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How Liable should an Exporter be? The Case of Trade in Hazardous Goods*

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Abstract

This paper analyzes liability issues in the context of internationally traded goods like hazardous waste. If waste disposers of a small open economy are judgement-proof, then the extension of liability to waste exporters distorts the factor allocation and may reduce disposal care. Hence the optimal extension is partial at most. However, extending liability increases incentives of the waste importing country to hold domestic disposers liable. Interaction through the price system and through contracts that condition payments for disposal services on the occurrence of an accident yield identical outcomes if disposers are judgement-proof.

Keywords: extended liability, hazardous waste trade, externalities, moral hazard

JEL-classification: K13, Q38, F18, D63

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1 Introduction

This paper analyzes liability issues in the context of internationally traded goods. A pertinent example concerns liability for damages that are caused by hazardous waste exports. During the 1980s, costs of waste disposal increased substantially in many OECD countries. Consequently, exports of hazardous wastes accelerated. It was widely perceived that this constituted a particular threat to developing countries who often lack the administrative, financial and technical capacities to ensure the environmentally sound disposal of hazardous waste (Strohm 1993; Montgomery 1995).[1]

Subsequent international negotiations led to the adoption of the 'Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal' (1989), who's central element is the requirement that waste exporters must obtain the 'prior informed consent' of importers.[2] Ten years later, the Convention was supplemented by the 'Basel Protocol on Liability and Compensation' (1999). While the Protocol holds waste exporters liable, it does so only for accidents that occur during the shipment of waste. In particular, Article 4.1 (Strict Liability) states that waste exporters "shall be liable for damage until the disposer has taken possession of the hazardous wastes and other wastes. Thereafter the disposer shall be liable for damage."

This provision has been criticized by some observers. The apprehension is that disposers will not take adequate care if they are judgement-proof. In national law, similar concerns have led to an extension of liability to lenders of judgement-proof firms, most notably with the 1980 Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) in the US (see, e.g., Boyer and Laffont 1996). Hence, the question arises whether exporters of hazardous waste should be subjected to extended liability for damages that occur during waste disposal, but that are not covered by the disposers themselves.

I investigate this issue from the perspective of a small open economy with two

[1]Some sensational incidents reinforced this view. One example concerns a Nigerian farmer who rented his land to an Italian company that deposited barrels with highly toxic polychlorinated biphenyl (PCB) and asbestos. Some barrels burst and local people, being unaware of the toxic load, even used them to store water (Logan 1991).

[2]Especially developing countries argued that an improved exchange of information is insufficient to control the risks that are associated with hazardous waste exports. In 1995, this led to a decision by the Parties to the Basel Convention to completely ban such exports from developed to developing countries. However, countries are reluctant to ratify the ban, which has not yet entered into force.

production activities. Firstly, the economy produces waste disposal services which are partly sold to waste exporters (i.e. importers of disposal services). Secondly, the economy produces a final consumption good which uses disposal services as an input. Waste disposal may lead to environmental accidents so that expected damage costs depend on two factors: the size of the disposal sector and the care chosen by disposers.

Various cases are considered. Firstly, I distinguish whether waste exporters and disposers interact through the price system, or through contracts that condition payments for waste disposal on the occurrence of an accident. The disposers' choice of care, however, is never contractible because it cannot be observed or verified. Secondly, I assume that disposers are judgement-proof for either of the two following reasons: Disposers may not have sufficient assets to compensate the victims. Alternatively, regulatory provisions may limit compensatory payments to the victims. For example, the Protocol on Liability and Compensation stipulates only a lower limit for disposer liability of currently 2 million Special Drawing Rights for any one incident (Annex B). Especially in developing countries, governments may face political difficulties to increase liability above this required minimum.

Besides deriving policy recommendations for the specific problem of hazardous waste trade, the paper contributes to the wider literature on extended liability and judgement-proof firms. For a moral hazard framework with a potentially judgement-proof firm that is similar to the one analyzed in this paper, Pitchford (1995) has shown that the (second best) optimal extension of liability is partial. The reason is that a waste exporter will demand financial compensation for the extension of liability upon it. If the disposer's wealth constraint binds, the exporter can do so only by lowering its payments in the no-accident state. Hence this state becomes less attractive for the disposer, reducing its incentives to take care. Interestingly, I find that price interaction, which has usually not been considered in the literature, yields exactly the same outcome. The reason for this 'degeneration' of contracts is the combination of a binding wealth constraint of the disposer (the principal) and a binding participation constraint of the waste exporter (the agent).

Accordingly, contracts are advantageous over price interaction only in the absence of wealth constraints, or if bargaining power is on the side of the waste exporter so that its participation constraint does not bind (see Balkenborg 2001). Moreover, in this case fully extending liability to waste exporters yields socially optimal care. Nevertheless, the factor allocation remains inefficient. The reason is that extending liability to waste exporters is similar to an export tax. It introduces a distortion by lowering the price of waste disposal for domestic producers of the consumption good, who will use too much disposal inputs. Therefore, making waste exporters liable for all damages that are not covered by the disposers themselves is never optimal. In addition, an accident probability above the socially optimal level reduces marginal returns of waste disposers, which further distorts the factor allocation. If waste exporter liability reduces care, it may even be optimal not to extent liability at all.

I also consider how waste exporter liability affects incentives of the government in the waste importing country to hold its domestic disposers liable. I find that a welfare maximizing domestic regulator chooses a higher level of disposer liability if waste exporters are also hold liable. This reflects that waste exporters will deduct their expected liability costs from the price they pay to disposers. Therefore, disposers have an incentive to keep these costs low. A higher level of domestic liability enables disposers to commit to more care and, thereby, to a lower accident probability.

