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An optimal incentive contract to avert firm relocation

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- Preliminary and Incomplete Version -

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Abstract

In a globalized economy, firms move production to other countries without turning a hair. A local policy maker who seeks to avert relocation faces a dynamic problem – incentivizing the firm to remain in its home country today does not guarantee that the firm also stays in the future. We investigate situations where contracts between a local regulator and the firm can be written on some contractible productive activity, e.g. labor, output, or the firm’s emissions. The firm undertakes a location-specific investment that is not contractible. When long-term contracts are feasible, the regulator averts relocation by postponing a sufficient amount of transfer to the second period. With limited commitment, i.e. when only short-term contracts are feasible, contracts with positive transfers in the second period cannot be implemented if the firm’s investment is unobservable to the regulator. The regulator can avoid this problem by a tighter regulation in the first period. This induces the firm to invest more, which creates a ‘lock-in effect’ that prevents relocation without transfers in period 2. An important application of our model is in the area of climate policy, where firm relocation can be triggered via a unilateral introduction of an emissions price by a country.

Keywords: moral hazard; contract theory; limited commitment; firm mobility; abatement capital

JEL classification: D82, D86, L51

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1 Introduction

In a globalized world economy, a firm's location becomes a strategic choice. Changes in tax regimes, regulations of productive activities, work norms, or environmental regulations can render production more or less profitable in one country compared to another. When trade barriers are low, unilateral policy changes can, thus, induce firms to shift their production to other countries. Firm relocation may, however, be perceived by policy makers as harmful, because it is often associated with a loss of employment or tax revenues.

We study the issue of firm relocation in a dynamic setting, where a local regulator seeks to prevent the relocation of a firm to some other country in both periods. A moral hazard problem arises when the regulator cannot observe all productive decisions of the firm. We assume that the firm can undertake a location-specific investment (e.g., in more energy-efficient equipment, R&D, or abatement capital), that is not observable to the regulator or not verifiable and, hence, not contractible. However, the regulator can make transfer payments to the firm contingent on its location, as well as on other indicators of the firm's productive activity, such as its output, labor input, or emissions. While the firm's optimal choice of these activities is related with the investment, they are not fully revealing – some activities remain unobservable to the regulator so that the firm's investment cannot be inferred. What is crucial is that the investment cost is sunk, e.g. because the specific capital is immobile or has a lower value to the firm in the foreign country. Inducing a higher investment in the first period is, then, a lever to avert firm relocation on a long-term basis. We assume that the regulator's objective is to avert the firm's relocation permanently with a minimum of transfers.

An important distinction that we make is between long-term and short-term contracting. Under long-term contracting ('full commitment'), the regulator can offer to the firm contracts that last for two periods, and specify transfers as well as the firm's choice of its (verifiable) production decisions for both periods. Under short-term contracting ('limited commitment'), the regulator cannot make binding commitments that last for two periods. With changing majorities, legislation may be volatile over time, so that commitments can only be made on a short-term basis. We assume that under limited commitment, the regulator offers to the firm a new set of contracts in each period.

The regulator's problem under long-term contracting is simple, because the regulator's and the firm's interests are to some extent aligned. While the firm seeks to maximize its profits, the regulator seeks to avert the firm's relocation at minimal costs. But this clearly requires maximal profits. Hence, all productive variables are set to their profit-maximizing levels and the transfer is chosen such that it just compensates the firm for not relocating.¹

¹Alternatively the contract does not specify any choice of productive variables. The 'contract' is

With short-term contracting, the situation changes drastically. The optimal long-term contract is not implementable, when the firm prefers to pocket the transfer and relocate after one period. This allows for lowering the investment and, thus, saves investment cost. As a response, the regulator has to promise some transfer payment for the second period, when the firm did not relocate. However, contracts have to be sequentially optimal and promises of rewards in the future are not credible. The firm's private knowledge about its investment creates a hold-up problem. As long as positive transfers in the second period are required to avert the firm's relocation in that period, the regulator only pays a second-period transfer that makes the firm just indifferent towards relocation. But then the firm earns the same profit in its home country as in the foreign country in period 2, and finds it strictly profitable to lower its investment in period 1, planning to relocate in the second period from the beginning. This way, it incurs lower investment costs, but earns the same second-period profit. This hold-up problem is so severe that no outcomes can be implemented that involve any positive transfers in the second period when the firm's investment is unobservable to the regulator.

To circumvent this issue, the regulator can set a more stringent target for the firm's observable choices in the first period. This induces the firm to invest more, even when it plans to stay in its home country for only one period. But this implies that if the regulation in the first period is sufficiently restrictive, then the firm will not find it profitable anymore to relocate in period 2, even without transfers in that period due to the 'lock-in effect' of the investment. Via a tighter regulation in the first period, the regulator can, thus, subvert the hold-up problem, and prevent the firm's relocation in both periods, even though transfers are paid only in the first period. The cost of this lies in a larger (total) transfer payment and larger investments. This is the central result of our paper.

We also consider the case where the regulator can observe the firm's investment, but the investment is not verifiable and, hence, cannot be specified in a contract. We show that this enlarges the set of implementable outcomes. In particular, by setting a policy target in the first period that is sufficiently loose, the regulator can assure that the firm's investment is sufficiently *small*. In effect, the regulator is then committed to pay a positive transfer to the firm in the second period. Such an outcome is implementable if the investment is so small that it is optimal for planned relocation in period 2, given the policy target for the first period. Nevertheless, in equilibrium the firm does not relocate in any period. Hence, when the relocation option is sufficiently profitable, the regulator can either avert relocation by implementing an outcome with an inefficiently high investment (exploiting the lock-in effect), or an outcome that involves an inefficiently lax regulation in the first period, and a smaller investment. We show that when the profit in the foreign

merely a subsidy that is paid if the firm accepts to stay in the country. For the case of climate policy, subsidies in the form of 'grandfathering' of permits are structured in this way.

country is in an intermediate range, the regulator tightens the policy target for the firm in the first period in order to overcome the hold-up problem with the lock-in effect, as under unobservable investment. If the profit in the foreign country is sufficiently high, then this outcome becomes too distortive, so that the regulator resorts to the outcome with an inefficiently lax regulation in the first period. Although this outcome is distortive, too, the distortion in this case does not depend on the firm's profit in the foreign country.

