risk-neutral owner and two risk-averse managers. The firm sells two products: 1 and 2. There are two functional areas: environmental protection E and production P. Production should be seen here as a proxy for all non-environmentally related functional areas. For product $i = 1, 2$, denote e_i and p_i as the effort levels the managers

[2] Without this last assumption, for equal environmental damages the *total* amount of fines paid under the two organizational structures would then be different. Therefore, this assumption allows us to isolate any possible effect in this respect.

expend on functions E and P respectively. In a functional organization e_i is the effort of the environmental manager to reduce the emissions of product i; in a product-based organization e_i is the effort of the manager that is responsible for product line i to reduce the emissions associated with his product. A similar intuition applies to p_i. Whereas it expresses the effort of the production manager to manufacture product i in a functional organization, in a product-based organization p_i represents the effort of the manager that is responsible for product line i to manufacture his product. The effort levels are endogenous and cannot be verified by outside parties. Therefore, they cannot form the basis for enforceable contracts.

Let $z_i^T = (p_i, e_i)$ (with $i = 1, 2$) and $v_i^T = (i_1, i_2)$ (with $i = e, p$) denote the effort vectors in a product-based and functional organization respectively. It is assumed that the disutility of effort for a divisional manager in a product-based organization is given by $C_i(z_i)$; in case of a functional organization the disutility of effort is $C_i(v_i)$. That is, the product manager must decide how to allocate effort between the two products while the functional manager must decide how to allocate effort between the two functional tasks. It is assumed there are "diseconomies of span" when a manager has to split his time and attention between different tasks, and these diseconomies of span are the extra costs as a result of this (Besanko et al., 2005). The size of these costs are measured by the cross-partials $\frac{\partial C_i(z_i)}{\partial p_i \partial e_i}$, $\frac{\partial C_i(v_i)}{\partial e_i \partial e_j}$ and $\frac{\partial C_i(v_i)}{\partial p_i \partial p_j}$. To avoid any prior bias in favour of one of the possible organizational structures, we assume that the cost of effort does not depend on the type of task to which it is allocated, but only on the amount of effort.

Assuming perfect symmetry, these effort levels have two results. First, profits before wages and environmental penalties are:[3]

$$\pi_i = \pi_i(p_i, e_i, p_j, e_j) \qquad i = 1, 2 \qquad i \neq j \tag{1}$$

with $\frac{\partial \pi_i(\cdot)}{\partial p_i} > 0$ and $\frac{\partial \pi_i(\cdot)}{\partial e_i} < 0$. The latter term expresses the idea that environmental protection leads to changes in the production process (e.g., the purchase of abatement equipment) that increase production costs in the short run. No assumptions are made with respect to the sign of the spillover effects, $\frac{\partial \pi_i(.)}{\partial p_j}$ and $\frac{\partial \pi_i(.)}{\partial e_j}$. For instance, these spillover effects could capture the idea that marketing and R&D efforts expended on behalf of one product can often benefit the firm's other products as well (Besanko et al., 2005). Alternatively, this formulation allows for individual managers to undertake "sabotage" actions against other

[3] From now on we will refer to this as *gross* profits.

managers if there are conflicts of interests between the different departments. Furthermore, it is assumed that profits (1) can be measured without noise.

Environmental damage, D, from manufacturing product i read as:

$$D_i = D_i\left(p_i, e_i, p_j, e_j\right), \qquad i = 1, 2 \qquad i \neq j \tag{2}$$

where $\frac{\partial D_i(\cdot)}{\partial p_i} > 0$ and $\frac{\partial D_i(\cdot)}{\partial e_i} < 0$. As with profits, we also make no prior assumptions with respect to the signs of the spillover effects. Equations (1) and (2) are based on the assumption that the link between effort on the one hand, and profits and environmental damages on the other hand, does not depend on the organizational structure of the firm, i.e., a given vector of effort allocations will result in the same gross profits or environmental damages, whatever the organizational structure. While this may seem a restrictive assumption, this is the only way to isolate how different organizational structures affect the cost of effort undertaken by the managers on the one hand, and the risk incurred by these managers on the other hand.