The paper is in line with several others that have found a partial extension of liability to be optimal, while using different arguments (see, e.g., Boyd and Ingberman 1997; Boyer and Laffont 1997; Lüdeke and Endres 1999). Only some papers that allow for safety monitoring – an issue which is only briefly addressed in the concluding remarks – have argued for fully extended liability (Lewis and Sappington 2001; Feess and Hege 2003). Furthermore, most authors have analyzed how extended liability affects the care to avoid accidents for an individual project of fixed size. By contrast, I am also interested in how the liability regime affects the factor allocation and, therefore, activity levels. Other papers that analyze output effects are Hiriart and Martimort (2004), Laffont (1995) as well as Dionne and Spaeter (2003), but they use a different approach then the present paper. In the first, output effects are due to private cost information of the seller, leading to adverse selection. In the other two contributions, effort cost are monetary so that there is a trade-off between devoting effort to accident prevention or to production.

Finally, the paper is related to the literature on hazardous waste trade. Even though this literature is large,[3] there are only few contributions that use economic analysis. An exception is Copeland (1991) who analysis taxes on foreign waste (see also Rauscher 1997). However, it is straightforward to see that a liability system is preferable to a tax on waste disposal. A tax would also have to be paid in the no-accident case and, therefore, provides less incentives to exert care.

[3]See, e.g., the numerous references listed by the Basel Action Network (www.ban.org).

The Liability Protocol to the Basel Convention is one of the very few global environmental agreements that specify liability rules. In this respect, the Protocol is of substantial importance for the further development of international environmental law and politics. For examples, the analysis is relevant for the regulation of trade in hazardous chemicals and pesticides ('Rotterdam Convention of Prior Informed Consent'), and for trade in living modified organisms, which is regulated in the 'Cartagena Protocol on Biosafety'. Notably, the Cartagena Protocol provides that "the Conference of the Parties shall, at its first meeting, adopt a process with respect to the appropriate elaboration of international rules and procedures in the field of liability and redress for damage resulting from transboundary movements of living modified organisms" (Article 27).[4]

The paper is organized as follows. Section 2 introduces the basic model and determines the social optimum. Sections 3 and 4 analyze care choices if agents interact through the price system and state specific contracts, respectively. In Section 5, I turn to factor allocations and determine optimal liability rules. Section 6 analyzes how extended exporter liability affects incentives for the regulator in the waste importing country to hold domestic disposers liable. Section 7 concludes.

2 A model of trade in hazardous goods

I analyze trade in hazardous waste from the perspective of a small open economy with two production activities (see Copeland 1991). For parsimony, I assume that there is only one primary input factor k, which may be thought of as a vector of inputs that are used in fixed proportions. This input is used by a representative producer of a final consumption good $x = f(k_x, s_x)$.

Waste is a by-product of this production process, and the x-producer must pay for its disposal. Accordingly, it has to use disposal services s_x as a second input. Such services are produced by a domestic disposal firm from the primary input factor according to $s = g(k_s)$. I assume that both production functions are strictly concave in their arguments and that $f(k_x, s_x)$ exhibits constant returns to scale.

The consumption good x and disposal services s are traded at fixed world prices p_x and p_s, respectively. I normalize $p_x = 1$. Without taxes, liability rules or other

[4]The Rotterdam Convention entered into force on 24 February 2004, the Biosafety Protocol on 11 September 2003. Its first Conference of Parties established an Ad Hoc Group on Liability and Redress, which shall complete its work in 2007.

distortions, the domestic price for waste disposal equals the fixed world price p_s. Throughout the paper I assume that p_s is sufficiently high so that the economy under consideration is an exporter of waste disposal services. In particular, $g(k_s) = s_x + s_e$, where $s_e > 0$ are exports of disposal services.

Waste disposal is harmful if and only if an accident occurs. Expected monetarized damages are $\pi D g(k_s)$, where π is the non-contractible accident probability and $D \in \mathbb{R}^+$ are damages per waste unit in the case of an accident. Disposers can reduce the accident probability. As in the seminal contribution by Shavell (1986), I assume that this leads to a non-pecuniary (or effort) cost per unit of waste disposal, whose monetary equivalent is $c(\pi)$. In the concluding section I will discuss how pecuniary costs of care that reduce the disposers' assets would affect the results. I make standard assumptions $c'(\pi) < 0$, $c''(\pi) > 0$, $\lim_{\pi \to 0} c'(\pi) = -\infty$ and $c(1) = 0$. Finally, all parties are assumed to be risk-neutral.

To simplify the analysis and to focus on liability aspects, I assume that utility $u(\cdot)$ of the representative consumer in the waste disposal country is linear in the consumption good, in expected damages, and in non-pecuniary care costs. The consumer spends his complete income on x. Hence, the social optimum is obtained by maximizing $u(\cdot)$, subject to the economy's income constraint, and the given factor endowment, K (for parsimony, I always suppress the normalized price $p_x = 1$)

$$\max_{\{k_x, k_s, s_x, \pi\}} u(\cdot) = x - [\pi D + c(\pi)]\, g(k_s) \qquad \text{subject to} \tag{1}$$

$$x \leq f(k_x, s_x) - p_s s_x + p_s g(k_s), \tag{2}$$

$$k_x + k_s \leq K. \tag{3}$$

The r.h.s. of (2) specifies the economy's income, which consists of revenues of the x-firm less the costs of disposal inputs, and revenues of the disposal firm. Note that primary inputs k_s and k_x constitute revenues for consumers but costs for firms and, therefore, cancel out.

Throughout the paper, I assume that the economy does not specialize in either x or s. Given the above model specification, the constraints will then hold with equality. Substitution of (2) into (1) yields a concave objective function, with first order conditions for a social optimum (for parsimony, I always omit the binding factor endowment constraint):

$$\frac{\partial f(\cdot)}{\partial k_x} = [p_s - c(\pi^*) - \pi^* D]\,\frac{\partial g(\cdot)}{\partial k_s}, \tag{4}$$

$$\frac{\partial f(\cdot)}{\partial s_x} = p_s, \tag{5}$$

$$[D + c'(\pi^*)]\, g(\cdot) = 0. \tag{6}$$

According to (4) the marginal value of factor input k is equalized across sectors; according to (5) the marginal value of disposal input s_x equals its cost; and according to (6) the accident probability π^* equalizes marginal costs and benefits of care. In the absence of policy intervention, the private solution will obviously be suboptimal because accident costs of waste disposal are externalized. One way to correct this market failure is to make waste disposers fully liable for accidental damages. However, as argued in the introduction this policy may not be feasible, especially in developing countries. Accordingly, in the following I assume that liability of waste disposers is limited due to either wealth constraints or regulatory liability limits.

