Environmental Liability and Organizational Structure

Laurent Franckx \textsuperscript{a,*} \hspace{1em} Frans P. de Vries \textsuperscript{b †}

\textsuperscript{a}Department of Economics, Royal Military Academy, Belgium
\textsuperscript{b}Department of Economics and CentER, Tilburg University, The Netherlands

Abstract

This paper presents a multitask principal-agent model to examine how environmental liability rules for individual managers within a corporate hierarchy affect, on the one hand, the incentive schemes the organization provides and, on the other hand, the choice between a functional or a product-based organizational structure. If managers are risk neutral, a product-based organization dominates a functional organization and allows to obtain first-best effort level. If, moreover, there are no diseconomies of span, both organizational forms are equivalent. With risk averse managers, we identify under which conditions it does not matter who is held liable for environmental damages.

Keywords: contracts, liability, firm structure, principal-agent

JEL-codes: K3; L2; Q2
1 Introduction

Internalization of negative externalities caused by the production of goods and services has predominantly been investigated within the standard neoclassical framework. Fundamental in neoclassical theory is that the firm is viewed as a single decision maker and as such is treated as a “black box”. That is, decisions that are made at the corporate and subsequent the lower managerial levels are treated as if taken and implemented by a single agent. However, most of the economic activities still take place within the boundaries of organizations (Stiglitz [23]). An emphasis on environmental policy at the corporate level would therefore complement the many studies that have been conducted within neoclassical theory.

A natural way to study this is by employing a (multi-task) principal-agent framework. A first issue that has been investigated using such a framework is the relative efficiency of different penalty schemes (civil liability of the corporation versus civil liability of individual managers, criminal sanctions taken against individual managers). To the best of our knowledge, Kornhauser [14] and Sykes [24, 25] are the seminal papers in this tradition (see Kraakman [8] for a recent literature review on this issue), while Segerson and Tietenberg [20] offer a first application to the specific problem of environmental enforcement.

A second issue is the allocation of environmental resources within the corporate boundaries, which has been initiated by Gabel and Sinclair-Desgagné [9, 10]. For instance, Gabel and Sinclair-Desgagné [9] examine the effect of monetary incentives within corporations on environmental risk reducing activities using a multi-tasking principal-agent model. 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.
In this paper we also make use of a multi-task principal-agent model. However, in addition to focusing on the inducement of behavior as in Gabel and Sinclair-Desgagné [9] and Segerson and Tietenberg [20], the question we want to answer is how the incentives affect the organizational structure of the corporation. To do so, we adopt the model of Besanko et al. [2], who make a distinction between a functional organization and a product-based organization. When a corporation is organized in a functional mode, it consists of several functional departments (e.g., production, R&D, marketing, finance, personnel, and environmental protection), whereas a corporation is organized into product lines in case of a product-based organization.

It is assumed that, if a corporation chooses a functional structure, then it features a simple structure with just two departments: one department taking care of production (and marketing and finance) of the final good; the other taking care of environmental protection. These two actions lead to a certain level of gross profits and a certain amount of expected environmental damages. The CEO’s of the corporation can develop an incentive scheme for both departments, but cannot perfectly monitor the individual managers’ effort levels. However, as proposed by Gabel and Sinclair-Desgagné [9], they can observe a signal that is imperfectly correlated with environmental performance.

The contribution of our paper is twofold. First, we provide an analysis of the effects of environmental penalties on organizational structure, which was identified as a future research need by Gabel and Sinclair-Desgagné [9]. Second, contrary to [9], we do not consider the firm’s wish to provide incentives for environmental protection as exogenous, but we derive this from profit maximizing behavior by the firm. The relationship between environmental performance and profits is determined by the different civil liability rules to which the firm is subjected, as in Segerson and Tietenberg [20] — in this sense, our analysis also complements this strand of literature.
The structure of the paper is as follows. Section 2 outlines the basic modeling framework and features the explicit distinction between a product-based and functional organization under the assumption of risk averse managers. We analyze the specific situation of risk neutral managers in Section 3. Section 4 considers the special cases of zero spillover effects and absence of diseconomies of span, assuming that managers are risk averse. Conclusions and directions for future research are given in Section 5.

2 The model

2.1 Introduction

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 \( P \).\(^1\) For product \( i = 1, 2 \), denote \( e_i \) and \( p_i \) as the effort levels expended on functions \( E \) and \( P \) respectively. Assuming perfect symmetry, these effort levels have two results. First, profits before wages and environmental penalties, are\(^2\):

\[
\pi_i = \beta p_i + \gamma e_i + \theta \beta p_j + \xi \gamma e_j, \quad i = 1, 2 \text{ and } i \neq j
\]

where \( \beta > 0 \) and \( \gamma < 0 \). No assumptions are made with respect to the sign of the spillover coefficients \( \theta \) and \( \xi \). Moreover, assume that profits can be measured without noise.\(^3\)

Second, environmental damages \( D \) due to product \( i \) are:

\[
D_i = bp_i + ge_i + vb p_j + w ge_j, \quad i = 1, 2 \text{ and } i \neq j
\]

where \( b > 0 \) and \( g < 0 \). Like with profits, we make no prior assumptions with respect to the signs of the spillover coefficients \( v \) and \( w \). Now several possibilities exist. Suppose first that

\(^1\)Production should be seen here as a proxy for all non-environmental related functional areas.

\(^2\)From now on we shall call this “gross profits”.

\(^3\)One could also argue that \( \gamma > 0 \). For instance, profits could increase due to improvements in material usage and energy efficiency of the production process, i.e. the Porter hypothesis (e.g., [17], [18], [19]). However, Porter’s story is basically a dynamic one. Due to intensified environmental innovative activities (a higher environmental effort level), firm profits could go up in the future. Our story is, in essence, static. No dynamic considerations about future profits are included; only current levels are investigated. Therefore, our focus is on the short run assuming \( \gamma < 0 \), i.e., we follow the path that more environmental effort adversely affects short run profits.
the environmental regulator generates the following verifiable sign of environmental quality $\tilde{D}$ linked to product $i$:

$$\tilde{D}_i = D_i + \tilde{\varepsilon}_i, \quad i = 1, 2$$

(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:

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

(4)

Here $\sigma_D^2$ is the variance of measured environmental quality and $s \in [-1, 1]$ is the correlation between measured product-line environmental damages. This formulation makes sense if the two products are produced on different locations or lead to emissions of different pollutants.

However, 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

$$\tilde{D}_{tot} = \sum_{i=1,2} D_i + \tilde{\varepsilon}_i.$$ 

(5)

We shall not consider this possibility here, but it is left for future research. Following Besanko et. al. [2], we assume that it is impossible to identify the contributions of the functional areas. In order to simplify the analysis a bit, we directly concentrate on the different penalty schemes as proposed by Segerson and Tietenberg [20]. They consider the following instruments: monetary penalties imposed on the firm, monetary penalties imposed on the manager and criminal sanctions imposed on the managers.

Throughout this paper, we shall focus on the situation where monetary penalties are imposed directly on the managers. Therefore, in the case of a product-based organization, we assume that manager $i$ pays a penalty that is equal to environmental damage caused by product $i$. In the case of a functional organization, we suppose all managers are held jointly
liable. This means that in our situation of two functional areas, the two managers pay a fine that is proportional to total damage with the sum of the fines equal to total environmental damage.\footnote{If we would not introduce this last assumption, then, for equal environmental damages, the total fines paid under the two organizational structures would be different. This assumption therefore allows to isolate any possible effect in this sense.} In order to allow a comparison with Segerson and Tietenberg \cite{20}, we shall verify these results with what happens when the penalties are imposed directly on the firm rather than on individual managers. The study of criminal sanctions is left as an area for further research.

Let us finally move to the incentives provided within the firm. In a classic paper, Holmstrom \cite{11} has shown that incentive schemes should incorporate all signals that allow to reduce the noise in the measurement of an agent’s effort levels. In this model, there are four performance measurements: product-line profits and observed environmental performance \((\pi_1, \pi_2, \tilde{D}_1, \tilde{D}_2)\). We will restrict the compensation packages provided by the firm to be linear functions of these variables.\footnote{This assumption may seem restrictive – see however Holmstrom and Milgrom ~\cite{12} for a classic justification.} Moreover, it can be verified that a contract that depends on all these variables simultaneously is always overdetermined, both in a functional and in a product-based organization - this shows that there are redundancies in the information provided by these signals. Therefore, compensation of product managers is only linked to the performance in their own generated product. Similarly, compensation of functional managers is only linked to performance in their own field. We shall argue below that it is not possible to improve on these schemes.