Our modeling framework is very general, and various applications can be found.² The striking features of our results can perhaps be best understood in the context of climate policy. It is well-known that the unilateral introduction of an emissions price (e.g., under emissions trading) by a country can induce firms to relocate to other countries with less stringent environmental regulation.³ Firms may be incentivized to stay in their home country via a free allocation of emission permits, that may be coupled with firm-specific emission targets. Furthermore, the firm can reduce its emissions costs via investments in abatement capital or low-carbon technologies. Once the firm has invested enough in abatement capital, it is less affected by the emissions price, and its optimal emissions are lower. The regulator must, thus, assure that the firm does not secretly lower its investment in the first period, planning to relocate in the second period. This can be achieved via a more stringent emissions target for the firm in the first period. When the outside option is very attractive, i.e. the profit from relocation is very large, then the optimal contract indeed requires a very low level of emissions in the first period. The firm's emissions in the first period are, thus, distorted downwards (below their first-best level), and as a result, the firm's investment in abatement capital is distorted upwards when the investment is unobservable to the regulator. Our results, thus, indicate that the transfers which are implicit in any free allocation of emission permits to firms, should be made contingent on firms' current emissions or other indicators of their productive activity (such as output), rather than to allocate free permits only on the basis of a firm's past emissions ('grandfathering').

Related Literature

Our paper is closely related to the literature on repeated moral hazard. This literature, as surveyed by Chiappori et al. (1994), derives a principal's optimal contract when motivating an agent to exert costly effort. Rey and Salanie (1990) and Fudenberg et al. (1990)

²For example, in 1999 the Finnish telecommunications company Nokia received a subsidy from the German state North Rhine-Westphalia to maintain production of mobile phones in the region. The subsidy was linked to a guarantee to maintain at least 2.860 full-time jobs. In 2008, Nokia nevertheless announced to shut down production and relocate to Romania.

³Firm relocation is an important channel of 'carbon leakage' or more generally the leakage of emissions to other countries in response to unilateral emissions regulation. When leakage occurs, the emissions in a foreign country rise in response to the introduction of an emissions control policy in the home country (see, e.g., Babiker (2005)). Leakage is yet another reason why firm relocation may be perceived as harmful by the local regulator (in addition to job destruction or losses in tax revenues).

provide sufficient conditions for the implementability of the optimal long-term contract via a sequence of short-term contracts. However, they remain largely silent on the negative part, i.e. how the optimal sequence of short-term contracts differs from the optimal long-term contract when the two are not identical. Fudenberg et al. (1990) report two examples for environments where optimal long-term contracts fail to be implementable with short-term contracts, but do not go deeper into this problem.⁴

Only recently, a growing body of literature tackles the problem of limited commitment in repeated moral hazard problems. Manso (2011) looks at an agent who is motivated to innovate. The optimal long-term contract that induces the agent to experiment is shown to be not implementable with a sequence of short-term contracts. It is further shown that under certain conditions, outcomes with experimentation completely fail to be implementable. Bergemann and Hege (1998) study the problem of providing venture capital in a dynamic agency model and argue that short-term contracts can never substitute long-term contracts. In their model, however, problems of implementation do not arise. In another paper, Bergemann and Hege (2005) study the funding of a research project with uncertain return and date of completion. Only short-term contracts are considered and a distinction is made between observable and unobservable effort. As opposed to our results, they show that unobservable effort leads to a Pareto-superior outcome, compared to observable investment.

At the core of this paper, the ratchet effect plays a crucial role. Pioneered by Weitzman (1980), it has found its ways into the literature on contracting with limited commitment. Examples abound Lazear (1986), Gibbons (1986), Freixas et al. (1985) and Laffont and Tirole (1988). While Lazear (1986) argues that high-powered incentives are able to overcome the ratchet effect, Laffont and Tirole (1988) prove a result on the impossibility of implementing full separation with a continuum of types. All these works study models of adverse selection. The issue is then to compensate the agent today for that he will be exploited in the future, because *ex-ante* private information is typically revealed over time. We instead study a model of moral hazard, where the exploitation in the future has severe consequences on the problem of implementing effort in the first place.

A recent paper that studies the ratchet effect in model with moral hazard is Bhaskar (2014). He studies a dynamic principal-agent problem with moral hazard and learning. The difficulty of the job, undertaken by the agent, is *a priori* unknown to both parties. Conditional on first-period effort and output, both principal and agent update their beliefs. When shirking, the agent's posterior differs from the principal's, which gives rise to a ratchet-effect. A more pessimistic agent may refuse any second-period contract offer the principal makes. With continuous effort choices, any interior level turns out to be not implementable. The reason for the failure of implementability is similar to the

⁴Our model can be seen as a version of Example 1 in Fudenberg et al. (1990). The intuition behind their Example 2, however, fits better the observed implementation problem in our paper.

one present in our paper. The Ratchet-Effect gives rise to a 'take-the-money-and-run' strategy, which makes deviations from interior values profitable.⁵

Our paper is also related to the literature on incomplete contracts, e.g. Hart and Moore (1988). As in this literature, we allow contracts to depend on some observable characteristics, but not on investments. A well-known result is that with selfish investments, first-best outcomes can be achieved by committing to the optimal quantity before the investment stage.⁶ This is in line with our results in the case of long-term contracting. However, under short-term contracting the hold-up problem reappears once the investment cost cannot be recovered within one period. To account for this, the optimal contract is tougher and induces more investment. Joskow (1987) finds empirical evidence for a link between the contractual commitments of future trade and importance of relationship-specific investment. Our paper provides a theoretical foundation: when the contract length falls short of the time in which investments are recouped, efficient investment cannot be implemented.

In a model of repeated climate contracting between countries, Harstad (2012) finds somewhat similar results than we do. Countries repeatedly negotiate climate contracts, where emission levels are decided upon. Between the contracting stages they invest in abatement technology. A major finding, paralleling our results, is that shorter contract duration leads to tougher contracts and *lower* emission levels are agreed upon. However, due to the public good nature of investments, they remain at an sub-optimally low level, whereas in our model both the contracts are tougher and investments indeed are sub-optimally high.