Now several possibilities exist. First, suppose that the environmental regulator observes the following verifiable sign of environmental quality $\tilde{D}$ linked to product i:

$$\tilde{D}_i = D_i + \tilde{\varepsilon}_i, \qquad i = 1, 2 \tag{3}$$

where the measurement error $\tilde{\varepsilon}_i$ has zero mean and $(\tilde{\varepsilon}_1, \tilde{\varepsilon}_2)$ follows a bivariate normal distribution with the following variance-covariance matrix:

$$\Omega_D = \begin{pmatrix} \sigma_D^2 & s\sigma_D^2 \\ s\sigma_D^2 & \sigma_D^2 \end{pmatrix}. \tag{4}$$

The term σ_D^2 is the variance of measured environmental quality and $s \in [-1, 1]$ is the correlation between product-line environmental damages. This formulation with two identifiable signals makes sense if the two products are produced on different locations or lead to emissions of different pollutants. The term $s \neq 0$ then expresses that the noise in the measurement of these signals is correlated, possibly because the signals are measured by the same type of equipment or by the same inspectors.[4] Further, following Besanko et al. (2005), we assume that it is impossible to identify the contributions of the functional areas.

Let us next move to the incentives within the firm. In a seminal paper, Holmstrom (1979) showed that incentive schemes should incorporate all signals that allow to reduce the

[4] If the two products are produced on the same location and lead to the emission of the same pollutants, then the environmental regulator can only measure a signal of *total* environmental damages $\tilde{D}_{tot} = \sum_{i=1,2} D_i + \tilde{\varepsilon}_i$. However, considering this case is beyond the scope of the current paper.

noise in the measurement of an agent's effort levels. Our model captures four performance measurements: product-line profits and observed environmental performance, i.e., $\pi_1, \pi_2, \tilde{D}_1$ and $\tilde{D}_2$. As commonly done in the literature (for a seminal justification, see Holmstrom and Milgrom,1987), we will restrict the compensation packages that are provided by the firm to be linear functions of these variables. Somewhat less conventional, the incentive schemes will be limited to a subset of these variables. Indeed, it can be verified that a contract which depends on all these variables simultaneously is always overdetermined, both in a functional and in a product-based organization. This implies that there are redundancies in the information provided by these signals, which is not surprising taking into account that with spillover effects there are reciprocal externalities between the managers. Hence, compensation of product managers is only linked to the performance in their own generated *product*. Similarly, compensating functional managers is only linked to performance in their own *field*. In other words, the job title of each manager corresponds to the particular vector of performance signals the firm holds him responsible for. We will argue below that it is not possible to improve upon these schemes.

If the contributions of individual products to pollution can be observed and in case strict liability is imposed on the managers, total wages $\tilde{W}_i$ received by the manager of product division $i = 1, 2$ read as:

$$\tilde{W}_i = a_{i0} + (\pi_i; \tilde{D}_i)a_i - \tilde{D}_i, \tag{5a}$$

where a_{i0} is a constant and $a_i^T \equiv (a_{\pi_i}, a_{D_i})$ representing the payment schedule for a product division. Strict liability implies that $\tilde{D}_i$ is also the penalty schedule imposed by the regulator on manager i. If the firm adopts a functional organization, payments read:

$$\begin{aligned} \tilde{W}_e &= \alpha_{e0} + \tilde{D}^T \alpha_e - \psi_e(\tilde{D}_1 + \tilde{D}_2), & \text{(5b)} \\ \tilde{W}_p &= \alpha_{p0} + \pi^T \alpha_p - \psi_p(\tilde{D}_1 + \tilde{D}_2), & \text{(5c)} \end{aligned}$$

where α_{e0} and α_{p0} are constants, $\alpha_e^T \equiv (\alpha_{D_1}, \alpha_{D_2})$ represents the payment schedule for an environmental division and $\alpha_p^T \equiv (\alpha_{\pi_1}, \alpha_{\pi_2})$ is the payment schedule for a production division, while $\pi^T \equiv (\pi_1, \pi_2)$ and $\tilde{D}^T \equiv (\tilde{D}_1, \tilde{D}_2)$. Finally, $\psi_i(\tilde{D}_1 + \tilde{D}_2)$ denotes the penalty schedule imposed by the regulator on manager i in a functional organization, with $\psi_e + \psi_p = 1$.