If the contributions of individual products to pollution can be observed, total wages \(\bar{W}_i\) received by the manager of product division \(i = 1, 2\) is:

\[
\bar{W}_i = a_{i0} + (\pi_i; \tilde{D}_i) a_i - \tilde{D}_i,
\]

(6a)

where \(a_{i0}\) is a constant, \(a_i^T \equiv (a_{\pi_i}, a_{D_i})\) represents the payment schedule for a product division.
and $\tilde{D}_i$ is the penalty schedule imposed by the regulator on manager $i$.

If the firm adopts a functional organization, payments are:

$$\tilde{W}_e = \alpha_{e0} + \tilde{D}^T \alpha_e - \psi_e(\tilde{D}_1 + \tilde{D}_2),$$  \hspace{1cm} (6b)  

$$\tilde{W}_p = \alpha_{p0} + \pi^T \alpha_p - \psi_p(\tilde{D}_1 + \tilde{D}_2),$$  \hspace{1cm} (6c)

where $\alpha_{e0}$ and $\alpha_{p0}$ are constants, $\alpha^T_e \equiv (\alpha_{D1}, \alpha_{D2})$ represents the payment schedule for an environmental division and $\alpha^T_p \equiv (\alpha_{\pi1}, \alpha_{\pi2})$ is the payment schedule for a production division, while $\pi^T \equiv (\pi_1, \pi_2)$ and $\tilde{D}^T \equiv (\tilde{D}_1, \tilde{D}_2)$. $\psi_i(\tilde{D}_1 + \tilde{D}_2)$ denotes the penalty schedule imposed by the regulator on manager $i$ in a functional organization.$^6$

It is assumed that the disutility of effort $\Delta_i$ for a divisional manager is quadratic, i.e.,

$$\Delta_i \equiv \begin{cases} 
\frac{z_i^T D z_i}{2} & \text{for } i = 1, 2 \\
\frac{v_i^T D v_i}{2} & \text{for } i = E, P 
\end{cases}$$  \hspace{1cm} (7)

where $z_i^T = (p_i, e_i)$ ($i = 1, 2$) and $v_i^T = (i_1, i_2)$ ($i = e, p$) are the effort vectors in a product-based and functional organization respectively. That is, the product manager must decide how to allocate effort between two functional tasks while the functional manager must decide how to allocate effort between the two products. Matrix $D$ measures the extent of diseconomies of span, this is “the extra cost that results when a manager must split his time and attention between different tasks” (Besanko et al. [2]):

$$D = \begin{pmatrix} 1 & \delta \\ \delta & 1 \end{pmatrix},$$  \hspace{1cm} (8)

with $\delta \in [0, 1]$. Combining (6a) and (7), the expected utility $EU$ for a manager $i$ is obtained:

$$EU_i \equiv E(\tilde{W}_i) - \frac{1}{2} \rho Var(\tilde{W}_i) - \Delta_i,$$  \hspace{1cm} (9)

where $\rho > 0$ represents the manager’s risk aversion, which is assumed to be constant and the same for all managers. It is straightforward to verify that the variance of the compensation

$^6$With $\psi_1 + \psi_2 = 1$. 
schemes $\tilde{W}_i$ are equal to:

\begin{align}
\text{Var}(\tilde{W}_i) &= \sigma_D^2 (1 + a_i^TWa_i - 2a_i^Tv), \tag{10a} \\
\text{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{10b} \\
\text{Var}(\tilde{W}_p) &= 2(1 + s)\psi_p^2 \sigma_D^2 \tag{10c}
\end{align}

where in (10a) $W \equiv \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix}$ and $v \equiv \begin{pmatrix} 0 \\ 1 \end{pmatrix}$. Now, (9) can be explicitly specified for the two distinguished organizational structures. Substituting (6a), (7) and (10a) into (9), the expected utility for managers in a product-based organization reads:

\begin{align}
EU_i &= a_i \beta + (z_i^T Q_i + z_j^T Q_j; z_i^T S_i + z_j^T S_j) a_i - (z_i^T S_i + z_j^T S_j) \\
&\quad - \frac{\rho}{2} \sigma_D^2 (1 + a_i^T W a_i - 2a_i^T v) - \frac{1}{2} z_i^T D z_i \quad i \neq j
\end{align}

with $Q_i = \begin{pmatrix} \beta \\ \gamma \end{pmatrix}$, $Q_j = \begin{pmatrix} \theta \beta \\ \xi \gamma \end{pmatrix}$, $S_i = \begin{pmatrix} b \\ g \end{pmatrix}$, $S_j = \begin{pmatrix} v_b \\ wg \end{pmatrix}$. 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{align}
\text{EU}_e &= \alpha_e \beta + \left( \sum_{j \in E,P} v_j^T T_j \right) \alpha_e - \psi_e \left( \sum_{j \in E,P} v_j^T T_j \right) u - \frac{1}{2} v_e^T D v_e \tag{12a} \\
&\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), \\
\text{EU}_p &= \alpha_p \beta + \left( \sum_{j \in E,P} v_j^T R_j \right) \alpha_p - \psi_p \left( \sum_{j \in E,P} v_j^T R_j \right) u - \frac{1}{2} v_p^T D v_p \tag{12b} \\
&\quad - \rho(1 + s)\psi_p^2 \sigma_D^2,
\end{align}

where $T_e = \begin{pmatrix} g & wg \\ wg & g \end{pmatrix}$, $T_p = \begin{pmatrix} b & v_b \\ v_b & b \end{pmatrix}$, $R_e = \begin{pmatrix} \gamma & \xi \gamma \\ \xi \gamma & \gamma \end{pmatrix}$ and $R_p = \begin{pmatrix} \beta & \theta \beta \\ \theta \beta & \beta \end{pmatrix}$.

As in Besanko et. al. [2], we normalize the managers’ reservation utility to zero. The intercept of the compensation schemes can then be used to satisfy the participation constraint.\(^8\) In that case, the owner’s objective is to maximize total surplus, i.e., profits, minus

\(^7\)See appendix for the derivation of (10a), (10b) and (10c).

\(^8\)Note that the participation constraint is expressed in expected terms. This means that there is no guarantee
risk premium, minus disutility of effort, minus penalties imposed on the managers, subject to the incentive compatibility constraints. Let us see how this applies to the two organizational regimes.

2.2 Surplus maximization

2.2.1 Product-based organization

In a product-based organization, the owner maximizes

\[ \Pi^{\text{prod}} = \sum_{i=1,2, i \neq j} z_i^T (Q_i + Q_j) - (z_i^T S_i + z_j^T S_j) - \frac{1}{2} z_i^T D z_i - \frac{\rho}{2} \sigma_D^2 (1 + a_i^T W a_i - 2 a_i^T v), \]

subject to

\[ (Q_i; S_i) a_i - S_i = D z_i, \]  

with (14) representing the usual incentive compatibility constraints for \( i = 1, 2 \). Note that in (13), \( z_i^T (Q_i + Q_j) \) is production manager \( i \)'s contribution to total profits\(^9\) and not the profit on product \( i \). The first-order condition with respect to \( a_i \) is:\(^10\)

\[ (Q_i; S_i)^T D^{-1} (Q_i + Q_j - S_j) + \rho \sigma_D^2 v = \left[ \rho \sigma_D^2 W + (Q_i; S_i)^T D^{-1} (Q_i; S_i) \right] a_i. \]  

(15)

After substitution of the expressions for \( Q_i, Q_j, S_i, S_j, W, D \) and \( v \) as given above into (15), the term between squared brackets on the RHS of (15) can be written as:

\[ \rho \sigma_D^2 W + (Q_i; S_i)^T D^{-1} (Q_i; S_i) = \frac{1}{1 - \delta^2} \left( \frac{\beta^2 + \gamma^2 - 2 \delta \beta \gamma}{\beta b + \gamma g - \delta (\beta g + \gamma b)} \right. \]

\[ \left. \beta b + \gamma g - \delta (\beta g + \gamma b) \right) \]

(16)

In general, this matrix is non-singular and the incentive scheme has therefore a unique solution. Now we do the same for a functional organization.