The underlying assumption on a firm's incentive to relocate can be motivated from various strands in the literature. Horstmann and Markusen (1992), e.g., study the impact of a trade policy on market structure. They report that 'small policy changes can produce large welfare effects when equilibrium market structure shifts.' Also tax competition in general affects firm location, Wilson and Wildasin (2004) and Bucovetsky (2005) provide an overview.⁷

The impact of unilateral environmental regulation on firms' location decisions has first been analyzed formally by Markusen et al. (1993).⁸ In a two-country model, firms decide where to locate after governments have determined environmental taxes. Firms' location decisions are, therefore, very sensitive to differences in tax policies, as confirmed by Ulph

⁵We conjecture that the implementability problem in Bhaskar (2014) disappears when effort is observable, though remains to be non-contractible. Non-observability seems to be a crucial assumption to arrive at implementation problems of this kind.

⁶See for instance Proposition 5 in Segal and Whinston (2010).

⁷See also Hauffer and Wooton (2010).

⁸See also Markusen et al. (1995). Other examples comprise Motta and Thisse (1994), who analyze the relocation of firms already established in their home country in response to a unilateral anti-pollution policy pursued by the government in their home country. Further, Ulph and Valentini (1997) analyze strategic environmental policy in a setting where different sectors are linked via an input-output relation. Firms in different sectors, thus, have an incentive to agglomerate in a single country.

(1994) in a numerical calibration of the model. Our paper complements this literature in that it provides a method to counterbalance the adverse effects on firm location.

Schmidt and Heitzig (2013) study the dynamics of 'grand-fathering' schemes. They show that these, if optimally designed, can permanently avert firm-relocation. As compared to our paper, full contractual commitment by the regulator is assumed. Their findings comply with our results on long-term contracting. In particular, with full-commitment, simple transfer schemes are sufficient. With limited commitment, however, our results indicate that these simple grandfathering schemes are not optimal anymore and contracts should be made contingent on other observable characteristics, such as emissions.

The remainder of this paper is organized as follows. Section 2 introduces the model and identifies the lock-in effect of investments that plays a crucial role for our results. In section 3 we study the case of long-term contracting. Short-term contracting is investigated in section 4, where we also distinguish between observable and unobservable investment. Section 6 concludes. All formal proofs are relegated to the Appendix.

2 Model

2.1 Preliminaries

Consider two countries, A and B , and one regulated firm that is initially located in country A . The time frame under consideration consists of two periods. If the firm produces in country A , it realizes a per-period profit of $\pi_A(e, a)$, where e is an indicator of the firm's productive activity and a is a stock of capital available to the firm. The profit function $\pi_A(e, a)$ is given in *reduced form*. In particular, all other potential factors, such as input and output quantities, are already chosen optimally by the firm, given e and a .⁹

For illustrative purposes we henceforth present the model in terms of our environmental example. Then e stands for emissions and a is abatement capital. The reduced form profit consequently represents the firm's profit under optimal choices of output, prices, qualities etc.

The capital stock a is established at the beginning of period 1 and is thereafter available for both periods of production.¹⁰ The cost of installing a capital stock of $a \geq 0$ is given by the strictly convex cost function $K(a)$, with $K(0) = K'(0) = 0$. Emission levels are chosen in each period, so we denote e_τ the emission level in period $\tau \in \{1, 2\}$. The firm's discounted profit from producing in country A in *both* periods, when choosing

⁹Below, we will show how to derive the function $\pi_A(e, a)$ for a specific example, where the firm has one additional choice variable (output), which is chosen optimally for any given values of e and a .

¹⁰In particular we assume there is no depreciation of capital. Allowing for a positive rate of depreciation would not change our results.

emission levels e_1 and e_2 as well as capital a is

$$\pi_A(e_1, a) - K(a) + \delta\pi_A(e_2, a), \quad (1)$$

where $\delta > 0$ is the discount factor.¹¹ At the beginning of each period, the firm has the choice to relocate to country B , where it earns a per-period profit of π_B . Relocation is once and for all and for simplicity assumed to be costless. If the firm relocates immediately (at the beginning of period 1) to country B , it earns a total profit of

$$V_B = (1 + \delta)\pi_B. \quad (2)$$

In this case, the firm has no incentive to invest in abatement capital. The firm can also stay in A for only one period, and relocate to B at the beginning of period 2. This strategy, referred to as ‘location plan AB ’, amounts to a discounted profit of

$$\pi_A(e_1, a) - K(a) + \delta\pi_B. \quad (3)$$

We assume that capital is immobile and can only be used in country A , and that the investment costs in a are *sunk*. We make the following technical assumptions regarding the profit function $\pi_A(e, a)$.

Assumption 1.

$$\frac{\partial^2 \pi_A}{\partial e^2} < 0, \quad \frac{\partial^2 \pi_A}{\partial a^2} < 0, \quad \frac{\partial^2 \pi_A}{\partial e \partial a} < 0,$$

as well as the Hessian of $\pi_A(e, a)$ is negative definite.¹²

The first two assumptions describe a decreasing-returns technology and the third implies that the firm’s optimal emissions are lower when it has installed a larger capital stock. Furthermore, let us define the firm’s *maximal profit* after having installed capital a , when choosing the emissions optimally,

$$\pi_A^*(a) = \max_e \pi_A(e, a), \quad (4)$$

and denote $e^*(a)$ the corresponding maximizer. We make the following assumption:

Assumption 2. $\pi_A^*(a)$ is strictly increasing in a , the value $e^*(a)$ is unique and finite.

Hence, we assume that the firm is better off with a larger stock of capital, when

¹¹We allow for $\delta > 1$, which admits time periods of different length and/or economic importance.

¹²The assumption on the Hessian is required to prove global concavity of the value functions V_A and V_{AB} defined in equations (5) and (6). This in turn is used to prove uniqueness of maximizers. Obviously milder assumptions on π_A are sufficient for this purpose, but this would lead to tedious case-by-case discussions.

it chooses its emissions optimally.¹³ It will turn out convenient to define the following short-hand notations. Let

$$V_A(e_1) = \max_a (\pi_A(e_1, a) - K(a) + \delta\pi_A^*(a)) \quad (5)$$

be the firm's profit when staying in country A in both periods, with first-period emissions e_1 , choosing e_2 optimally in period 2 and choosing a optimally in period 1. The corresponding maximizer is denoted by $a_A(e_1)$. Similarly,

$$V_{AB}(e_1) = \max_a (\pi_A(e_1, a) - K(a) + \delta\pi_B) \quad (6)$$

is the firm's profit under location plan AB with first-period emissions e_1 , given an optimal investment for this location plan. The corresponding maximizer is denoted by $a_{AB}(e_1)$. We shall assume that the values $a_A(e_1)$, resp. $a_{AB}(e_1)$ indeed exist.¹⁴ The following Lemma provides helpful properties of the defined functions and their maximizers.