Hence, the question arises whether liability should be extended to the firms that make transactions with waste disposers. To focus on waste exporter liability, I assume that this is feasible only w.r.t. waste exporters, while political constraints make it impossible to extend liability to domestic producers of the consumption good. This reflects that discussions in connection with the Basel Protocol on Liability and Compensation have mainly focused on increasing responsibilities of waste exporting countries, who often belong to the OECD. I also assume that extended liability is limited to damages that are caused by the disposal of the exported waste. If an unequivocal attribution of damages to a specific source is not possible, then liability of the waste exporter is "proportional" to the share of its waste exports in the total amount of waste disposed of (see Boyd and Ingberman 1997). Finally, I assume that the accident probability is the same for the disposal of imported and domestic waste. For concreteness, one may imagine that waste is disposed of in a single incineration plant or deposited on a single landfill.

3 Accident probability with price interaction

Turning to the private solution, the sequence of events is depicted in figure 1. First, the level of extended exporter liability is chosen. Second, waste exporter and disposer

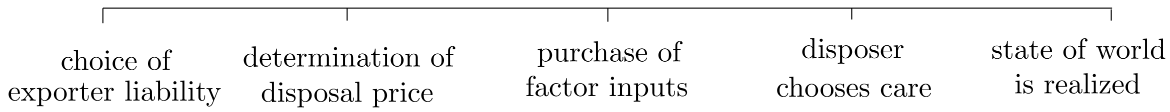

Figure 1: Timing in the model

decide on the price for disposal services. Third, producers of waste disposal services and the consumption good choose factor inputs k_s, k_x, and s_x. Fourth, the disposal firm chooses the accident probability π. Subsequently, with probability π an accident occurs, and payments are made.

By backwards induction, I begin with analyzing the waste disposer's choice of π. Let $E[p]$ be the expected unit price that the disposer receives for its services after accounting for its own liability cost. Then its maximization problem is

$$\max_{\{\pi\}} \left[E[p] - c(\pi)\right] g(k_s) - rk_s, \tag{7}$$

where r denotes the price of input k_s. Observe that the only relevant term is $E[p] - c(\pi)$. This facilitates a comparison of the results with the literature on extended liability, which has usually analyzed the case of an individual project of given size (e.g., Pitchford 1995; Balkenborg 2001).

$E[p]$ depends on the price that parties have agreed to in the second stage of the game. As discussed in the introduction, I distinguish between liability limits that are due to insufficient wealth and regulations, respectively. In the first case, let $\hat{F}$ represent the disposer's initial net wealth per waste unit disposed. The primary factor input, k_s, is paid prior to production; hence the remaining wealth is $F \equiv \hat{F} - r\frac{k_s}{g(k_s)}$, where $k_s/g(k_s)$ is the average input use per disposal unit.

Waste exporters can always buy disposal services at the world market price p_s without facing any liability obligations. For concreteness, this may be thought of as the price that waste exporters pay if they trade with OECD countries that use safe disposal technologies. Accordingly, if they trade with the waste disposal country, they will only be willing to pay p_s less their expected liability costs. I denote this price by

$$v_p = p_s - \pi(T - F - v_p), \tag{8}$$

where π is the anticipated accident probability, $T \geq 0$ is the joint or *total* liability of the disposer and the waste exporter per unit of waste, and subscript $_p$ refers to the scenario of price interaction. This reflects that payments are as follows. The waste exporter pays v_p to the disposer. In the accident case, the disposer uses this together with wealth F to compensate the victims, and the waste exporter pays $T-(F+v_p)$ to the government (or directly to the victims, which makes no difference in this model). Observe that the setup includes the case where total liability T is lower than disposer liability, $F+v_p$, so that the waste exporter would receive a subsidy if an accident occurs. Rearranging yields

$$v_p(\pi) = \frac{p_s - \pi(T-F)}{1-\pi}. \tag{9}$$

Due to arbitrage and the assumption that the disposer remains an exporter of its services at price v_p, the domestic x-firm also pays v_p. I restrict attention to cases where assets of the waste disposer are insufficient to fully cover damages D. Otherwise, strict liability of the disposer would implement the first best solution.

Assumption 1: $D > F + v_p(\bar{\pi})$, where $\bar{\pi}$ is the equilibrium accident probability.

Accordingly, if an accident occurs the disposer looses its complete wealth F. Otherwise, it gets v_p, yielding an expected unit payoff from disposal services

$$E[p] = -\pi F + (1-\pi)v_p. \tag{10}$$

Upon substitution into (7), the (privately) optimal accident probability, $\bar{\pi}$, solves

$$F + v_p(\pi) + c'(\pi) = 0, \tag{11}$$

which takes into account that v_p is given when the disposer chooses π.

Proposition 1 *(Interaction through the price system).*

- $\bar{\pi} > \pi^*$*, i.e. the accident probability exceeds the socially optimal level.*
- $d\bar{\pi}/dT > 0$*, i.e. the accident probability increases in the level of extended liability.*

Proof. See Appendix.

When choosing care, the disposer takes only its own liability obligations, $F+v_p$, into account (see 11). These are, by assumption, lower than D. We have a typical moral hazard problem because care is exerted *ex post*, i.e. after waste disposal services have been sold. Note that this problem would persist even if it were possible to extend liability to domestic waste producers as well.