\(^9\)This is the direct impact on product \( i \) plus the spillover effects to product \( j \).

\(^10\)See appendix for the intermediate steps in order to derive (15).
2.2.2 Functional organization

Maximization of the surplus under a functional organization is expressed by:

\[
\Pi^{\text{func}} = u^T R_e v_e - \psi_e \left( \sum_{j \in E, P} v_j^T T_j \right) u - \frac{1}{2} v_e^T D v_e
\]

\[
- \frac{\rho}{2} \left( \alpha_e^T \Omega_D \alpha_e + 2(1 + s) \psi_e^2 \sigma_D^2 - 2(1 + s) \psi_e \sigma_D^2 \alpha_e^T u \right)
\]

\[
+ u^T R_p v_p - \psi_p \left( \sum_{j \in E, P} v_j^T T_j \right) u - \rho(1 + s) \psi_p^2 \sigma_D^2 - \frac{1}{2} v_p^T D v_p,
\]

subject to the incentive compatibility constraints for \( i = e, p \):

\[
T_e \alpha_e - \psi_e T_e u = D v_e,
\]

\[
R_p \alpha_p - \psi_p T_p u = D v_p.
\]

Here, we also have a difference with Besanko et. al. [2] because we have to take into account the additional risk imposed on the managers through the environmental fines. Moreover, these fines do not go to the owner of the firm.

Before proceeding, note that \( \psi_e + \psi_p = 1 \), implying that \( \Pi^{\text{func}} \) in (17) can be simplified to:

\[
\Pi^{\text{func}} = v_e^T (R_e - T_e) u - \frac{1}{2} v_e^T D v_e
\]

\[
- \frac{\rho}{2} \left( \alpha_e^T \Omega_D \alpha_e + 2(1 + s) \psi_e^2 \sigma_D^2 - 2(1 + s) \psi_e \sigma_D^2 \alpha_e^T u \right)
\]

\[
+ v_p^T (R_p - T_p) u - \rho(1 + s) \psi_p^2 \sigma_D^2 - \frac{1}{2} v_p^T D v_p.
\]

From (19) we see that the problem of the environmental and product manager can be separated. The first-order conditions with respect to \( \alpha_e \) and with respect to \( \alpha_p \) are then respectively:\footnote{The intermediate steps are again provided in the appendix.}

\[
T_e D^{-1} (R_e + (\psi_e - 1)T_e) u + \rho(1 + s) \psi_e \sigma_D^2 u = (\rho \Omega_D + T_e D^{-1} T_e) \alpha_e,
\]

\[
R_p D^{-1} (R_p + (\psi_p - 1)T_p) u = R_p D^{-1} R_p \alpha_p.
\]
If $\rho \Omega_D + T_D D^{-1} T_e$ in (20a) and $R_p D^{-1}$ in (20b) have full rank, the incentive problems have again a unique solution.

So far, we have examined the modeling framework with a focus on risk averse managers. We will now consider the case where managers are risk neutral and examine how this affects the different relationships within the two organizational structures.

3 Risk neutral managers

3.1 Product-based organization

In case of a product-based organization, the first-order condition with respect to $a_i$ reduces to:

$$(Q_i; S_i)^T D^{-1} (Q_i + Q_j - S_j) = (Q_i; S_i)^T D^{-1} (Q_i; S_i) a_i.$$  \hspace{1cm} (21)

If $(1 - \delta^2)(\beta g - \gamma b) \neq 0$ then $(Q_i; S_i)^T D^{-1}$ has full rank. Premultiplying both sides of this equality by its inverse, we obtain:

$$(Q_i; S_i)^{-1} (Q_i + Q_j - S_j) = a_i.$$  \hspace{1cm} (22)

Further developing this expression leads to

$$a_{\pi_i} = \frac{g(\theta \beta - vb) - b(\xi \gamma - wg)}{\beta g - \gamma b} + 1,$$  \hspace{1cm} (23a)

$$a_{D_i} = \frac{\beta(\xi \gamma - wg) - \gamma(\theta \beta - vb)}{\beta g - \gamma b}.$$  \hspace{1cm} (23b)

From (23) we see that the existence of diseconomies of span does not affect the optimal incentive scheme. Without spillover effects, i.e., $\theta = \xi = w = v = 0$, we would obtain $a_{\pi_i} = 1$ and $a_{D_i} = 0$. In this case, optimal compensation consists of holding the product manager fully liable for profits in his product and not linking compensation to environmental damages, which have already been fully internalized by the fines imposed by the regulator. In other words, without spillover effects, we obtain the standard result that with risk-neutral managers it is optimal to “sell” the firm to the manager (or, to put it still differently, to offer
a “franchise” contract). However, with spillover effects it is not optimal to hold a product manager entirely liable for the profits in his area, as this ignores the spillover effects to gross profits generated by the other product manager and to the fines paid by the other product manager. As a result, the fines imposed by the environmental regulator are not sufficient and need to be supplemented by an internal incentive scheme.

In both cases, the net spillover effects of productive activities are captured by the term $\theta \beta - vb$, whereas $\xi \gamma - wg$ captures the net spillover effects in environmental protection. Substitution of (22) into (14), the following effort levels are derived:

$$(Q_i; S_i) (Q_i; S_i)^{-1} (Q_i + Q_j - S_j) - S_i = Dz_i,$$  

or

$$D^{-1} (Q_i + Q_j - S_j - S_i) = z_i.$$  

Thus, while diseconomies of span do not affect the optimal incentive scheme, they do affect the optimal effort levels. Substituting (25) in (13) the expected profits read:

$$(Q_i + Q_j - S_j - S_i)^T D^{-1} (Q_i + Q_j - S_j - S_i).$$  

In scalar form this equalizes

$$\frac{1}{1 - \delta^2} \{[(1 + \theta) \beta - (1 + v)b]^2 + [(1 + \xi) \gamma - (1 + w)g]^2$$

$$-2\delta [(1 + \theta) \beta - (1 + v)b][(1 + \xi) \gamma - (1 + w)g]\}.$$  

For $\delta \in [0, 1]$, the expected profits (27) are always positive.

### 3.2 Functional organization

#### 3.2.1 Environmental manager

$T_e D^{-1}$ is a square matrix. If it has full rank, we can premultiply both sides of the equation by its inverse in order to obtain:

$$(T_e)^{-1} (R_e + (\psi_e - 1) T_e) u = \alpha_e,$$
or:

\[ (T_e)^{-1} R_e u + (\psi_e - 1)u = \alpha_e. \]  \hspace{1cm} (29)

Again, we see that the existence of diseconomies of span does not affect the incentive scheme. More explicitly:

\[ (g(1 + w))^{-1} \left( \frac{(1 + \xi)\gamma + (\psi_e - 1)g(1 + w)}{(1 + \xi)\gamma + (\psi_e - 1)g(1 + w)} \right) = \alpha_e. \]  \hspace{1cm} (30)

The interpretation of (30) is as follows. \((1 + \xi)\gamma\) is the total decrease in gross profits due to a unit increase in environmental protection. \((1 - \psi_e)g(1 + w) = \psi_pg(1 + w)\) is the decrease in environmental penalties paid by the production manager due to a unit increase in environmental management. Thus, if \(|(1 - \psi_e)g(1 + w)| > (1 + \xi)\gamma\), the firm will reward the environmental manager for an increase in environmental protection (otherwise, the environmental manager will be penalized). This per unit reward or punishment is proportional to the net externality the environmental manager imposes on the other agents within the firm.

Furthermore, substituting (30) into the incentive compatibility constraint for \(i = e\) (18a) yields

\[ (R_e - T_e) u = Dv_e. \]  \hspace{1cm} (31)

Note that \(v_e\) is independent of the exact distribution of environmental penalties amongst managers, although \(\alpha_e\) is not. Moreover, although the incentive scheme is independent of the existence of diseconomies of span, the optimal effort levels are not.