Lemma 1. *Given Assumptions 1 and 2, the functions V_A and V_{AB} are strictly concave and thus the maximizers $a_A(e_1)$, resp. $a_{AB}(e_1)$ are unique. Furthermore it holds that*

$$a_A(e_1) > a_{AB}(e_1) \quad \forall e_1.$$

Hence, if the firm plans to stay in A in both periods, it invests more than when it plans to relocate after one period

The following Lemma is an immediate consequence of the investment costs being sunk.

Lemma 2. *For any level of first-period emissions, the option to relocate after one period is always inferior to either immediate relocation or no relocation (or both). More specifically, it holds for any e_1 that $V_{AB}(e_1) < \max\{V_A(e_1), V_B\}$.*

The Lemma establishes the *lock-in* effect the firm faces. Whenever she finds it optimal to stay for one period in country A , the firm will undertake some investment. Location plan AB can only be optimal if the net profit in period 1, i.e. profit from production minus the cost of installing capital, exceeds the profit in country B . But then the corresponding per-period profit of production in country A already exceeds π_B . Therefore, it is now optimal to stay in country A also for the second period if the firm is free to choose its emissions in that period.

An immediate consequence of the lock-in effect is that a sufficiently high investment in period one will render the relocation option of the firm sub-optimal in period 2. This

¹³This is a natural assumption, because with a larger a the firm can implement the same production plan (e.g., output) with fewer emissions and, therefore, lower emissions costs.

¹⁴Imposing Inada conditions on the firm's profit function $\pi_A(e, a)$ yields existence. As can be seen from our example below, milder assumptions serve the same purpose. Imposing stronger conditions helps only for existence, but complicates the analysis of specific examples substantially.

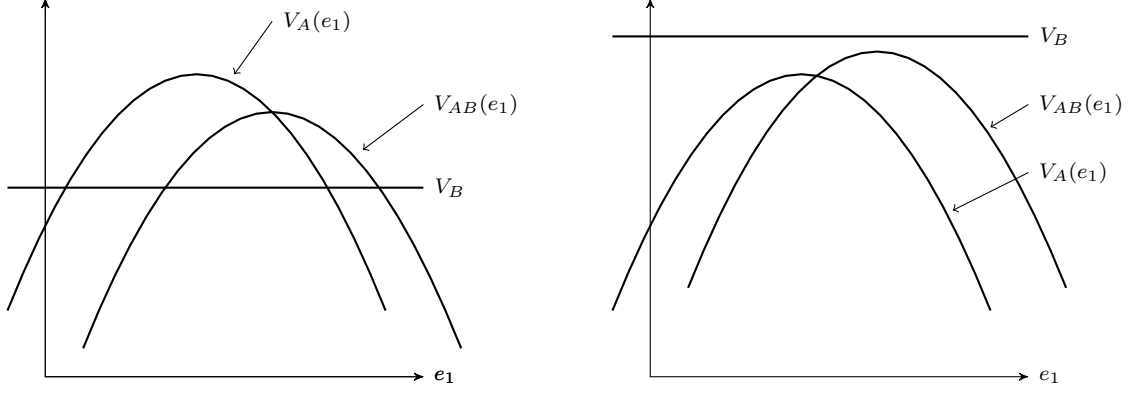


Figure 1: Characteristic profit functions and their relation to one another for low profit π_B (left) and large profit π_B (right).

will play a crucial role later on. Figure 1 illustrates the typical shape of the firm's profit function for the different location plans. Note, that raising π_B does not affect V_A , whereas it shifts V_{AB} as well as V_B upwards.

According to Lemma 2, the firm prefers either to stay in country A for both periods or to relocate immediately. Only the latter case is of interest for us, since it calls for regulatory intervention, as we will point out later on. To make this assumption more precise, let e_A^o be the optimal (first-period) emission level when the firm plans to stay in country A for both periods. It is given by

$$e_A^o = \arg \max_{e_1} V_A(e_1). \quad (7)$$

It is straightforward to verify that given this optimal choice of first-period emissions, it holds that $e_2 = e_1 = e_A^o$.¹⁵ Also define $V_A^o = V_A(e_A^o)$. Therefore, the firm strictly prefers immediate relocation over no relocation if and only if

$$V_B > V_A^o \quad \Leftrightarrow \quad \pi_B > \frac{V_A^o}{1 + \delta} =: \pi_B^0. \quad (8)$$

Throughout the paper we maintain the assumption that π_B satisfies inequality (8), which means the firm strictly prefers to relocate to country B immediately rather than to stay in A in both periods (in the absence of regulatory intervention).

Let us briefly look at a specific example, that illustrates how the profit function $\pi_A(e, a)$ can be derived in a specific environment.

Example 1. Consider a polluting firm, that produces a quantity q emitting e units of greenhouse gases. The firm faces the inverse demand $P(q) = 3 - q/2$. Marginal costs of production are constant and normalized to zero. The emissions price in A (e.g., following

¹⁵After all, the firm uses the same stock of investment in both periods. Hence, the optimal emissions across periods are constant.

the introduction of a cap-and-trade scheme) is equal to 1. Consequently, the firm's per-period profit in country A, gross of abatement capital installation cost is $\tilde{\pi}_A(e, q) = (3 - q/2)q - e$.

Emissions are a function of output and the firm's abatement capital stock. More precisely, the firm's emissions are additive in q and a , i.e. $e(q, a) = q - a$. Inserting this into $\tilde{\pi}_A(e, q)$, we obtain the firm's profit function in *reduced form*:¹⁶

$$\pi_A(e, a) = 3a + 2e - (a + e)^2/2. \quad (9)$$

Maximizing this over e , we find that the firm's optimal emissions (given a) are $e^*(a) = 2 - a$. This leads to a maximal per-period profit in A of $\pi_A^*(a) = 2 + a$.