Turning to the second statement, Pitchford (1995) has already shown that extending liability may reduce care if agents interact via contracts that condition payments on the occurrence of an accident. Proposition 1 shows that the same result obtains if agents interact via the price system. Increasing T and, thereby, exporter liability reduces the price v_p that the disposer receives in the no-accident case, while leaving its payoff with an accident, $-F$, unaffected (see 10 and 9). This reduces incentives to avoid an accident.

It may be surprising that this holds even for $T < F + v_p$, i.e. for the case where the waste exporter receives a 'subsidy' if an accident occurs. The reason is that the expected price which the waste exporter pays must always equal the world market price p_s (due to the assumption that the disposer represents a small country). Accordingly, any (expected) payments that the waste exporter receives above p_s – such as the 'subsidy' – must be given back to the disposer. The only way to do so is to pay a higher price in the no-accident case, thereby increasing incentives for care. Therefore, setting $T < F + v_p$ has the same effect as a direct government subsidy of equal size that the disposer receives in the no-accident case.

Finally, note that the expected price $E[p]$ is the same if the disposer has unlimited wealth, but regulatory provisions limit its liability to $F + v_p(\bar{\pi})$. Accordingly, the same accident probability obtains. However, in the absence of wealth limits such an outcome is unlikely to occur because Pareto-improving, self-enforcing contracts exist. Such contracts are analyzed in the next section.

4 Accident probability with contracts

Now I assume that waste disposers and exporters can sign contracts that condition payments on the occurrence of an accident (see Pitchford 1995). In particular, a waste exporter pays the waste disposer v_0 if no accident occurs and v_1 if an accident occurs. Given the focus on a small country, there will be many waste exporters competing for a contract *ex ante*. If contracts yield an expected price for disposal services (after accounting for the costs of extended liability) below the world price p_s, the waste disposer can play the exporters off against each other. Therefore, I assume that the disposer holds all the bargaining power in contract negotiations.[5]

As in the previous section, I first consider the case of a binding wealth limit and

[5]For a discussion of the role of bargaining power see Balkenborg (2001), Pitchford (1998) as well as Demougin and Helm (2005).

then briefly turn to regulatory liability limits. The waste disposer chooses contract elements (v_0, v_1) and accident probability π so as to maximize the expected price for disposal services after accounting for liability and care costs – subject to the constraints that (i) the waste exporter (weakly) prefers this contract to trading at the world price p_s, and that (ii) the accident probability as specified in the contract is incentive compatible.

A contract $v_0 = v_1 = v_p(\bar{\pi})$ would be identical to the scenario of price interaction as analyzed in the last section. Since the waste exporter's participation constraint binds in this case, it will not accept a contract with $v_0, v_1 > v_p(\bar{\pi})$. Furthermore, $v_1 \leq v_0$ as otherwise the accident state would be rewarded. Therefore, $v_1 \leq v_p(\bar{\pi})$ and $D > F + v_1$ by assumption 1. Accordingly, any payments v_1 that the disposer receives in the accident state are drawn upon for liability claims. This yields an expected price of disposal services after accounting for liability of

$$E[p] = -\pi F + (1 - \pi)v_0. \tag{12}$$

Hence the incentive compatible accident probability solves (11) if one replaces v_p by v_0. Furthermore, the waste exporter will only participate if its expected payments to the disposer, $(1-\pi)v_0+\pi v_1$, plus expected cost of extended liability, $\pi(T-F-v_1)$, do not exceed the world price p_s. It is straightforward to show that the participation constraint binds (otherwise the disposer would demand a higher price). This yields (9), replacing v_p by v_0. Accordingly, the solution is determined by the same equation system as with price interaction, and $v_p = v_0 \equiv v$.

Proposition 2 *(Interaction through contracts, binding wealth constraint). The privately optimal contract induces the same accident probability as price interaction.*

Accordingly, the effect identified by Pitchford (1995) – that care may decrease in extended liability – arises only because contracts are 'degenerate' in the sense that they replicate the situation with price interaction. The reason for this is the combination of a binding participation and wealth constraint. If we reversed the allocation of bargaining power, then the waste exporter's participation constraint would (usually) not bind and he would respond to a higher T by inducing the disposer to take more care (see Balkenborg 2001). Alternatively, if the wealth constraint did not bind, i.e. if $F + v_1$ were not completely drawn upon for liability claims, then increases in v_0 could be offset by reductions in v_1.

Taking up the latter case, suppose that the disposer has unlimited wealth. However, there is a regulatory liability limit of exactly the same size as at the end of the previous section, i.e. of $F + v_p(\bar{\pi})$. After accounting for liability costs, it then receives an expected price for its services of

$$E[p] = (1-\pi)v_{0n} + \pi v_{1n} - \pi[F + v_p(\bar{\pi})], \tag{13}$$

where subscript $_n$ refers to the no wealth constraint scenario. Furthermore, expected costs of extended liability for the waste exporter are $\pi[T - F - v_p(\bar{\pi})]$, so that the participation constraint becomes $E[p] + \pi T \leq p_s$. It is straightforward to show that the optimal accident probability will solve the first order condition (see, e.g., Pitchford 1995)

$$-T - c'(\pi) = 0. \tag{14}$$

The next result follows straightforwardly from (14), and comparing it with (6).

Proposition 3 *(Interaction through contracts, no wealth constraint). The accident probability decreases in the level of extended liability, and fully extending liability upon waste exporters induces the socially optimal accident probability.*

5 Factor allocation and optimal liability rules

I now turn to the choice of factor inputs. In the previous sections, I have distinguished between four cases along the following two lines: price versus contract interaction, and limited wealth versus regulatory liability limits. In all four cases, appropriate substitution shows that the disposer receives an expected unit payoff of $E[p] = p_s - \pi T$, though π may differ across cases. Intuitively, the waste exporter will shift its expected costs from extended liability to the disposer as it can always trade at the world market price p_s. Accordingly, the waste disposer chooses factor input k_s so as to[6]

$$\max_{\{k_s\}} \left[p_s - \pi T - c(\pi)\right] g(k_s) - rk_s, \tag{15}$$

with first order condition

$$[p_s - \pi T - c(\pi)]\frac{\partial g(\cdot)}{\partial k_s} - \frac{d\pi}{dk_s}[T + c'(\pi)]\frac{\partial g(\cdot)}{\partial k_s} = r. \tag{16}$$

[6]The assumption that the waste disposer exports its services can now be concretized. It requires that the unit payoff from selling to the international market, $p_s - \pi T - c(\pi)$, exceeds the domestic market clearing price. This will always be the case if p_s is sufficiently large.