3.2.2 Production manager

\(R_p\) is a square matrix. If it has full rank, we can premultiply both sides of the equation by its inverse in order to obtain:

\[ (R_p + (\psi_p - 1)T_p) u = R_p\alpha_p, \]  \hspace{1cm} (32)
or:

$$\alpha_p = u + (\psi_p - 1) (R_p)^{-1} T_p u,$$

and more explicitly:

$$\alpha_p = \beta^{-1} (1 - \theta)^{-1} \left( (1 - \theta) \beta + (\psi_p - 1)(1 + v)b \right).$$  \hfill (34)

As before, we see that the incentive scheme is independent of the existence of diseconomies of span. The interpretation of (34) is as follows. \((1 - \theta) \beta\) is the *increase* in gross profits due to a unit increase in production effort. \((1 - \psi_p)(1 + v)b = \psi_e(1 + v)b\) is the *increase* in environmental penalties paid by the environmental manager due to a unit increase in production effort. Thus, if \((1 - \theta) \beta > (1 - \psi_p)(1 + v)b\), the firm will reward the product manager for an increase in production effort. Otherwise, the product manager will be penalized. This per unit reward or punishment is proportional to the net externality the product manager imposes on the other agents within the firm. Substituting (34) in (18b) gives:

$$(R_p - T_p) u = Dv_p.$$ \hfill (35)

Here \(v_p\) is independent of the exact distribution of environmental penalties amongst managers, although \(\alpha_p\) is not. As in case of the environmental manager, the incentive scheme is independent of the existence of diseconomies of span, whereas the optimal effort levels are not.

In the following two subsections we will compare the two organizational forms in terms of profits and effort levels, keeping in mind the assumption of risk neutrality.

### 3.3 Organizational comparison by profit levels under risk neutrality

First note that a social planner would choose effort levels in order to maximize

$$\sum_{i=1,2; j \neq i} \left[ z_i^T (Q_i + Q_j) - (z_i^T S_i + z_j^T S_j) - \frac{1}{2} z_i^T D z_i \right].$$  \hfill (36)
The first-order condition for $z_i$ then would be:

$$Q_i + Q_j - S_i - S_j = Dz_i,$$

which exactly coincides with (25). Therefore, the incentive scheme we have developed for a product-based organization allows to effectively obtain the first-best effort levels. However, by substituting (35) and (31) into (19) we obtain that, for $\rho = 0$, expected profits in a functional organization reduce to:

$$\frac{1}{2}u^T(R_e - T_e)^TD^{-1}(R_e - T_e)u + \frac{1}{2}u^T(R_p - T_p)^TD^{-1}(R_p - T_p)u.$$  

(38)

In scalar terms, this function explicitly reads:

$$\frac{1 - \delta}{1 - \delta^2} \left[ ((1 + \xi)\gamma - (1 + w)g)^2 + ((1 + \theta)\beta - (1 + v)b)^2 \right].$$  

(39)

This shows clearly that the distribution of the joint liability between the two functional managers does not affect total profits, and has thus no efficiency effects.\footnote{At least, if there is no upper bound to the amounts that can be imposed on individual managers. Otherwise, it might be optimal to impose the highest fine on the manager with the “deepest pockets”.} Comparing this with (27), it is straightforward to verify that expected profits are higher in a product organization for $\delta > 0$. When $\delta = 0$, profits are the same under both organizational structures.

Following the same procedure as above, it is straightforward to verify that if the firm would be held directly liable for the environmental damages, then it would choose a product-based organization and write an incentive contract that would induce first-best effort levels. Therefore,

**Proposition 1** If managers are risk neutral, then it does not matter whether environmental liability is imposed on the firms or on the managers: a product-based organization always dominates a functional organization and allows to obtain first best effort levels. If there are no diseconomies of span ($\delta = 0$), both organizational forms are equivalent. This result is in-
dependent of the magnitude of spillover effects. Total profits within a functional organization do not depend on the allocation of liability between the functional managers.

In order to understand the result in proposition 1, note first that (30) and (34) imply that the incentive scheme for the environmental manager does not depend on the parameters that determine how the production manager’s effort affects gross profits and environmental damages (this is, \( \beta, b, \theta \) and \( v \)), and that the production manager’s incentives do not depend on the parameters that determine how the environmental manager’s effort affects gross profits and environmental damages (this is, \( \gamma, g, \xi \) and \( w \)). In other words, in a functional organization, the incentive schemes do not contain all relevant information (whereas they do in a product-based organization). This does, however, not follow from the particular incentive scheme we have considered here: it can be verified that this result is true for all conceivable incentive schemes and follows directly from the separability we have identified in (19). Thus, functional organizations provide less information than product-based organizations.

Another way to understand this result is to note that (30) and (34) also show that, even without spillover effects, it is impossible to offer a “franchise contract” to the functional managers. It is interesting to compare this result with the conclusions obtained by Segerson and Tietenberg [20]. They claim that with risk neutral managers, “efficiency can be achieved (...) with a penalty on the responsible individual” [20, p. 187]. We have shown here that this indeed true for a product based organization. In the case of a functional organization, it is not possible to attribute environmental damages to the actions of an individual. In that case, Segerson and Tietenberg suggest to use a flat wage for individual managers. Our results here show that this is not optimal in general.

Our analysis also shows that, with risk-neutral managers with large enough assets, at least one argument against managerial liability is not valid. Indeed, Kornhauser [14, p. 1351] has argued that “enterprises are more able than courts to identify responsible actors;
consequently, this fact suggests that more care results from a system of enterprise liability.”

Our analysis shows that this is not true with a product-based organization. The first-best can be obtained, even if the regulator does not know the spillover effects as long as the firm’s owner knows them: 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.

Finally, it is also possible to interpret Proposition 1 in the light of the Coase theorem (see Coase [3]): as the impossibility for a firm’s owner to “sell” the firm to a functional manager makes it impossible to obtain the first best solution if there are diseconomies of span, this impossibility of writing a “franchise contract” is, per definition, a transaction cost linked to this organizational structure.

3.3.1 Organizational comparison by effort levels under risk neutrality

With respect to effort levels, the comparison is also straightforward. Table 1 contains the expressions of the environmental and product effort levels under the two organizational modes. The effort levels under a product-based organization are described by (25). The environmental and production effort under a functional organization are determined by (31) and (35) respectively.

<table>
<thead>
<tr>
<th>Effort levels</th>
<th>Product organization</th>
<th>Functional organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production effort</td>
<td>$(1+\theta)\beta-(1+\nu)b-\delta(1+\xi)\gamma+\delta(1+w)g$</td>
<td>$\frac{(1-\delta)(1+\theta)\beta-(1+\nu)b}{1-\delta^2}$</td>
</tr>
<tr>
<td>Environmental effort</td>
<td>$(1+\xi)\gamma-(1+w)g-\delta(1+\theta)\beta+\delta(1+w)b$</td>
<td>$\frac{(1-\delta)(1+\xi)\gamma-(1+w)g}{1-\delta^2}$</td>
</tr>
</tbody>
</table>

Effort levels are the same for both organizational modes if there are no diseconomies of span. However, we have no prior restrictions on the signs of $(1 + \xi)\gamma - (1 + w)g$ and
(1 + \theta)\beta - (1 + v)b \text{ and therefore we cannot say under which regime effort levels are the highest when } \delta > 0. \text{ Otherwise, it is straightforward to verify that production (environmental) effort is higher (lower) under a product-based organization if and only if}

\[(1 + \theta)\beta - (1 + v)b > (1 + \xi)\gamma - (1 + w)g.\] (40)

How can we interpret (40)? In a product-based organization with risk neutral managers, profits for product line \(i\) are:

\[z_i^T (Q_i + Q_j) - (z_i^T S_i + z_j^T S_j) - \frac{1}{2} z_i^T D z_i.\]

Compared to a problem without environmental policy, the only difference lies in the term \(z_i^T S_i + z_j^T S_j\): the fine levied to product manager \(i\). Therefore, firm profits before compensation of effort are \(z_i^T (Q - S)\) rather than \(z_i^T Q\) as in Besanko et. al. [2]. In their terminology, production is the dominant function if \((1 + \theta)\beta - (1 + v)b > (1 + \xi)\gamma - (1 + w)g.\) Otherwise, it is environmental protection. In turn,

**Proposition 2** If, after the introduction of environmental fines, production is still 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 becomes 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 2 is then completely compatible with the observation of Besanko et. al. [2, p. 21] that “if there is a dominant function, effort costs tend to be higher in a functional organization”.