Let investment costs be given by the quadratic cost function $K(a) = a^2/2$. If the firm plans to stay in country A in both periods, it thus solves:

$$\max_a 3a + 2e - \frac{(a + e)^2}{2} - \frac{a^2}{2} + \delta(2 + a).$$

This yields $a_A(e) = (3 - e + \delta)/2$ and $e_A^o = 1 - \delta$. The resulting value of the firm's discounted profits is $V_A^o = \frac{1}{2}(5 + 6\delta + \delta^2)$.

If the firm plans to stay in country A for only one period, it solves:

$$\max_a 3a + 2e - \frac{(a + e)^2}{2} - \frac{a^2}{2} + \delta\pi_B,$$

yielding $a_{AB}(e) = (3 - e)/2$ and $e_{AB} = 1$. Observe that the firm's emissions are higher and the abatement capital investment is smaller when it plans to relocate after one period.

2.2 Regulation

Returning to our general model, we now consider the interaction of the firm with a regulator, resp. a policy maker, in country A. The regulator's objective is to incentivize the firm to stay in country A for *both* periods with minimal transfers payments.

Tot this end, the regulator offers the firm contract(s) in a take-it-or-leave-it manner. We assume that the firm's emissions in each period are contractible. However, the investment in abatement capital is not contractible and for most of the paper assumed to be not observable to the regulator.¹⁷ Consequently contracts specify a transfer to the firm, denoted by t , and emission levels the firm has to comply with. The payment of a transfer is made contingent on the firm's location. We assume that any payments stop as soon as the firm relocates. The firm also has the possibility to refuse any contract offer and

¹⁶It is easy to verify that the function $\pi_A(e, a)$ fulfills our earlier assumptions.

¹⁷We make the distinction between observable and unobservable investment in section 4. With long-term contracts observability of a does not make a difference.

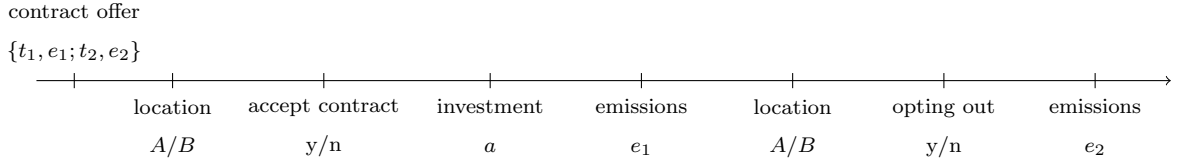


Figure 2: Timing with long-term contracting.

either relocate to country B , or produce in country A on its own account.

Throughout the paper, we distinguish between long-term and short-term contracts. The former specify emission levels and transfers for each single period, i.e. a long-term contract is a quadruple (t_1, e_1, t_2, e_2) . This implicitly assumes that the regulator can fully commit to all present and future contractual obligations. The firm, however, maintains an exit-option: At the beginning of period 2 she can leave the contract and either relocate to country B or produce in county A on her own account, i.e. stay without being regulated.¹⁸

The timing with long-term contracting is depicted in Figure 2. First, the regulator offers a contract for both periods. The firm observes the contract offer and decides whether or not to relocate to country B in period 1. If the firm relocates, the game ends. Otherwise, it decides whether or not to accept the contract, and chooses a level of abatement capital investment and production starts according to the terms specified in the contract.¹⁹ Hereafter, first-period transfers are paid out. If the firm stays in A without accepting a contract, it produces on its own account, and there are no transfers. At the beginning of the second period, the firm again decides about its location. If it relocates, the game ends. If it stays in A , production takes place in period 2 according to the contractual obligations if the firm has accepted a contract in period 1 and sticks with the contract in period 2. Transfers are, then, paid as specified in the contract. If the firm opts out of the contract in period 2 but stays in A , or if it has not accepted a contract in period 1 and did not relocate, it produces on its own account in period 2.

We contrast long-term contracts, i.e. full commitment on the regulator's side, with short-term contracts. Under short-term contracting we understand that the regulator offers a sequence of one-period contracts (t_τ, e_τ) . The timing for this case is depicted in Figure 3. In the first period a short-term contract (t_1, e_1) is offered to the firm. The firm learns the contract and decides whether to relocate. If she does not relocate she decides upon accepting the contract. Thereafter she invests in abatement capital and production takes place (according to the terms specified in the contract if accepted). The second period starts with a new contract offer (t_2, e_2) by the regulator (unless the firm already

¹⁸Exit Options are common in the literature on repeated moral hazard, see the discussion in Chiappori et al. (1994). The assumption in our paper does not affect the qualitative results. Rather it provides an evident link between long-term and short-term contracts.

¹⁹The firm's decisions within a period are, of course, simultaneous. We split them up here for reasons of tractability.

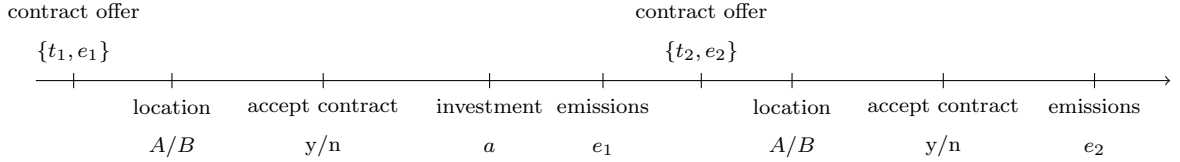


Figure 3: Timing with short-term contracting.

relocated in period one). The firm observes the offered contract and decides whether to relocate in period 2 or not. If it stays in A , the firm can accept the contract and produce according to the contractual terms or reject the contract, in which case she produces on her own account and does not receive any transfer payment in period 2.

3 Long-term contracting

We begin our analysis of the optimal regulatory policy with the case of long-term contracting (full commitment). The objective of the regulator is to incentivize the firm to produce in country A in both periods, using a minimum of transfers.