The expected utility for manager i can be written as:

$$EU_i \equiv E(\tilde{W}_i) - \frac{1}{2}\rho Var(\tilde{W}_i) - C_i(\cdot), \tag{6}$$

where $\rho > 0$ represents the manager's degree of risk aversion, which is assumed to be constant and the same for all managers. For notational convenience, let $W \equiv \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix}$, $u \equiv \begin{pmatrix} 1 \\ 1 \end{pmatrix}$ and $v \equiv \begin{pmatrix} 0 \\ 1 \end{pmatrix}$. Taking into account that the only non-deterministic component of the manager's utility function is environmental damage, it is straightforward to verify that the variances of the compensation schemes $\tilde{W}_i$ are equal to:

$$Var(\tilde{W}_i) = \sigma_D^2(1 + a_i^T W a_i - 2a_i^T v), \tag{7a}$$

$$Var(\tilde{W}_e) = \alpha_e^T \Omega_D \alpha_e + 2(1+s)\psi_e^2\sigma_D^2 - 2(1+s)\psi_e\sigma_D^2\alpha_e^T u, \tag{7b}$$

$$Var(\tilde{W}_p) = 2(1+s)\psi_p^2\sigma_D^2. \tag{7c}$$

Manager i's expected utility, as expressed by (6), can now explicitly be specified for the two distinguished organizational structures. Substituting (5a) and (7a) into (6), the expected utility for managers in a product-based organization reads as expected wages minus the expected liability payments, minus the risk premium, and minus the disutility of effort:

$$EU_i = a_{i0} + (\pi_i(z_i, z_j); D_i(z_i, z_j))^T\, a_i - D_i(z_i, z_j) - \frac{\rho}{2}\sigma_D^2(1 + a_i^T W a_i - 2a_i^T v) - C_i(z_i) \quad i \neq j$$

The expected utilities of managers that are engaged in a firm with a functional structure can be derived in the same way. That is,

$$\begin{aligned} EU_e &= \alpha_{e0} + (D_1(v_E, v_P); D_2(v_E, v_P))^T\, \alpha_e - \psi_e\left(\sum_{i\in 1,2} D_i(v_E, v_P)\right) \\ &\quad -\frac{\rho}{2}\left(\alpha_e^T\Omega_D\alpha_e + 2(1+s)\psi_e^2\sigma_D^2 - 2(1+s)\psi_e\sigma_D^2\alpha_e^T u\right) - C(v_e), \end{aligned} \tag{8a}$$

$$\begin{aligned} EU_p &= \alpha_{p0} + (\pi_1(v_E, v_P); \pi_2(v_E, v_P))^T\, \alpha_p - \psi_p\left(\sum_{i\in 1,2} D_i(v_E, v_P)\right) \\ &\quad -\rho(1+s)\psi_p^2\sigma_D^2 - C(v_p). \end{aligned} \tag{8b}$$

Following Besanko et al. (2005), we normalize the managers' reservation utility to zero. The intercept of the compensation schemes can then be used to satisfy the participation constraint.[5] In that case, the owner's objective is to maximize total surplus, i.e. profits

[5] Note that the participation constraint is expressed in *expected* terms. This means that there is no guarantee that the managers will obtain their reservation utility for *all* possible realizations of the stochastic variable. This implies that it is possible that — for some realizations of the stochastic variable — the managers will have to make a financial transfer to the firm (rather than the other way around) and that this transfer exceeds their assets. With imperfect capital markets the managers might not be able to borrow against their future wages and file for bankruptcy (or with imperfect insurance markets they will not be able to insure themselves against extreme contingencies).

minus risk premium, minus disutility of effort, minus penalties imposed on the managers, subject to the incentive compatibility (IC) constraints.