Now we have analyzed the effects under the assumption of risk neutral managers, we now turn back to the situation of risk averse managers but analyze the cases when there are no spillover effects and no diseconomies of span.
4 Absence of spillover effects and diseconomies of span

Here we keep the assumption that managers are risk averse, however, suppose now that there are no spillover effects and no diseconomies of span. Without spillover effects, i.e., \( \theta = \xi = w = v \), we get \( S_j = Q_j = (0 0)^T \). To simplify notation, let \( S \equiv S_i \) and \( Q \equiv Q_i \). Let us first look at the incentives for the product managers within a product-based organization and then turn to the incentives within a functional organization.

4.1 Product-based organization

The first-order condition with respect to \( a_i \) can be written as:

\[
(Q; S)^T Q + \rho \sigma^2_D v = (\rho \sigma^2_D W + (Q; S)^T (Q; S)) a_i. \tag{41}
\]

Solving (41) for \( a_i \) yields:

\[
(k_1^2 + \rho \sigma^2_D k_3)^{-1} \left( \frac{k_1^2 + \rho \sigma^2_D (k_3 - k_2)}{\rho \sigma^2_D k_3} \right), \tag{42}
\]

where \( k_1 = \beta g - \gamma b, k_2 = \beta b + \gamma g \) and \( k_3 = \beta^2 + \gamma^2 \). In case of risk neutrality (42) reduces to: \((1, 0)^T\), which is exactly the result we already obtained in Section 3. So, in order to compensate for the risk imposed by the environmental fines when managers are risk averse, the firm must introduce a wage that depends on environmental performance, while this is not necessary if the managers are risk neutral. Moreover,

\[
\frac{k_1^2 + \rho \sigma^2_D (k_3 - k_2)}{k_1^2 + \rho \sigma^2_D k_3} < 1, \tag{43}
\]

which means that the incentives for production effort are lower under risk aversion because higher production effort increases the expected fines.

Substitution of (42) in (14) and solving for \( z_i \) gives

\[
(k_1^2 + \rho \sigma^2_D k_3)^{-1} \left( \frac{(\beta - \beta)k_1^2 + \rho \sigma^2_D (k_3 - k_2)\beta}{(\gamma - \beta)k_1^2 + \rho \sigma^2_D (k_3 - k_2)\gamma} \right), \tag{44}
\]
Under risk neutrality, this reduces to: \((\beta - b, \gamma - g)^T\). Production effort will be higher under risk neutrality if \((\beta - b)(k^2 + \rho \sigma_D^2 k_3) > (\beta - b)k^2 + \rho \sigma_D^2 (k_3 - k_2)\beta\), i.e., if \(\beta g > b \gamma\).

Similarly, environmental effort will be higher under risk neutrality if \((\gamma - g)(k^2 + \rho \sigma_D^2 k_3) > (\gamma - g)k^2 + \rho \sigma_D^2 (k_3 - k_2)\gamma\), i.e., if \(\gamma b > g \beta\). Thus:

**Proposition 3** In a product-based organization without spillover effects, risk aversion leads to a decrease in production effort (increase in environmental effort) if and only if \(\beta g > b \gamma\).

Now, in order to find profits, first note that (41) and the symmetry of \((\rho \sigma_D^2 W + (Q; S)^T (Q; S))^{-1}\) imply that:

\[ a_i^T \rho \sigma_D^2 W + (Q; S)^T (Q; S) a_i \] (45)

By substituting this into (13) and rearranging, we find the expression for total profits:

\[ (\beta - b)^2 + (\gamma - g)^2 - \frac{\rho \sigma_D^2 k_1}{k^2 + \rho \sigma_D^2 k_3}, \] (46)

which clearly shows that due to risk aversion, total profits decrease with \(\frac{\rho \sigma_D^2 k_1}{k^2 + \rho \sigma_D^2 k_3}\).

It is 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. Thus, contrary to what was conjectured by Segerson and Tietenberg [20, footnote 11], we obtain that the risk aversion of the managers is not an argument against holding them liable rather than the firm: who has to pay the fines does not affect how risk is shared between the firm and its managers.

Of course, in reality, a firm’s assets will generally be larger than that of a manager. A firm will therefore generally be able to afford higher monetary penalties than a manager.

Let us now turn back to a functional organization in order to explore how absence of spillover effects and absence of diseconomies of span affect the incentives of the environmental and product manager respectively.
4.2 Functional organization

4.2.1 Environmental manager

In this case, \((\rho \Omega_D + T_eT_e)\) is equal to:

\[
\begin{pmatrix}
\rho \sigma_D^2 + g^2 & \rho s \sigma_D^2 \\
\rho s \sigma_D^2 & \rho \sigma_D^2 + g^2
\end{pmatrix},
\] (47)

and \(\alpha_e\) reads:

\[
(\rho(1 + s)\sigma_D^2 + g^2)^{-1} \begin{pmatrix}
g \gamma + (\psi_e - 1)g^2 + \rho(1 + s)\psi_e \sigma_D^2 \\
g \gamma + (\psi_e - 1)g^2 + \rho(1 + s)\psi_e \sigma_D^2
\end{pmatrix}.
\] (48)

With risk neutrality (48) this reduces to: \((g)^{-1} (\gamma + (\psi_e - 1)g, \gamma + (\psi_e - 1)g)^T\). Now substitute (48) in (18a) in order to obtain the effort levels:

\[
(\rho(1 + s)\sigma_D^2 + g^2)^{-1} g^2 \begin{pmatrix}
\gamma - g \\
\gamma - g
\end{pmatrix}.
\] (49)

We see that environmental effort does not depend on the fines levied on the environmental manager. With risk neutrality, environmental effort reduces to \(\gamma - g\). Thus, environmental effort is higher under risk neutrality if \((\gamma - g) (\rho(1 + s)\sigma_D^2 + g^2) > g^2(\gamma - g)\), which always holds. Actually, (49) directly shows that:

**Proposition 4** In a functional organization, the environmental manager’s effort level is decreasing in his level of risk aversion, but is independent of the fines he has to pay.

What is the environmental manager’s contribution to expected profits? Using the symmetry of \((\rho \Omega_D + T_eT_e)^{-1}\), it can be shown that (see appendix for derivation):

\[
\frac{g^2(\gamma - g)^2}{\rho(1 + s)\sigma_D^2 + g^2}
\] (50)

As \(\frac{g^2}{\rho(1 + s)\sigma_D^2 + g^2} < 1\), the effect of risk aversion is that the functional manager’s contribution to total profits decreases with this factor. This factor is independent of the fine levied on the environmental manager. This is consistent with the observation we made with respect to environmental effort. Apparently, it is indeed optimal for the firm to compensate the effects of fines imposed on the environmental manager.
4.2.2 Production manager

Because $R_p$ is a square matrix with full rank, multiplication by its inverse yields

\[(R_p + (\psi_p - 1)T_p)u = R_p\alpha_p,\]  

or

\[\alpha_p = u + (\psi_p - 1)(R_p)^{-1}T_p u.\]  

and so

\[\alpha_p = \beta^{-1} \left( \frac{\beta + (\psi_p - 1)b}{\beta + (\psi_p - 1)b} \right).\]  

Here $\beta$ is the increase in gross profits due to a unit increase in production effort. $(1 - \psi_p)b = \psi_e b$ is the increase in environmental penalties paid by the environmental manager due to a unit increase in production effort. Thus, if $\beta > (1 - \psi_p)b$, then the firm will reward the production manager for an increase in production effort (otherwise, the production manager will be penalized). This per unit reward or punishment is proportional to the net externality he imposes on the other agents within the firm.

Substitution of (53) in (18b) gives:

\[\left( \frac{\beta - b}{\beta - b} \right) = v_p,\]  

where $v_p$ is independent of the exact distribution of environmental penalties amongst managers, even though $\alpha_p$ is not. We can even go a step further by arguing that:

**Proposition 5** In a functional organization, risk aversion does not affect the production manager’s incentives or effort levels.