The second term on the l.h.s. arises since changes in k_s affect disposer wealth per waste unit, $F \equiv \hat{F} - r\frac{k_s}{g(k_s)}$, which in turn affects π. This effect will be negligible if the average input use per disposal unit, $k_s/g(k_s)$, changes only by a negligible amount as k_s is marginally increased. In the following, I assume that this is the case so that the second term can be neglected. Observe that it is equal to zero with constant unit cost.[7] More generally, it is small if the production function $g(k_s)$ is not very curved and if output is relatively large. Without this simplification, the following elaborations would depend on third order derivatives in a rather complex way, making the analysis untractable.

Turning to the domestic x-firm, denote by ν_s the price that it pays for waste disposal services. After accounting for liability costs, the disposer's expected unit payoff from selling to the x-firm is $(1-\pi)\nu_s - \pi F$. Due to arbitrage, this must equal the expected unit payoff from selling to waste exporters, i.e.

$$(1-\pi)\nu_s - \pi F = p_s - \pi T. \tag{17}$$

Comparing this with (9), it follows that $\nu_s = v(\pi)$. Hence the profit maximization problem of the domestic x-firm becomes

$$\max_{\{k_x, s_x\}} f(k_x, s_x) - v(\pi)s_x - rk_x, \tag{18}$$

with first order conditions w.r.t. factor inputs

$$\frac{\partial f(\cdot)}{\partial k_x} = r, \tag{19}$$

$$\frac{\partial f(\cdot)}{\partial s_x} = v(\pi). \tag{20}$$

As in the social optimum (eqs. 4 to 6), the marginal value of factor input k is equalized across sectors (see 16 and 19), and the marginal value of disposal input s_x equals its cost. However, these marginal values may differ from the social optimum for two reasons: firstly, the accident probability, as given by (11) and (14), may be suboptimal; secondly, $v(\pi)$ may differ from p_s.

Proposition 4 *If the disposer is judgement-proof, i.e. $F + v(\bar{\pi}) < D$, then the private solution is always suboptimal.*

[7] Obviously, it is also zero for the case of contracts and no wealth limits, for which $T + c'(\pi) = 0$.

Proof. From propositions 1, 2 and 3, care is too low except for the case of contracts and no wealth constraints, where $T = D$ induces efficient care. However, by assumption 1 this implies $T > F + v(\bar{\pi})$ so that $v(\bar{\pi}) < p_s$ (by 8). Comparing (5) and (20), the marginal product of disposal inputs in the x-sector will be too low. □

Intuitively, the first best outcome could be achieved with full disposer liability and no extended liability, $F + p_s \geq D = T$, as this would completely internalize the externality. However, assumption 1 excludes this case. By contrast, if liability is partially shifted to waste exporters, this reduces the equilibrium price for disposal inputs. Domestic x-producers benefit from this reduced price without being liable themselves. Hence they will use too many disposal inputs. This effect of extended exporter liability is similar to an export tax.

Given proposition 4, the question for the optimal extent of waste exporter liability arises.[8] In particular, I am looking for the T that maximizes utility of the representative consumer – as given by (1) – subject to the income constraint

$$x = f(k_x, s_x) - v(\pi)s_x + [p_s - \pi T]g(k_s) + \pi[F + v(\pi)]g(k_s) + \pi[T - F - v(\pi)]s_e. \quad (21)$$

The first two terms are the income of the x-sector less costs for disposal inputs. The third term is the income of the waste disposal sector after accounting for the reduced price due to extended liability and own liability. The fourth and fifth term represent income from liability claims against domestic waste disposers and waste exporters, respectively. Note that the income constraint is the same in all four cases analyzed in Sections 3 and 4, though evaluated for different accident probabilities.[9]

Substitution of (21) into (1) and total differentiation w.r.t. T yields[10]

$$\frac{du(\cdot)}{dT} = -\pi(D - T)\frac{dg}{dT} - \pi[T - (F + v(\pi))]\frac{ds_x}{dT} - [D + c'(\pi)]\frac{d\pi}{dT}g. \quad (22)$$

Three effects are associated with an increase of waste exporter liability. Firstly, disposal is reduced because the disposer receives a lower price ($dg/dT < 0$, see

[8]See Copeland (1991) for a similar problem with taxes on foreign waste as the optimization variable.

[9]With contracts the disposer receives no payment in the accident case from waste exporters that can be drawn upon for liability. Accordingly, the income from liability claims is $\pi[F + v(\pi)]s_x + \pi F s_e + \pi(T - F)s_e$. The first two terms are the income from liability of disposal firms if they sell to the x-sector and waste exporters, respectively. The final term is income from extended liability. Rearranging the expression, it is identical to the last two terms in (21).

[10]To obtain this, note that $dk_x = -dk_s$ due the fixed factor endowment and use the equilibrium conditions for factor inputs, assuming that $d\pi/dk_s \approx 0$.

Appendix). Accordingly, also damages that are not covered by liability decrease. Secondly, the domestic x-sector now faces a lower price for waste disposal inputs and will increase their usage ($ds_x/dT > 0$, see Appendix). To the extent that liability for the disposal of domestic waste is lower than for imported waste, this reduces utility. Thirdly, extending liability affects the equilibrium accident probability. With price interaction, this effect is negative. With contracts, it is negative with a binding wealth constraint and positive else (see propositions 1 to 3).