In case of a product-based organization, the IC constraint for $i = 1, 2$ is:

$$(Q_i; S_i)\, a_i - S_i = C_i, \tag{9}$$

where $Q_i = \begin{pmatrix} \frac{\partial \pi_i}{\partial p_i} \\ \frac{\partial \pi_i}{\partial e_i} \end{pmatrix}$, $S_i = \begin{pmatrix} \frac{\partial D_i}{\partial p_i} \\ \frac{\partial D_i}{\partial e_i} \end{pmatrix}$ and $C_i = \begin{pmatrix} \frac{\partial C_i}{\partial p_i} \\ \frac{\partial C_i}{\partial e_i} \end{pmatrix}$.

Under a functional organizational structure the IC constraint for $i = e, p$ is:

$$T_e \alpha_e - \psi_e T_e u = C_e, \tag{10a}$$

$$R_p \alpha_p - \psi_p T_p u = C_p. \tag{10b}$$

with $T_e = \begin{pmatrix} \frac{\partial D_i}{\partial e_i} & \frac{\partial D_j}{\partial e_i} \\ \frac{\partial D_i}{\partial e_j} & \frac{\partial D_j}{\partial e_j} \end{pmatrix}$, $T_p = \begin{pmatrix} \frac{\partial D_i}{\partial p_i} & \frac{\partial D_j}{\partial p_i} \\ \frac{\partial D_i}{\partial p_j} & \frac{\partial D_j}{\partial p_j} \end{pmatrix}$, and $R_p = \begin{pmatrix} \frac{\partial \pi_i}{\partial p_i} & \frac{\partial \pi_j}{\partial p_i} \\ \frac{\partial \pi_i}{\partial p_j} & \frac{\partial \pi_j}{\partial p_j} \end{pmatrix}$. Also, $C_e = \begin{pmatrix} \frac{\partial C_i}{\partial e_i} \\ \frac{\partial C_i}{\partial e_j} \end{pmatrix}$ and $C_p = \begin{pmatrix} \frac{\partial C_i}{\partial p_i} \\ \frac{\partial C_i}{\partial p_j} \end{pmatrix}$. We have now completed the full description of the model. Next we will examine how the various conditions apply to the two organizational regimes and analyze and compare the organizational structures assuming managers are risk-averse.

3 Analysis of organizational structures

3.1 Product-based organization

In a product-based organization the owner of the firm maximizes

$$\Pi^{prod} = \sum_{i=1,2; i \neq j} \left[\pi_i(z_i, z_j) - D_i(z_i, z_j) - C_i(z_i) - \frac{\rho}{2} Var(\tilde{W}_i) \right] \tag{11}$$

subject to the IC constraints (9). Straightforward calculations and rearranging terms lead to the following explicit solution for (9):

$$a_{\pi_i} = \frac{\frac{\partial D_i}{\partial e_i}\frac{\partial C_i}{\partial p_i} - \frac{\partial D_i}{\partial p_i}\frac{\partial C_i}{\partial e_i}}{\frac{\partial \pi_i}{\partial p_i}\frac{\partial D_i}{\partial e_i} - \frac{\partial \pi_i}{\partial e_i}\frac{\partial D_i}{\partial p_i}}, \tag{12a}$$

$$a_{D_i} = \frac{\frac{\partial \pi_i}{\partial p_i}\frac{\partial C_i}{\partial e_i} - \frac{\partial \pi_i}{\partial e_i}\frac{\partial C_i}{\partial p_i}}{\frac{\partial \pi_i}{\partial e_i}\frac{\partial D_i}{\partial p_i} - \frac{\partial \pi_i}{\partial p_i}\frac{\partial D_i}{\partial e_i}}. \tag{12b}$$

Substituting these expressions back into (7a) one obtains:

$$Var(\tilde{W}_i) = \left(\frac{\frac{\partial \pi_i}{\partial e_i}\frac{\partial C_i}{\partial p_i} - \frac{\partial \pi_i}{\partial p_i}\frac{\partial C_i}{\partial e_i}}{\frac{\partial \pi_i}{\partial p_i}\frac{\partial D_i}{\partial e_i} - \frac{\partial \pi_i}{\partial e_i}\frac{\partial D_i}{\partial p_i}} \right)^2. \tag{13}$$