Let us now look at the production manager’s contribution to expected profits. Substitution of (54) in (64) and simplifying yields:\[\text{13}^3\]

\[\frac{(\beta - b)^2}{\rho(1 + s)\psi_p^2\sigma_D^2}.\]  

\[\text{13}^3\text{See appendix for intermediate steps.}\]
Equation (55) expresses the fact that the risk imposed on the production manager does not depend on the incentive scheme received by the firm (which is completely deterministic), but only on the risk imposed by the environmental fines. Therefore, the production manager’s contribution to expected profits exactly decreases with the risk premium he must receive from the firm in order to satisfy his participation constraint. As the fines do not affect incentives, but only impose a risk on the production manager, these fines are a deadweight loss. Therefore, it is socially optimal to set $\psi_p = 0$. Alternatively, it is straightforward to verify that the same effect would be obtained if all fines were imposed directly on the firm (keep in mind that the firm is risk neutral).

Gabel and Sinclair-Desgagné [9, p. 238] have suggested that in a multi-departmental organization, “profit should be the responsibility of line managers with incentive contracts, while environmental risk reduction should be assigned to personnel under a fixed-salary contract.” Our results here provide no justification for this conjecture. The reason is that [9], a priori, presume that environmental activities are more difficult to monitor than production activities. This problem disappears in our setting due to the linearity of the model.\(^{14}\)

Now all expressions that show to what extent the two organizational structures contribute to expected profits are available, we can compare the regimes with each other on this variable.

### 4.3 Organizational comparison by contribution to expected profits

Total profits under a functional organization are equal to the sum of (55) and (50):

$$
(\beta - b)^2 - \rho(1 + s)\psi_p^2 \sigma_D^2 + \frac{g^2(\gamma - g)^2}{\rho(1 + s)\sigma_D^2 + g^2}.
$$

This we have to compare with total expected profits under a product-based organization (46):

$$
(\beta - b)^2 + (\gamma - g)^2 - \frac{\rho \sigma_D^2 (\beta g - \gamma b)^2}{(\beta g - \gamma b)^2 + \rho \sigma_D^2 (\beta^2 + \gamma^2)}.
$$

\(^{14}\)On the one hand, our model might seem somewhat restrictive in this regard compared to [9]. On the other hand, the conclusion of [9] presumably only holds in the limit case where environmental efforts cannot be estimated from measurable results.
Hence, profits are higher under a product-based organization if:

\[ \rho (1 + s) \psi_p^2 \sigma_D^2 > \rho \sigma_D^2 \frac{(\beta g - \gamma b)^2}{(\beta g - \gamma b)^2 + \rho \sigma_D^2 (\beta^2 + \gamma^2)} - \frac{\rho (1 + s) \sigma_D^2 (\gamma - g)^2}{\rho (1 + s) \sigma_D^2 + g^2}. \] (58)

In general, it is difficult to say anything about this expression, even with \( \psi_p = 0 \) (remember that we have shown that \( \psi_p \) is a deadweight loss). This ambiguity can be better understood if we compare our results with Besanko et. al. [2].

The central result in their paper is that without cross-product externalities or diseconomies of span, a product-based organization yields higher profits than a functional one if all functions have the same effect on profits (Proposition 1). The intuition for their result is that in “a product organization, any desired symmetric level of efforts can be induced by tying a manager’s reward to the performance of the division that he oversees. (...) In a functional organization (...) the desired symmetric effort levels can be obtained by linking the pay of each manager to the performance of each of the two products”. Therefore, “the head of a product division bears the risk associated with the noisy profit signal in his product while the head of a functional division bears the risk associated with noisy profit signals in both product lines.” Moreover, “in a product organization, the owner (...) can link the compensation of a division manager (...) to the profits of the other division to provide him with insurance against compensation risk without affecting effort incentives. By contrast, in a functional organization desired effort levels can be obtained only by linking the pay of each manager to the profits of both products. Hence ‘free insurance’ against compensation risk is unavailable.”

In our model, however, the nature of the problem itself implies that the two functions have asymmetric effects, and thus that we have a dominant function. In Proposition 2 of [2], it is then shown that the existence of a dominant function favors a functional organization, and that this effect becomes more pronounced when the dominant function becomes more
so. Besanko et. al. [2, p. 13] explain this effect as follows: “The incentive sensitivity effect means that given the higher marginal profitability of function $X$, the owner ideally wants to induce greater effort levels in that function than in function $Y$. The owner can achieve this with a functional form: it suffices to give the manager in charge of function $X$ higher-powered incentives than the manager in charge of function $Y$. In a product-based organization, however, the division manager for product $i$ controls both $x_i$ and $y_i$, so it is not possible to give higher-powered incentives for activity $x_i$ than for activity $y_i$. As a result, the owner is forced to make an ‘incentive compromise’.” This explains why, in general, the comparison between a functional and a product based organization is ambiguous in our model. Therefore, let us consider some special cases.

First, suppose that environmental protection does not affect gross profits, i.e., $\gamma = 0$.$^{15}$ In this case, environmental protection only affects total profits because the owner must compensate the managers for the risk imposed by the environmental fines. The RHS of (58) then reduces to:

$$\begin{align*}
- \left( \frac{\rho \sigma_D^2 g^4 s}{(g^2 + \rho \sigma_D^2)} \frac{1}{(g^2 + \rho \sigma_D^2 + g^2)(\rho(1 + s)\sigma_D^2 + g^2)} \right)
\end{align*}$$

Therefore,

**Proposition 6** A product-based organization dominates a functional organization if environmental protection does not affect gross profits.

Suppose next that there is a perfect negative correlation between the measurement errors in environmental performance. Then (56) reduces to the first-best profits, while (46) is independent of this correlation. Taking the derivative of (56) with respect to $s$, we obtain:

$$\begin{align*}
-2\psi_p^2 \sigma_D^2 - \frac{g^2(\gamma - g)^2}{(\rho(1 + s)\sigma_D^2 + g^2)^2} \rho \sigma_D^2 < 0.
\end{align*}$$

$^{15}$The other extreme case ($b = 0$) does not make any economic sense: if production effort does not affect the environment, then no environmental regulation is needed.
Proposition 7 If there is a perfect negative correlation between the measurement errors in environmental performance, a functional organization allows to obtain the first-best solution and dominates the product organization. The higher the correlation, the lower the profits under a functional organization.

The intuition behind this result is as follows (note that it follows exactly the same logic as the intuition Besanko et. al. provide for Proposition 1 in their paper). In case of a product-based organization, the product manager is always subject to some risk, as the only stochastic component in his remuneration is the pollution linked to his own product. In the case of a functional organization, both managers are subject to two risks. If the correlation between these two risks is perfectly negative, they both have a perfectly diversified portfolio.

5 Conclusions and directions for future research

5.1 Conclusions

This paper presents a principal-agent model to examine how different liability rules for environmental damages affect the compensation and penalty schemes offered to individual managers. These schemes depend on the managers’ contribution to profits and their performance on environmental damages caused by production respectively, and are evaluated both within a product-based and a functional organization. In the former case, a firm is divided into product lines. The latter case refers to a firm that is organized as a collection of various functional departments; in our analysis a production and an environmental department. It is also verified how these liability rule affect the choice between organizational forms.

When managers are risk neutral and liability is unlimited, it does not matter whether it is the firm or the managers who are held liable for environmental damages. Moreover, if there are no spill-over effects between product lines, then a product-based organization allows to
obtain first-best effort levels by offering a “franchise contract” to the managers. In the other
case, the firm’s owner can compensate for any possible misallocation induced by a liability
rule that ignores spillovers within the firm. Moreover, if there are diseconomies of span, then a
product-based organization dominates strictly a firm with a functional organization structure.
In case there are no diseconomies of span, both organizational forms are equivalent. These
results are independent of the height of spillover effects. The dominance of a product-based
organization is due to the fact that contracts in a functional organization can never be based
on all relevant information without being redundant.

If environmental protection becomes the dominant function after the introduction of envi-
ronmental taxes, then environmental protection is higher under a product-based organization.
In case production is the dominant function after the introduction of environmental taxes,
production effort will be higher in a product-based organization then in a functional organiza-
tion. The organizational form that induces the highest environmental effort when managers
are risk neutral, induces the lowest production effort and vice versa.