In the optimum $du(\cdot)/dT = 0$. Solving for the optimal exporter liability, thereby using $ds_x = dg - ds_e$, yields

$$T^* - [F + v(\pi)] = (D - [F + v(\pi)]) \frac{dg/dT}{ds_e/dT} + \frac{d\pi}{dT} \frac{[D + c'(\pi)]\frac{g}{\pi}}{ds_e/dT}, \tag{23}$$

where T^* denotes the (privately) optimal level of total liability. Assuming that the second order condition holds, the next result follows.[11]

Proposition 5 *Fully extending liability to the waste exporter is never optimal, i.e.* $T^* < D$. *Except for the case of contracts and unlimited wealth, the optimal extension may even be negative, i.e.* $T^* - [F + v(\pi)] \leq 0$ *is possible. Furthermore, optimal extended liability is higher with contracts – compared to price interaction – if and only if there is no binding wealth constraint.*

Proof. See Appendix.

Extending liability to waste exporters reduces the price for domestic disposal services s_x and, thereby, distorts the factor allocation in a similar way as an export tax. In particular, $ds_x/dT > 0$ implies that $\frac{dg/dT}{ds_e/T} \in (0, 1)$ in (23). Therefore, $T^* < D$ even in the most optimistic scenario of contracts and unlimited wealth, for which the last term in (23) would be zero with $T^* = D$.

As explained after equation (22), two further effects determine the optimal level of extended liability. In particular, it tends to be lower if the disposal sector does not contract much as T is increased, i.e. if dg/dT is low. It is further reduced if a higher T induces a substantial increase in the accident probability, i.e. if $d\pi/dT$ is large. If this is effect is strong, it may even be optimal to set $T^* < F + v(\pi)$, since this induces the waste exporter to pay the disposer a bonus in the no-accident state (see the discussion after proposition 1).

[11] From the expressions for dk_s/dT and ds_x/dT in the appendix it is straightforward to see that the second order condition depends on third order derivatives in a non-trivial way.

6 Exporter versus disposer liability

In the previous section, I have analyzed the optimal extension of liability to waste exporters, i.e. $T - [F + v(\pi)]$. In the real world, regulators often have at least some discretion in choosing domestic liability. This is most obvious if F is a regulatory liability limit. In addition, even if F represents available wealth, the regulator may be able to influence it; for example by denying firms with insufficient wealth a licence for waste disposal or by stipulating obligatory insurance.

However, increasing domestic liability will usually be costly. In particular, the regulator may face fierce political lobbying by waste disposers, or it may be difficult to enforce due liability payments.[12] To represent this effect, I now assume that making domestic waste disposers liable involves costs $\theta(F)$ for the regulator, with $\theta'(F) > 0, \theta''(F) \geq 0$. This also provides an explicit argument for the assumption of limited disposer liability as used in the preceding sections.

How will the extension of liability to waste exporters affect the domestic regulator's choice of F? One might worry that governments perceive extended liability as a way to protect their domestic industry at the expense of waste exporters, while still assuring cover for damages that accrue domestically. In this scenario, waste exporter liability would have a negative effect on incentives to impose domestic liability. However, as the following proposition shows, the opposite is the case.[13]

Proposition 6 *(Price interaction and contract interaction with wealth constraints). Consider a waste importing country that disposes one unit of waste of the exporting country. The domestic regulator's incentive to raise waste disposer liability increases in the level of waste exporter liability, i.e. $dF/dT > 0$, provided that $c'''(\pi)$ is not too large.*

Proof. See Appendix.

The intuition is straightforward. It has already been mentioned that the waste exporter, who can always buy disposal services at the world market price p_s, shifts

[12] Obviously, in the absence of such costs a welfare maximizing domestic regulator would fully internalize damages by employing a rule of strict disposer liability and requiring $F + p_s \geq D$.

[13] I restrict attention on a single waste disposal project and abstain from an analysis of activity levels because they depend on T and F in a very complex way. However, it seems that an incorporation of effects on activity levels would further strengthen the result. In particular, it has been argued above that $T > F + v(\pi)$ distorts the factor allocation because the domestic x-firm pays a lower price for waste disposal than the waste exporter. The higher T, the greater the incentives to raise F so as to reduce this distortion.

any cost from extended liability to the domestic disposer. Therefore, the disposer benefits if it can commit to a lower accident probability π. In the cases of price interaction and contract interaction with wealth constraints, the only way to do so is via a higher level of domestic liability because the equilibrium level of care is determined by $F + v(\pi) + c'(\pi) = 0$. The higher T, the higher the price increase that the disposer obtains due to a lower accident probability.

Finally, note that in the case of contract interaction with unlimited wealth, the domestic regulator would choose $F = 0$ independent of the level of T. The reason is that imposing a positive level of F is costly, while it does not reduce the accident probability (see 14).

7 Conclusion

This paper has analyzed the extension of liability for damages of hazardous waste disposal to the exporters of such waste. Essentially, an extension of liability has three effects. Firstly, it leads to a contraction of the disposal sector, which is always positive if damages exceed the joint liability of waste disposers and exporters. Secondly, it affects the disposers' choice of care to prevent accidents. Thirdly, since it becomes more expensive to export disposal services, their domestic price falls in a small open economy. Accordingly, domestic producers increase the input of disposal services. In a more complex model, pollution intensive industries would benefit most from the lower disposal price. Though imports of hazardous waste would decrease, the country would become more attractive for pollution intensive industries.

Four different cases have been considered. Only in the case of contracts and unlimited wealth, the optimal extension of liability is always positive. However, even here it is only partial. In the other cases that have been considered – price interaction and contracts with limited wealth – the optimal extension of liability is higher if this leads to a large contraction of the damaging disposal sector, without increasing the accident probability too much. In principle, it may even be optimal to choose a negative level of extended liability. The intuition is that in a small open economy this resembles a subsidy which the disposer receives in the accident free state. Such a direct subsidy has not been considered in the model, but from a policy point of view it certainly seems much more realistic than 'subsidizing' waste exporters.