Given emission levels e_1 and e_2 , the firm accepts a total transfer t whenever²⁰

$$\max_a (t + \pi_A(e_1, a) - K(a) + \delta\pi_A(e_2, a)) \geq V_B. \quad (10)$$

The constraint is binding, which yields $t = V_B - \max_a (\pi_A(e_1, a) - K(a) + \delta\pi_A(e_2, a))$. Minimizing the transfer, thus, corresponds to maximizing the firm's profit. Formally, maximizing the expression for t with respect to e_1 and e_2 is equivalent to maximizing

$$\pi_A(e_1, a) - K(a) + \delta\pi_A(e_2, a)$$

first over e_2 , then over a and lastly over e_1 . Using our definitions from the last section, maximization over e_2 and a yields the function $V_A(e_1)$.²¹ Now, maximizing $V_A(e_1)$ yields $e_1 = e_A^o$, as described in (7) and the required transfer is $t = V_B - V_A^o$. We summarize this in the following Proposition.

Proposition 1. *The optimal long-term contract specifies $e_1 = e_2 = e_A^o$ and pays a total transfer of $t = V_B - V_A^o$.*

Notice that equivalently the regulator can just set the total transfer as specified above and leave all other decisions at the firm's discretion. When the firm accepts the contract

²⁰Because the discount factor is the same for the firm and the regulator, it is sufficient to consider the total transfer, not specifying when it is paid. With differing discount factors the regulator would have a strict preference for either paying transfers in period one or in period two. This has only effects on the implementation of long-term contracts, the analysis with short-term contracts remains unaffected.

²¹See equation (5) for details.

she finds it in her best interest to choose e_1 and e_2 at their profit maximizing levels. On the other hand, the firm accepts the payment only if her profit plus transfer exceeds the profit from (immediate) relocation.

3.1 Implementation with short-term contracts

To segue from long-term to short-term contracts, we examine whether and how the optimal long-term contract can be implemented via a sequence of short term contracts. With short-term contracts the timing of transfer payments plays a crucial role. In the second period optimality requires a minimal transfer payment, that is just high enough to avert relocation. In particular, the second period transfer cannot account for the investment the firm undertook in period one, because this investment is now sunk. As an immediate consequence, the long-term contract can only be implemented via a sequence of short-term contracts if the first-period transfer fully compensates the firm's investment.

Thus, paying the entire transfer in period one would be sufficient. But this facilitates the firm to make use of a 'take-the-money-and-run'-strategy. Short-term contracts also imply that the firm is free to reject any second-period offer. The firm can, for large first-period transfers, choose to underinvest in period one while planning to relocate in period two. Then the second-period transfer, which refers to a higher investment, is insufficient to keep the firm in country A . The tension created by this makes it impossible to implement a long-term contract with short-term contracts, whenever this requires a positive second-period transfer.

Proposition 2. *The optimal long-term contract can be implemented via a sequence of short-term contracts, if and only if $V_A^o \geq V_{AB}(e_A^o)$.*

This equivalent to $\pi_B \leq \pi_B^\sharp$, where $\pi_B^\sharp > \pi_B^0$ is defined by

$$\pi_B^\sharp := \frac{V_A^o - \pi_A(e_A^o, a_{AB}(e_A^o)) + K(a_{AB}(e_A^o))}{\delta}.$$

The respective contracts are $(t_1, e_1) = (V_B - V_A^o, e_A^o)$ and $(t_2, e_2) = (0, e_A^o)$.

If the condition of Proposition 2 is met, it is unprofitable for the firm to plan relocation in period two. Furthermore, which is shown in the proof, the first-period emission level is already sufficient to create a lock-in-effect. With the respective investment, no second-period transfer is necessary to avert relocation in period two. In fact, the firm strictly prefers to stay in country A also in period two. Whenever the condition is not met, some transfer payment must be delayed to period two in order to allure the firm from planned relocation. But this transfer strictly exceeds the sequentially optimal level that just compensates the firm in period two for not relocating, because it entails a mark-up for first-periods investment.

We conclude this section by reflecting the above results in our earlier example.

Example 2. Let us briefly return to Example 1. Applying Proposition 1, the optimal long-term contract specifies emission targets $e_1 = e_2 = e_A^o = 1 - \delta$. Total transfer is $t = V_B - V_A^o = (1 + \delta)\pi_B - \frac{1}{2}(5 + 6\delta + \delta^2)$.

From this we have $V_A^o = \frac{1}{2}(5 + 6\delta + \delta^2)$. Notice, that $a_{AB}(e_A^o) = 1 + \delta/2$ and therefore $V_{AB}(e_A^o) = \frac{1}{2}(5 - \delta^2/2) + \delta\pi_B$. We have $V_A^o \geq V_{AB}(e_A^o)$ if and only if $\pi_B \leq \pi_B^\# = 3 + \frac{3}{4}\delta$. Notice that $a_A^o = 1 + \delta$ and $\pi_A^*(a_A^o) = 3 + \delta > \pi_B$ whenever $\pi_B \leq \pi_B^\#$. This is again the lock-in-effect.

4 Short-term contracting

In this section we assume that the regulator cannot commit to a contract that specifies emissions and transfers for both periods and instead has to resort to a sequence of short-term contracts. This sort of limited commitment adds new constraints to the principal's problem. Clearly, the second-period contract offer must be sequentially optimal. When the offer is made, the firm has already accepted the first-period contract and has made the initial investment. Furthermore, the firm chooses its investment given the contract offer (t_1, e_1) from period 1, but before it is offered a second-period contract (t_2, e_2) . Hence, it will anticipate that offer, and choose its investment as a best response to the anticipated second-period offer.

In our setup, moral hazard can manifest itself in two different ways, and in this section we will distinguish between them because this matters under short-term contracting. On the one hand, it may be that the regulator can observe the firm's actual investment in capital but a is not verifiable, i.e. contracts including a remain not enforceable. On the other hand, a may be unobservable to the regulator. In the first case, the regulator will take the true value of a into consideration when designing the second-period contract offer. In the second case, this is not possible, so the second-period contract offer cannot depend on the true value of a .

In both cases, we can apply Subgame Perfect Equilibrium as our solution concept and backward induction as the solution method. In the first case (observable investment), this is obvious, because every action of the firm is observable, and there is a proper subgame after every move.²² In the second case (unobservable investment), the firm's investment remains private knowledge of the firm, and the firm cannot change its investment when the second-period contract offer (t_2, e_2) is being made. Effectively, the two sequential stages where the firm makes the investment and the regulator offers a new contract in period 2, can be treated as a simultaneous move game. The firm's investment choice creates no further information, until the regulator made the contract offer. Only after accepting or rejecting this offer, some information is revealed. Hence, Subgame Perfect

²²In particular, the regulator can make her offer (t_2, e_2) dependent on a .