We have also analyzed the problem with risk-averse managers in the particular case with-
out spillover effects or diseconomies of span. In the case of a product-based organization, it
is again shown that it does not matter whether it is the firm or the managers that are held
liable for environmental damages, as long as the managers do not face limited liability. In
a functional organization, the environmental manager’s effort level is decreasing in his level
of risk aversion, but also independent of the fines he has to pay. Moreover, risk aversion
does not affect the production manager’s effort levels in such a situation. More important,
we show that the fines imposed on the production manager only affect expected profits, but
without affecting incentives. Therefore, in a functional organization it is optimal, either not
to hold production managers liable for environmental damages, or, equivalently, to hold the
firm liable for environmental damages.
With risk averse managers, there is no longer a dominant organizational form. However, if there is a perfect negative correlation between measurement errors in environmental performance, then a functional organization allows to obtain first-best effort levels and dominates a product-based organization. The higher the correlation, the lower profits are in a functional organization. Also, if environmental protection does not affect gross profits, then a product-based organization outperforms a functional organization. Otherwise, no general statements are possible.

We have also shown that several conjectures formulated in earlier contributions are not confirmed in our analysis. First, even if environmental damages cannot be attributed to the actions of one specific individual, flat wages are not optimal. Second, in the case of a product-based organization, risk aversion of the managers is not an argument against holding them liable rather than the firm. Third, environmental managers should not necessarily be given a fixed-wage contract.

5.2 Directions for future research

There are several directions for future research, that follow directly from some restrictive assumptions we have used. First of all, while our modeling approach allows to obtain an explicit solution for the problem, it also has an important drawback: the effect of effort on gross profits and environmental damages is perfectly linear. However, in reality, it is likely that there are fixed costs related to each task (see Corts [5] for an example). These fixed costs are arguably more important in a functional organization than in a product-based organization. This suggests that our analysis contains a bias in favor of product-based organizations. The linearity of the model also implies that there is no constraint on the sign of the optimal effort levels. It is, however, unclear how negative efforts should be interpreted.

\[16\text{It is arguably more costly to acquire skills in finance and marketing after having acquired skills in environmental management, than to switch from the general management of one product to the general management of another product.}\]
A second point is that for some realizations of the stochastic variable, the managers will have to make a payment to the firm — these payments may exceed their assets. We have not explicitly considered this constraint. But the existing literature shows that this can be an important point. Indeed, Kornhauser [14] already showed that limited liability of the agent has non-trivial effects on the choice between agent liability and enterprise liability. Similarly, Sykes [24, p. 1241-42] pointed out that personal liability allows “the principal and the agent jointly to increase their expected profits by eschewing any risk-sharing agreement or any insurance policy that averts agent insolvency and concurrently provides greater compensation to injured parties”. One way of restoring “adverse” managerial behavior could then be by means of criminal sanctions like, for instance, incarceration of managers [20].

A third point is that in our model liability is imposed on either the firm or the individual managers. However, as Polinsky and Shavell [16] point out, firms are more limited in their capacity to discipline employees than the state, who can, for instance, impose criminal penalties on top of what the firms can impose. In that case, the liability optimally imposed on a firm should be adapted to reflect the higher wages employees will require in order to compensate them for the risk of criminal fines. Shavell [22] uses the same framework (but with no fines imposed on the employees) to show that a firm might have the pay above-market wages (efficiency wages) in order to induce the necessary effort levels.

Fourth, we only consider corporate civil liability — for forceful arguments against corporate criminal liability, see Arlen [1], Khanna [13] and Fishel and Sykes [7]; for specific applications to environmental crime, see Cohen [4] and Segerson and Tietenberg [20]. It should be noted though that Arlen’s central argument against corporate criminal liability can easily be adapted to the case of civil liability: increased enforcement by a corporation increases the probability of detection of employees who are negligent (and therefore reduces

\[17\] Sykes [25] extends this analysis to the case where the scope of employment is litigated.
the number of negligent employees), but also increases the probability that the government will detect negligence within the corporation and thus hold the corporation liable.

Fifth, we have limited ourselves to strict liability — liability under negligence rules is discussed in Chu and Qian [6] in the particular case where the firm can hide evidence, and in Segerson and Tietenberg [20] for incarceration based on negligence rules.

Sixth, the CEO in our model is very passive: she limits herself to providing incentives to the managers. Thus, she does not try to screen prospective employees (see Kornhauser [14]) or to affect the riskiness of the environment in which individual managers operate (see Kornhauser [14] and Shavell [22]).

Finally, throughout the paper we considered the case where individual pollution could be observed. However, as we have mentioned in the introduction, if production of the two goods generates the same pollutant, then only total pollution can be observed. This is a case we have not dealt with and is left for further research.
Appendix

Derivation of equations (10a), (10b) and (10c) First, let us focus on a product-based organization. In this case, equation (1) implies that \( \pi_i = z_i^T Q_i + z_j^T Q_j \) (\( i \neq j \)). Similarly, equation (2) implies that \( D_i = z_i^T S_i + z_j^T S_j \) (\( i \neq j \)). Furthermore, \( Var(\vec{W}_i) = (1 - a_D) \sigma_D^2 \); or in matrix form \( Var(\vec{W}_i) = \sigma_D^2 (1 + a_i^T W a_i - 2a_i^T v) \). Second, a functional organization. Equation (1) then also implies \( \pi_T = \sum_{j \in E,P} v_j^T R_j \); equation (2) implies \( D_T = \sum_{j \in E,P} v_j^T T_j \). It is then straightforward to verify that \( Var(\vec{W}_e) = \alpha_e \Omega D \alpha_e + 2(1 + s) \psi_e^2 \sigma_D^2 - 2(1 + s) \psi_e \sigma_D \alpha_e^T u \) and \( Var(\vec{W}_p) = 2(1 + s) \psi_p^2 \sigma_D^2 \).

Derivation of equation (15) Equation (13) can be rearranged to:

\[
\sum_{i=1,2,j \neq i} \left[ z_i^T (Q_i + Q_j - S_i - S_j) - \frac{1}{2} z_i^T D z_i - \frac{\rho}{2} \sigma_D^2 (1 + a_i^T W a_i - 2a_i^T v) \right].
\]  
Substitute (14) in (61) yields:

\[
\sum_{i=1,2,j \neq i} \left\{ ([Q_i; S_i] a_i - S_i^T) (D^{-1})^T (Q_i + Q_j - S_i - S_j) 
- \frac{1}{2} ([Q_i; S_i] a_i - S_i^T) D D^{-1} ([Q_i; S_i] a_i - S_i) - \frac{\rho}{2} \sigma_D^2 (1 + a_i^T W a_i - 2a_i^T v) \right\}.
\]

Using \( (D^{-1})^T = D^{-1} \), this expression can be reorganized to:

\[
\sum_{i=1,2} \left\{ a_i^T (Q_i; S_i)^T D^{-1} (Q_i + Q_j - S_i - S_j) - S_i^T D^{-1} (Q_i + Q_j - S_i - S_j) 
- \frac{\rho}{2} \sigma_D^2 - \frac{\rho}{2} \sigma_D^2 a_i^T W a_i + \rho \sigma_D^2 a_i^T v - \frac{1}{2} a_i^T (Q_i; S_i)^T D^{-1} (Q_i; S_i) a_i + \frac{1}{2} a_i^T (Q_i; S_i)^T D^{-1} S_i 
+ \frac{1}{2} (S_i)^T D^{-1} (Q_i; S_i) a_i - \frac{1}{2} (S_i)^T D^{-1} S_i \right\},
\]

which can be further simplified to:

\[
\sum_{i=1,2} \left\{ -\frac{\rho}{2} \sigma_D^2 a_i^T W a_i - \frac{1}{2} a_i^T (Q_i; S_i)^T D^{-1} (Q_i; S_i) a_i 
+ a_i^T (Q_i; S_i)^T D^{-1} (Q_i + Q_j - S_j) + \rho \sigma_D^2 a_i^T v 
- S_i^T (Q_i + Q_j - S_i - S_j) - \frac{\rho}{2} \sigma_D^2 - \frac{1}{2} (S_i)^T S_i \right\}. \tag{62}
\]

\[
- S_i^T (Q_i + Q_j - S_i - S_j) - \frac{\rho}{2} \sigma_D^2 - \frac{1}{2} (S_i)^T S_i \right\}. \tag{63}
\]
Derivation of equations (20a) and (20b)  Let us start with the first-order condition of environmental management (20a). Substitution of (18a) in (19) gives:

\[
[T_e \alpha_e - \psi_e T_e u]^T D^{-1} (R_e - T_e) u - \frac{1}{2} [T_e \alpha_e - \psi_e T_e u]^T D^{-1} [T_e \alpha_e - \psi_e T_e u] \\
- \frac{\rho}{2} (\alpha_e^T \Omega_D \alpha_e + 2(1 + s) \psi_e^2 \sigma_D^2 - 2(1 + s) \psi_e \sigma_D^2 \alpha_e^T u).
\]