It is now straightforward to verify that a product-based organization would lead to exactly the same profits if the environmental fines were imposed directly on the firm. To see this note that if the fines are imposed on the firm, the IC constraint becomes $(Q_i; S_i)\, a_i = C_i$. Then solving for a_{π_i} and a_{D_i}, and substituting back into (7a), leads again to (12). Also, total surplus for given effort levels is the same as when the fines are imposed on the managers. We can subsequently conclude that the optimization problem is the same under both regimes. Thus even without solving the model explicitly for optimal effort levels, we obtain that the managers' risk aversion is not an argument against holding them liable rather than the firm. In other words, who has to pay the fines does not affect how risk is shared between the firm and its managers. This confirms the neutrality proposition we announced in Section 1. That is, the allocation of liability between principal and agents does not matter with costless contracting and solvent agents (Kornhauser, 1982; Sykes, 1984; Arlen and MacLeod, 2005).[6]

Proposition 1 *In a product-based organization, efficiency does not depend on whether environmental liability is imposed on the firms or on the managers if managers are solvent.*

We can now determine the optimal effort levels. By substituting the IC constraints in (11) one obtains the first-order conditions for the optimal effort levels:

$$Q_i - S_i + Q_j - S_j - C_i - \frac{\rho}{2}\,(K_i + K_j) = 0, \tag{14}$$

where $K_i = \begin{pmatrix} \frac{\partial Var(\tilde{W}_i)}{\partial p_i} \\ \frac{\partial Var(\tilde{W}_i)}{\partial e_i} \end{pmatrix}$ and $K_j = \begin{pmatrix} \frac{\partial Var(\tilde{W}_j)}{\partial p_i} \\ \frac{\partial Var(\tilde{W}_j)}{\partial e_i} \end{pmatrix}$. If the managers pay the fines, then (14) and (9) imply that their wages are given by:

$$a_i = (Q_i + S_i)^{-1} \left(Q_i + Q_j - S_j - \frac{\rho}{2}\,(K_i + K_j) \right). \tag{15}$$

Alternatively, if the firm pays the fines, then (14) and the fact that the IC constraint equals $(Q_i; S_i)\, a_i = C_i$, the managers' wages are given by:

$$a_i = (Q_i + S_i)^{-1} \left(Q_i + Q_j - S_j - S_i - \frac{\rho}{2}\,(K_i + K_j) \right). \tag{16}$$

From (15) and (16) we see that the cross partial derivatives cancel out. This implies that diseconomies of span does not affect the optimal incentive scheme, although it does affect the optimal effort levels. The reason is that diseconomies of span affect the firm's and the manager's objective function in exactly the same way.

[6] In reality a firm's assets will typically be larger than that of a manager and a firm will therefore generally be able to afford higher monetary penalties than an individual manager.

3.2 Functional organization

In a functional organization where the managers pay the fines total surplus reads:

$$\begin{aligned}\Pi^{func} &= \pi_1(v_e,v_p)+\pi_2(v_e,v_p)-(D_1(v_e,v_p)+D_2(v_e,v_p)) \\ &\quad -C(v_e)-C(v_p)-\frac{\rho}{2}(\alpha_e^T\Omega_D\alpha_e+2(1+s)\psi_e^2\sigma_D^2 \\ &\quad -2(1+s)\psi_e\sigma_D^2\alpha_e^Tu)-\rho(1+s)\psi_p^2\sigma_D^2,\end{aligned} \tag{17}$$

which is to be maximized subject to the IC constraints (10a) and (10b), and with $\sum_{i=e,p}\psi_i = 1$. As for the product-based organization, one can determine the wages and variances that will induce a given effort vector. That is, solving (10a) for α_e, we obtain:

$$\alpha_{Di} = \frac{\frac{\partial D_j}{\partial e_j}\left(\frac{\partial C_i}{\partial e_i}+\psi_e\frac{\partial D_i+D_j}{\partial e_i}\right)-\frac{\partial D_j}{\partial e_i}\left(\frac{\partial C_i}{\partial e_j}+\psi_e\frac{\partial D_i+D_j}{\partial e_j}\right)}{\frac{\partial D_i}{\partial e_i}\frac{\partial D_j}{\partial e_j}-\frac{\partial D_i}{\partial e_j}\frac{\partial D_j}{\partial e_i}}. \tag{18}$$