Equilibrium is the appropriate equilibrium concept also under unobservable investment. This simplifies our analysis.

Assuming that the firm did not relocate in period 1, the final stage is the same in both cases: The firm, when having installed a capital stock a , accepts the second-period contract offer (t_2, e_2) if and only if²³

$$t_2 + \pi_A(e_2, a) \geq \max\{\pi_B, \pi_A^*(a)\}. \quad (11)$$

This assures that the firm does not relocate in period 2, or stays in country A on its own account (without accepting the second-period contract offer). In the latter case, the firm's maximal profit in period 2 is $\pi_A^*(a)$.

4.1 Observable Investment

Let us now focus on the case where the firm's investment is observable. When offering a contract that is to be accepted, the regulator thus minimizes the transfer payment t_2 by choosing

$$e_2(a) = \arg \max_e \pi_A(e, a) = e^*(a). \quad (12)$$

This is an immediate consequence of condition (11), where the right-hand side does not depend on e_2 . The corresponding second-period transfer is $t_2(a) = \max\{0, \pi_B - \pi_A^*(a)\}$. The following Lemma summarizes.

Lemma 3. *Assume the firm has not relocated in period 1 and has installed capital stock a . When a is observable, the regulator's optimal second-period contract offer is given by*

$$(t_2, e_2) = \begin{cases} (0, e^*(a)), & a \geq \bar{a}, \\ (\pi_B - \pi_A^*(a), e^*(a)), & a < \bar{a}, \end{cases} \quad (13)$$

where \bar{a} is defined by $\pi_B = \pi_A^*(\bar{a})$.

Intuitively, \bar{a} defines a critical investment level. If the firm installs a capital stock at least as large as \bar{a} , then no further transfers are required to prevent it from relocating in period 2, since the option to stay in A already dominates (given a). Conversely, if the regulator observes that the firm has invested less ($a < \bar{a}$), a positive transfer is required in period 2 to prevent the firm's relocation in that period. The transfer is just large enough to render the option to stay in A as profitable as the option to relocate in period 2.

Following Lemma 3, the firm's (expected) payoff at the investment stage after having accepted the first-period contract (t_1, e_1) , when it does not plan to relocate in any period, can be written as²⁴

²³We implicitly assume that the firm accepts any offer that keeps her just indifferent.

²⁴Notice that the expected profit does not depend on whether the firm accepts or rejects the offered

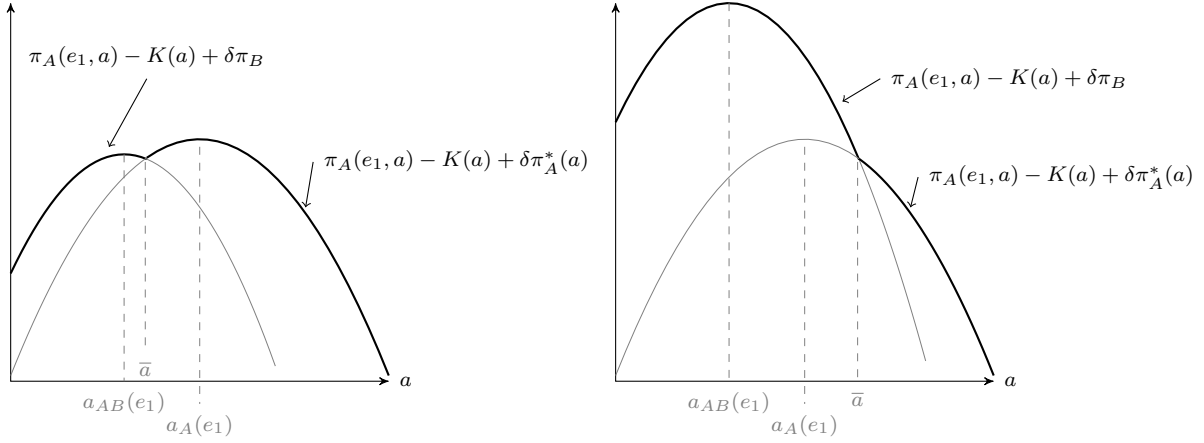


Figure 4: Firm's continuation payoff with observable investment as function of a for intermediate π_B (left) and large π_B (right).

$$t_1 + \pi_A(e_1, a) - K(a) + \delta \begin{cases} \pi_A^*(a), & a \geq \bar{a}, \\ \pi_B, & a < \bar{a}. \end{cases} \quad (14)$$

Hence, for $a < \bar{a}$, the firm achieves the same profit as in a situation where it stays in A for only one period – even though it stays in A in both periods. This is because the regulator offers a second-period transfer t_2 that makes the firm just indifferent towards relocation in period 2. Figure 4 illustrates the shape of the function defined in (14).

Now recall the definition of $a_A(e_1)$, resp. $a_{AB}(e_1)$, as the unique maximizer of $\pi_A(e_1, a) - K(a) + \delta\pi_A^*(a)$, resp. $\pi_A(e_1, a) - K(a) + \delta\pi_B$.²⁵ We have proven in Lemma 1 that $a_{AB}(e_1) < a_A(e_1)$, which implies that (14) is maximized by one of these values, in particular it cannot be maximized at the kink \bar{a} - unless $\bar{a} \in \{a_{AB}(e_1), a_A(e_1)\}$. Further notice that \bar{a} , defined by the equation $\pi_B = \pi^*(\bar{a})$, does not depend on e_1 .

To grasp some intuition on which level of investment maximizes (14), consider a large value e_1 , such that $a_A(e_1) \leq \bar{a}$. Because of this limp first-period emission target, an investment above \bar{a} does not pay off. The firm, therefore, always ends up requiring a subsidy in period two in order to avert relocation. Because the regulator only pays minimal transfers, the firm is better off anticipating a second period profit of π_B in the first place. Consequently she chooses a so as to maximize $\pi_A(e_1, a) - K(a) + \delta\pi_B$, which yields $a = a_{AB}(e_1)$. This case is depicted in the right panel of figure 4.

The opposite happens for fairly low levels of e_1 . Even when the firm plans with a second period profit of π_B , she ends up willing to stay in A even without further transfers. But then she is strictly better off taking into account her second period profit of $\pi_A^*(a)$

contract in case $a \geq \bar{a}$. The equilibrium outcome from this stage on is therefore independent on the regulator's contract offer for this case. Because the regulator's contract offer is unique when $a < \bar{a}$ the entire equilibrium outcome is uniquely determined.