Using \( T_e^T = T_e \), this expression can be reorganized to:

\[
\alpha_e^T T_e D^{-1} (R_e - T_e) u - \psi_e u^T T_e D^{-1} (R_e - T_e) u - \frac{1}{2} \alpha_e^T T_e D^{-1} T_e \alpha_e + \frac{1}{2} \psi_e \alpha_e^T T_e D^{-1} T_e u
\\
+ \frac{1}{2} \alpha_e \psi_e \psi_e^T T_e D^{-1} T_e \alpha_e - \frac{1}{2} \psi_e \alpha_e^T T_e D^{-1} T_e u - \frac{\rho}{2} \alpha_e^T \Omega_D \alpha_e - \rho(1 + s) \psi_e^2 \sigma_D^2 + \rho(1 + s) \psi_e \sigma_D^2 \alpha_e^T u.
\]

Moreover, as the transpose of a scalar matrix is the scalar itself, this expression can be further simplified to:

\[
\alpha_e^T T_e D^{-1} (R_e + (\psi_e - 1) T_e) u - \psi_e u^T T_e D^{-1} (R_e - T_e) u
\\
- \frac{1}{2} \alpha_e^T T_e D^{-1} T_e \alpha_e - \frac{1}{2} \psi_e \alpha_e^T T_e D^{-1} T_e u - \frac{\rho}{2} \alpha_e^T \Omega_D \alpha_e - \rho(1 + s) \psi_e^2 \sigma_D^2 + \rho(1 + s) \psi_e \sigma_D^2 \alpha_e^T u
\]

and thus:

\[
- \frac{1}{2} \alpha_e^T (\rho \Omega_D + T_e D^{-1} T_e) \alpha_e + \alpha_e^T (T_e D^{-1} (R_e + (\psi_e - 1) T_e) u + \rho(1 + s) \psi_e^2 \sigma_D^2 u)
\\
- \psi_e \alpha_e \alpha_e (R_e - T_e) u - \frac{1}{2} \psi_e \alpha_e^T T_e T_e \alpha_e - \rho(1 + s) \psi_e^2 \sigma_D^2.
\]

Therefore, the first-order condition with respect to \( \alpha_e \) equals:

\[
T_e D^{-1} (R_e + (\psi_e - 1) T_e) u + \rho(1 + s) \psi_e \sigma_D^2 u = (\rho \Omega_D + T_e D^{-1} T_e) \alpha_e
\]

Second, the first-order condition of production management (20a). Substitute (18b) in (19) gives:

\[
[R_p \alpha_p - \psi_p T_p u]^T D^{-1} (R_p - T_p) u - \frac{1}{2} [R_p \alpha_p - \psi_p T_p u]^T D^{-1} [R_p \alpha_p - \psi_p T_p u] - \rho(1 + s) \psi_p^2 \sigma_D^2.
\]

\[\text{\underline{18}}\text{Ignoring all terms that do not depend on } \psi_e \text{ and using the fact that the transpose of a scalar is the scalar itself and that } (D^{-1})^T = D^{-1}.
\]

\[\text{\underline{19}}\text{Ignoring all terms that do not depend on } \psi_e \text{ and using the fact that the transpose of a scalar is the scalar itself and that } (D^{-1})^T = D^{-1}.
\]
Using \((R_p)^T = R_p\), this expression can be reorganized to:

\[
-\frac{1}{2} \alpha^T R_p D^{-1} R_p \alpha + \alpha^T R_p D^{-1} (R_p + (\psi_p - 1)T_p) u
\]

\[
-\psi_p u^T (T_p)^T (R_p - T_p) u - \frac{1}{2} \psi^2_p u^T (T_p)^T T_p u - \rho(1 + s) \psi^2_p \sigma^2_D,
\]

and the first-order conditions with respect to \(\alpha_p\) reads:

\[
R_p D^{-1} (R_p + (\psi_p - 1)T_p) u = R_p D^{-1} R_p \alpha_p.
\]

\[\blacksquare\]

**Derivation of equation (50)**  
\(\alpha^e T (\rho \Omega_T + T_e T_e) \alpha_e\) can be simplified to:

\[
u^T [T_e (R_e + (\psi_e - 1)T_e) + \rho(1 + s) \psi_e \sigma^2_D] T (\rho \Omega_T + T_e T_e)^{-1} [T_e (R_e + (\psi_e - 1)T_e) + \rho(1 + s) \psi_e \sigma^2_D] u.
\]

Therefore, (64) reduces to:

\[
\frac{1}{2} u^T [T_e (R_e + (\psi_e - 1)T_e) + \rho(1 + s) \psi_e \sigma^2_D] T (\rho \Omega_T + T_e T_e)^{-1}
\]

\[
[T_e (R_e + (\psi_e - 1)T_e) + \rho(1 + s) \psi_e \sigma^2_D] u - \psi_e u^T T_e (R_e - T_e) u -
\]

\[
\frac{1}{2} \psi^2_e u^T T_e T_e u - \rho(1 + s) \psi^2_e \sigma^2_D,
\]

and thus:

\[
(\rho(1 + s) \sigma^2_D + g^2)^{-1} (g \gamma + (\psi_e - 1)g^2 + \rho(1 + s) \psi_e \sigma^2_D)^2
\]

\[
-2\psi_e g(\gamma - g) - \psi^2_e g^2 - \rho(1 + s) \psi^2_e \sigma^2_D,
\]

which can be reorganized to:

\[
\frac{(g \gamma + (\psi_e - 1)g^2 + \rho(1 + s) \psi_e \sigma^2_D)^2}{\rho(1 + s) \sigma^2_D + g^2} - \psi_e g(\gamma - g) - \psi_e (g \gamma + (\psi_e - 1)g^2 + \rho(1 + s) \psi_e \sigma^2_D),
\]

and so to:

\[
(g \gamma + (\psi_e - 1)g^2 + \rho(1 + s) \psi_e \sigma^2_D) \frac{g \gamma - g^2}{\rho(1 + s) \sigma^2_D + g^2} - \psi_e g(\gamma - g).
\]
Rewriting this yields:

\[ g(\gamma - g) \left( g\gamma + (\psi_e - 1)g^2 + \rho(1 + s)\psi_e\sigma_D^2 \right) \frac{1}{\rho(1 + s)\sigma_D^2 + g^2} - \psi_e \),

which can be reduced to the final expression (50):

\[ \frac{g^2(\gamma - g)^2}{\rho(1 + s)\sigma_D^2 + g^2}. \]

\[ \square \]

**Derivation of equation (55)** Substitution of (52) in (65) yields

\[ \frac{1}{2} \left[ u + (\psi_p - 1)(R_p)^{-1}T_p u \right]^T R_p R_p \left[ u + (\psi_p - 1)(R_p)^{-1}T_p u \right] - \psi_p u^T T_p (R_p - T_p) u - \frac{1}{2} \psi_p^2 u^T T_p T_p u - \rho(1 + s)\psi_p^2 \sigma_D^2, \]

which can be further developed into:

\[ \frac{1}{2} \beta^{-1} \left( \beta + (\psi_p - 1)b \right) \beta + (\psi_p - 1)b \right) R_p R_p \beta^{-1} \left( \beta + (\psi_p - 1)b \right) - 2\psi_p b(\beta - b) - \psi_p^2 b^2 - \rho(1 + s)\psi_p^2 \sigma_D^2, \]

and thus

\[ (\beta + (\psi_p - 1)b)^2 - \psi_p b(\beta + (\psi_p - 1)b) - \psi_p b(\beta - b) - \rho(1 + s)\psi_p^2 \sigma_D^2, \]

and

\[ (\beta + (\psi_p - 1)b) (\beta - b) - \psi_p b(\beta - b) - \rho(1 + s)\psi_p^2 \sigma_D^2, \]

to obtain (55)

\[ (\beta - b)^2 - \rho(1 + s)\psi_p^2 \sigma_D^2. \]

\[ \square \]
References