Substitution of this expression in (7b) yields the following expression for the variance of the environmental manager's wages:

$$Var(\tilde{W}_e) = \left(\frac{\frac{\partial D_j}{\partial e_j}\left(\frac{\partial C}{\partial e_i}+\psi_e\frac{\partial D_j}{\partial e_i}\right)-\frac{\partial D_j}{\partial e_i}\left(\frac{\partial C}{\partial e_j}+\psi_e\frac{\partial D_j}{\partial e_j}\right)}{\frac{\partial D_i}{\partial e_i}\frac{\partial D_j}{\partial e_j}-\frac{\partial D_i}{\partial e_j}\frac{\partial D_j}{\partial e_i}}\right)^2. \tag{19}$$

In a symmetric equilibrium, $\frac{\partial D_j}{\partial e_i}=\frac{\partial D_i}{\partial e_j}$ and $\frac{\partial D_i}{\partial e_i}=\frac{\partial D_j}{\partial e_j}$. The variance expression then further simplifies to:

$$Var(\tilde{W}_e) = \left(\frac{\frac{\partial C}{\partial e_i}}{\frac{\partial D_i}{\partial e_i}+\frac{\partial D_j}{\partial e_i}}\right)^2. \tag{20}$$

Now suppose that fines are imposed directly onto the firm instead of onto the managers. The only stochastic component in the wages is now the incentives provided to the environmental manager. The variance of the environmental manager's wage then reduces to $\alpha_e^T\Omega_D\alpha_e$, whereas the production manager's wage is now deterministic. Consequently, the firm's objective function becomes:

$$\begin{aligned}\Pi^{func} &= \pi_1(v_e,v_p)+\pi_2(v_e,v_p)-(D_1(v_e,v_p)+D_2(v_e,v_p)) \\ &\quad -C(v_e)-C(v_p)-\frac{\rho}{2}\alpha_e^T\Omega_D\alpha_e.\end{aligned} \tag{21}$$

The IC constraint of the environmental manager reduces to $T_e\alpha_e = C_e$, whereas the IC constraint for the production manager reduces to $R_p\alpha_p = C_p$. Substitution of α_e in $\alpha_e^T\Omega_D\alpha_e$ shows that the variance of the environmental manager's income is the same, irrespective of whether the fine is paid by the firm or by him. As the production manager's income is deterministic under a functional organization, we can conclude that:[7]

Proposition 2 *The neutrality proposition does not hold in a functional organization. However, if no liability is imposed onto the production manager or if the production manager is risk-neutral, then it does not matter whether the firm or the environmental manager pays the fine.*

Let us now determine the optimal effort levels if the environmental manager pays the fine. After substitution of the IC constraints into the firm's objective function, the first-order condition for the effort levels of the environmental manager is given by

$$\left(R_e - T_e - \frac{\rho}{2} M_e\right) u = C_e, \tag{22}$$

where $R_e = \begin{pmatrix} \frac{\partial \pi_i}{\partial e_i} & \frac{\partial \pi_i}{\partial e_j} \\ \frac{\partial \pi_i}{\partial e_j} & \frac{\partial \pi_i}{\partial e_i} \end{pmatrix}$ and $M_e = \begin{pmatrix} \frac{\partial Var(\tilde{W}_e)}{\partial e_i} \\ \frac{\partial Var(\tilde{W}_e)}{\partial e_j} \end{pmatrix}$. The first-order condition for the effort levels for the production manager are given by

$$\left(R_p - T_p\right) u = C_p. \tag{23}$$

Above we argued that the risk imposed on the production manager is independent of the incentive scheme received by the firm but only on the risk imposed by the environmental fines. Equation (23) shows that the fines do not affect the first-order condition for efficiency, and they should therefore not affect incentives either. However, if such a situation applies, the only effect of the fines is that they impose a risk on the production manager, without incentive effect. Therefore, they are a deadweight loss. Hence, it is socially optimal to set the penalty on the production manager equal to zero ($\psi_p = 0$). In that case, as in a product-based organization, the neutrality proposition again holds. From (22) we see that the environmental manager optimally allocates his effort equally between the two product lines, which confirms that we have perfect symmetry.