A positive effect of extending liability to waste exporters is that it usually increases incentives to hold domestic disposers liable. Nevertheless, the overall conclusion from the analysis is that quests to extend liability to exporters of hazardous goods should be treated with caution. If domestic firms that use the hazardous goods are judgement-proof, partial exporter liability may be welfare improving in some cases, but in others it is not.

A further result that has been obtained concerns the comparison of price interaction and interaction via state specific contracts. If a waste disposer's wealth constraint binds, then the two are actually equivalent and lead to the same accident probability.

An issue which has not been addressed is monitoring (see Feess 1999). For example, the disposer may allow the waste exporter to monitor its disposal activities, resulting in a signal whether the disposer has taken due care or not (Milgrom 1981). In the case of a bad signal, the disposer pays a fine to the waste exporter. A bad signal may arise also in the no-accident case, where the disposer's wealth limit does not bind. Therefore, such a scheme offers the disposer the possibility to commit to a lower accident probability by increasing the costs of too little care. Obviously, disposers have an incentive to do so only in the case of extended liability, in which they have to compensate waste exporters for the expected costs from extended liability.

A final caveat concerns the costs of care of a judgement-proof disposer. If these costs are pecuniary, then they reduce the assets with which the disposer is liable for damages. Effectively, care costs are paid only in the no-accident state. This increases incentives too take care, which may even be above the first best level (see Beard 1990 and Posey 1993). Nevertheless, waste exporters would still demand compensation for extended liability, and this compensation could be paid only in the no-accident state. Therefore, extended exporter liability would still increase the accident probability, counteracting the effect of monetary care costs. Accordingly, monetary care costs and the possibility of monitoring both seem to strengthen the argument for extending liability to waste exporters.

8 Appendix

Proof of proposition 1. The first statement follows straightforwardly from a comparison of (6) and (11), thereby noting assumption 1. For $T \leq F + p_s$, the second statement follows from implicit differentiation of (11). For $T > F + p_s$, it is proved along the lines of proposition 2(ii) in Pitchford (1995). Define

$$h(\pi, T) \equiv F + v_p + c'(\pi) \tag{24}$$

and suppose $\exists\, \pi = \pi^0$ such that $h(\pi^0, T) > 0$. Given the assumptions on $c'(\pi)$, then $\exists\, \bar{\pi} \in (0, \pi^0)$ such that (see Lemma A1 in Pitchford 1995)

$$\bar{\pi}(T) \equiv \min\{\pi | h(\pi, T) = 0\}. \tag{25}$$

From (9) one obtains $p_s > v_p$ for $T > F + p_s$ so that

$$h(\pi, T) < \; F + p_s + c'(\pi). \tag{26}$$

As $\lim_{\pi \to 0} c'(\pi) = -\infty$ by assumption, the right hand side is always negative for sufficiently small π. Accordingly, for any $T\, \exists\, \widehat{\pi} < \bar{\pi}(T)$ such that $h(\widehat{\pi}, T) < 0$. Now suppose that, in contradiction to proposition 1, $\bar{\pi}(T)$ is not increasing in T, i.e. for some $T_2 > T_1$ suppose $\bar{\pi}_2 \equiv \bar{\pi}(T_2) \leq \bar{\pi}(T_1) \equiv \bar{\pi}_1$. As $\partial h(\cdot)/\partial T < 0$ and $h(\bar{\pi}, T) = 0$,

$$h(\bar{\pi}_2, T_1) > h(\bar{\pi}_2, T_2) = 0 > h(\widehat{\pi}, T_1) \tag{27}$$

By the intermediate value theorem $\exists\, \pi \in [\widehat{\pi}, \bar{\pi}_2]$ such that $h(\pi, T_1) = 0$. However, $\bar{\pi}_1 \geq \bar{\pi}_2$ if $\bar{\pi}(T)$ is not increasing in T. Hence, this π cannot be the $\bar{\pi}(T_1)$ that solves $\min\{\pi | h(\pi, T_1) = 0\}$, a contradiction. □

Proof that $dg/dT < 0$ and $ds_x/dT > 0$. The endogenous variables, k_s, k_x, s_x, r, and π are defined by the first order conditions to the firms' maximization problems (15 and 18), full employment of factor endowments and the conditions determining the accident probability. It has been argued after eq. (16) that π is independent of the other endogenous variables, provided that the marginal effect of k_s on average input use per disposal unit is negligible; hence I abstract from the equations that determine it for the moment. Applying Cramer's rule to the remaining equation system then yields

$$\frac{dk_s}{dT} = \frac{[\pi + (T + c'(\pi))\frac{d\pi}{dT}]\frac{dg}{dk_s}\frac{\partial^2 f}{\partial s_x^2} + \frac{dv}{dT}\frac{\partial^2 f}{\partial s_x \partial k_x}}{[p_s - \pi T - c(\pi)]\frac{d^2 g}{dk_s^2}\frac{\partial^2 f}{\partial s_x^2} + \frac{\partial^2 f}{\partial k_x^2}\frac{\partial^2 f}{\partial s_x^2} - \left(\frac{\partial^2 f}{\partial s_x \partial k_x}\right)^2}. \tag{28}$$

Given the assumption that $f(k_x, s_x)$ is homogeneous of degree one in its arguments, by Euler's theorem $\frac{\partial^2 f}{\partial k_x^2}\frac{\partial^2 f}{\partial s_x^2} = \left(\frac{\partial^2 f}{\partial s_x \partial k_x}\right)^2$. Accordingly, the denominator of

(28) is clearly positive. Turning to the numerator, the effect of T on π has to be taken into account. Applying the chain rule to (9) yields

$$\frac{d}{dT}v(\bar{\pi}(T),T) = -\frac{\bar{\pi}}{1-\bar{\pi}} + \frac{p_s-(T-F)}{(1-\bar{\pi})^2}\frac{d\bar{\pi}}{dT}. \tag{29}$$

By proposition 1, $d\bar{\pi}/dT > 0$. For $T-(F+v) \geq 0$, substitution for v from (9) yields

$$\frac{(1-\bar{\pi})(T-F)-[p_s-\bar{\pi}(T-F)]}{1-\bar{\pi}} \geq 0 \qquad \Longrightarrow \qquad p_s-(T-F) \leq 0 \tag{30}$$

so that $dv/dT < 0$. Next, suppose $T-(F+v) < 0$. Implicit differentiation of (11) yields

$$\frac{d\bar{\pi}}{dT} = \frac{\bar{\pi}(1-\bar{\pi})}{p_s-(T-F)+c''(\bar{\pi})(1-\bar{\pi})^2}. \tag{31}$$

Upon substitution into (29), $dv/dT < 0$ since

$$\frac{\bar{\pi}}{1-\bar{\pi}} > \left(\frac{p_s-(T-F)}{(1-\bar{\pi})^2}\right)\left(\frac{\bar{\pi}(1-\bar{\pi})}{p_s-(T-F)+c''(\bar{\pi})(1-\bar{\pi})^2}\right). \tag{32}$$

Turning to the first term in the numerator of (28), in the case of contracts and no wealth constraints, $T+c'(\pi)=0$ (see 14). For the three other cases, suppose $v+F \leq T$. Using (11) yields $T+c'(\bar{\pi}) \geq 0$. If $v+F > T$, the sign is reversed and $T+c'(\bar{\pi}) < 0$. Dividing the numerator and denominator of (31) by $(1-\bar{\pi})$ and substitution then yields

$$\bar{\pi}+[T+c'(\bar{\pi})]\frac{d\bar{\pi}}{dT} = \bar{\pi} - \frac{[T+c'(\bar{\pi})]\bar{\pi}}{T+c'(\bar{\pi})-c''(\bar{\pi})(1-\bar{\pi})} > 0. \tag{33}$$

Finally, by homogeneity of degree 1, $\frac{\partial^2 f}{\partial s_x \partial k_x} > 0$ so that (28) is clearly negative, and

$$\frac{dg}{dT} = \frac{dg}{dk_s}\frac{dk_s}{dT} < 0. \tag{34}$$

Again using Cramer's rule,

$$\frac{ds_x}{dT} = \frac{[p_s-\pi T-c(\pi)]\frac{d^2g}{dk_s^2}\frac{dv}{dT} + [\pi+(T+c'(\pi))\frac{d\pi}{dT}]\frac{dg}{dk_s}\frac{\partial^2 f}{\partial s_x \partial k_x} + \frac{\partial^2 f}{\partial k_x^2}\frac{dv}{dT}}{[p_s-\pi T-c(\pi)]\frac{d^2g}{dk_s^2}\frac{\partial^2 f}{\partial s_x^2}} > 0 \tag{35}$$

by the above arguments. □

Proof of proposition 5. Above it has been shown that $dg/dT < 0$ and $ds_x/dT > 0$. Since $ds_e = dg - ds_x$, this implies $\frac{dg/dT}{ds_e/dT} \in (0,1)$ so that first term on the right hand side of (23) is always smaller than $D - (F + v)$. In the case of price interaction and/or a binding wealth limit – for which $d\bar{\pi}/dT > 0$ and $D + c'(\bar{\pi}) > 0$ – the second term further reduces optimal extended liability. If this effect is large, the r.h.s. may become negative.

Turning to the case of contracts and unlimited wealth, $d\pi/dT < 0$ so that the r.h.s. is positive for all $T < D$. Finally, in contradiction to proposition 5, assume that $T^* \geq D$. From proposition 3 this implies $\pi \leq \pi^*$ so that $D + c'(\pi) \leq 0$. Hence the second term on the right hand side of (23) can not be positive, and $D - (F + v) > T^* - (F + v)$ – a contradiction. The last statement in the proposition is obvious. □

Proof of proposition 6. The regulator's problem of choosing F is

$$\max_F x - c(\pi) - \pi D - \theta(F) \qquad \text{subject to} \tag{36}$$

$$x = p_s - \pi T + \pi(F + v) + \pi[T - (F + v)], \tag{37}$$

where the first two terms represent disposer profits and the other terms the income from liability claims against domestic disposer and waste exporter. The first order condition to this problem, and equation (11) that solves for the accident probability, determine the endogenous variables π, F. These two equations can be written as

$$p_s + F - \pi T + c'(\pi)(1 - \pi) = 0 \tag{38}$$

$$[c'(\pi) + D] \frac{d\pi}{dF} + \theta'(F) = 0. \tag{39}$$

Implicit differentiation of (38) yields

$$\frac{d\pi}{dT} = -\pi \frac{d\pi}{dF} = -\frac{\pi}{T - c''(\pi)(1 - \pi) + c'(\pi)} > 0, \tag{40}$$

where the sign follows from proposition 1. Upon substitution, (39) can be written as

$$c'(\pi) + D + [T - c''(\pi)(1 - \pi) + c'(\pi)]\theta'(F) = 0. \tag{41}$$

Implicit differentiation then yields

$$\frac{dF}{dT} = \frac{-\left[c''(\pi) + \left[2c''(\pi) - c'''(\pi)(1 - \pi)\right]\theta'(F)\right] \frac{d\pi}{dT} - \theta'(F)}{\left[c''(\pi) + \left[2c''(\pi) - c'''(\pi)(1 - \pi)\right]\theta'(F)\right] \frac{d\pi}{dF} + \theta''(F)\left[T + c'(\pi) - c''(\pi)(1 - \pi)\right]}. \tag{42}$$

Using (40), the numerator and the denominator are both negative, provided that $c'''(\pi)$ does not have a very large positive value. $\square$

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