The main result when managers are risk-neutral is straightforward. In that case $\rho = 0$, implying that the ICs are not binding. Hence the first-best allocation of effort (given the chosen organizational structure) is always obtained. This result is less obvious than it may seem. After all, the regulator's liability schemes do not take into account the existence of

[7] At least if there is no upper bound to the amounts that can be imposed on individual managers.

spillover effects inside the firm. However, so long as the firm's owner knows the spillover effects the first-best solution can be obtained, i.e., the firm's owner can compensate for any misallocation induced by the liability rule imposed by the regulator. Moreover, there is no need for the firm to monitor effort levels. As a final comparison let us look at the effort levels under the two organizational structures.

3.3 Organizational comparison by effort levels

Recall that the optimal marginal costs of effort under a product-based organization are described by (14) and the optimal marginal effort costs under a functional organization are determined by (22) and (23). Suppose that the marginal effects of effort on gross profits and environmental damages are constant. Equations (14), (22) and (23) then imply that production (environmental) effort is higher (lower) under a product-based organization if and only if: $\frac{\partial \pi_i + \pi_j - D_j - D_i}{\partial p_i} > \frac{\partial \pi_i + \pi_j - D_j - D_i}{\partial e_j}$. Using the terminology of Besanko et al. [2], production is the dominant function if for all levels of p_i and e_i this latter inequality holds. That is, a unit increase in production effort always has a higher impact on gross profits minus environmental fines than a unit increase in environmental effort. Otherwise, it is environmental protection. Consequently one straightforwardly derives the following:

Proposition 3 *Suppose that the marginal effects of effort on gross profits and environmental damages are constant. If, after the introduction of environmental fines, production is the dominant function, then production effort is higher under a product-based organization than under a functional organization. If, after the introduction of environmental fines, environmental protection is the dominant function, then environmental protection is higher under a product-based organization than under a functional organization. The organizational form that induces the highest environmental effort induces the lowest production effort and vice versa.*

The results above imply that there is always a dominant function in our model. Proposition 3 is then completely compatible with the observation of Besanko et al. [2, p. 458] that 'if there is a dominant function, effort costs tend to be higher in a functional organization.' However, it is unclear how this result could be generalized to a situation where the marginal effects are not constant.

4 Conclusions

This paper employs a multi-task principal-agent model to examine how different liability rules for environmental damages affect the incentive schemes offered to individual managers. These schemes depend on the managers' contributions to profits and their effects on negative externalities through environmental damages caused by production. The schemes are evaluated both for a product-based and a functional organization. In the former case, a firm is divided into product lines, whereas in case of a functional organization the firm is organized as a collection of different functional departments, in our case a production and an environmental department. we show how these liability rules affect the choice between the two organizational modes.

For a product-based organization it is shown that if managers do not face a limited liability scheme, efficiency is independent of who is liable for environmental damages, i.e., either the firm or the managers. In a functional organization, however, it is optimal either to hold the firm liable for environmental damages or, equivalently, not to hold the production managers liable for environmental damages. That is, the fines imposed on the production manager only affect expected profits without affecting the incentives.

If the marginal effects of effort on gross profits and environmental damages are constant, then it is also possible to compare the effort levels under the two organizational structures. It turns out that environmental protection is higher under a product-based organization if it becomes the dominant function after the introduction of environmental taxes. If production is the dominant function after the introduction of environmental taxes, then production effort will be higher in a product-based organization than in a functional organization. In sum, the organizational form that induces the highest environmental effort induces the lowest production effort, and vice versa. This suggests that production and environmental protection are substitutes rather than complements.

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