²⁵See Lemma 1 for details.

from the very beginning. This yields an optimal investment choice of $a = a_A(e_1)$.

In the intermediate case the firm's profit defined in (14) has two local maxima, this case is depicted in the left panel of figure 4. It applies to intermediate values of e_1 such that $a_A(e_1) > \bar{a} > a_{AB}(e_1)$. Any investment close to $a_{AB}(e_1)$ requires a second period transfer to avert relocation. But also for any investment close to $a_A(e_1)$ the firm is willing to stay in A even absent further transfer payments. Consequently both are local maximizers. To find the global maximum one now has to compare the values $V_A(e_1)$ and $V_{AB}(e_1)$.²⁶

The following lemma formally captures the above verbal analysis and provides a straightforward criterion for the optimal value in the latter case.

Lemma 4. *Provided the firm accepted the first-period contract (t_1, e_1) , its optimal investment decision $a(e_1)$ under observable investment is given by*

$$a(e_1) = \begin{cases} a_A(e_1), & e_1 \leq e^\sharp, \\ a_{AB}(e_1), & e_1 > e^\sharp, \end{cases}$$

where e^\sharp is the unique solution to $V_A(e) = V_{AB}(e)$.²⁷

The firm's resulting equilibrium profit in the first case ($e_1 \leq e^\sharp$ – see Lemma 4) is $t_1 + V_A(e_1)$. In the second case ($e_1 > e^\sharp$), the equilibrium profit is given by $t_1 + V_{AB}(e_1)$, which is the same profit that the firm would achieve when it plans to relocate after period 1, and chooses its investment accordingly.

Notice that the firm's investment strictly decreases with e_1 and obeys a downward jump at $e_1 = e^\sharp$. For low levels of first period emissions, the firm's investment is large such that she is willing to stay in country A also in the second period – even absent any further transfer payment. Decreasing e_1 obviously decreases the required optimal investment. At $e_1 = e^\sharp$, however, the underlying rationale drastically changes. Now the firm invests so few, that a second-period transfer is required to avert relocation. Again, lowering e_1 further only reduces investment incentives and thereby reduces $a(e_1)$.

The following Corollary links the previous Lemmata in order to pin down the equilibrium outcome under observable investment, following an initial contract offer (t_1, e_1) .

Corollary 1. *Consider a first-period contract (t_1, e_1) that was accepted by the firm. The*

²⁶See (5) and (6) for the definitions.

²⁷The firm actually is indifferent between $a_A(e_1)$ and $a_{AB}(e_1)$ for $e_1 = e^\sharp$. A potential mixed equilibrium, where the firm randomizes over the indicated investment levels can be ruled out as follows: The first-period transfer necessary to implement any mixing is the same, i.e. does not depend on the mixing. If the firm chooses $a_A(e_1)$ no second-period transfer is necessary to avoid relocation in period two. For $a = a_{AB}(e_1)$ the second-period transfer is strictly positive. The equilibrium where the firm chooses $a_A(e_1)$ with certainty therefore minimizes (expected) transfer payments among all these mixed equilibria.

unique subgame perfect equilibrium outcome²⁸ under observable investment is given by one of the following

- (i) $a = a_A(e_1)$, no second-period transfer and (conditionally) optimal second-period investment $e_2 = e^*(a)$ if $e_1 \leq e^\sharp$,
- (ii) $a = a_{AB}(e_1)$, strictly positive second-period transfer of $t_2 = \pi_B - \pi_A^*(a_{AB}(e_1))$ and (conditionally) optimal second-period investment $e_2 = e^*(a)$ if $e_1 > e^\sharp$.

Notice the properties of the second outcome. If e_1 is large, the firm chooses a as if she were to leave country A after period 1. Nevertheless, the firm stays in country A also for period 2, as she receives a second-period contract offer that makes her indifferent towards relocation. What appears to be a time-inconsistent investment behavior by the firm is possible in equilibrium, because locally the firm cannot affect her continuation payoff in period 2 – she always receives π_B , either from relocation or from production in A with an appropriate transfer payment. For limp first-period emission targets e_1 , it does not pay off to invest heavily in order to raise the second-period profit above π_B and therefore make relocation unprofitable. This happens only for strict emission targets e_1 (that are below e^\sharp), where ‘location plan AA ’ is strictly preferred by the firm, and the associated investment $a_A(e_1)$ renders relocation unprofitable, making a second-period transfer obsolete. In the latter case, the second-period contract, thus, merely consists of an optimal emission target for period 2 – optimal, given the (potentially distorted) first-period emission level e_1 .

The analysis above allows us to state the minimal *total* transfer payment $t(e_1)$, required to avert relocation in both periods when the first-period emission level is e_1 :

$$t(e_1) = \begin{cases} V_B - V_A(e_1), & e_1 \leq e^\sharp, \\ V_B - V_{AB}(e_1) + \delta\{\pi_B - \pi_A^*(a_{AB}(e_1))\}, & e_1 > e^\sharp. \end{cases} \quad (15)$$

If $e_1 \leq e^\sharp$, by Corollary 1, only a first-period transfer is necessary to avert relocation in period 1. The lock-in effect then guarantees that relocation is not preferred by the firm in period 2. If $e_1 > e^\sharp$, a strictly positive transfer is paid in period 2, which makes the firm just indifferent between relocation and no relocation.

As the last step in determining the regulator’s optimal first-period contract offer (t_1, e_1) , we determine the value of e_1 that minimizes (15).

Proposition 3. *Assume $a_{AB}(e)$ is concave in e .²⁹ With observable investment, the*

²⁸Footnote 27 applies once more. Uniqueness is in general not provided for $e_1 = e^\sharp$, but we assume the regulator, as the designer of the game, can pick his preferred outcome.

²⁹This assumption is sufficient to get concavity of $\pi_A(e, a_{AB}(e)) - K(a_{AB}(e)) + \delta\pi_A^*(a_{AB}(e))$, which itself is sufficient for uniqueness of e_A^{tr} . Only mild assumptions are required to get concavity of a_{AB} - in our example, see at the end of this section, $a_{AB}(e)$ is always concave.

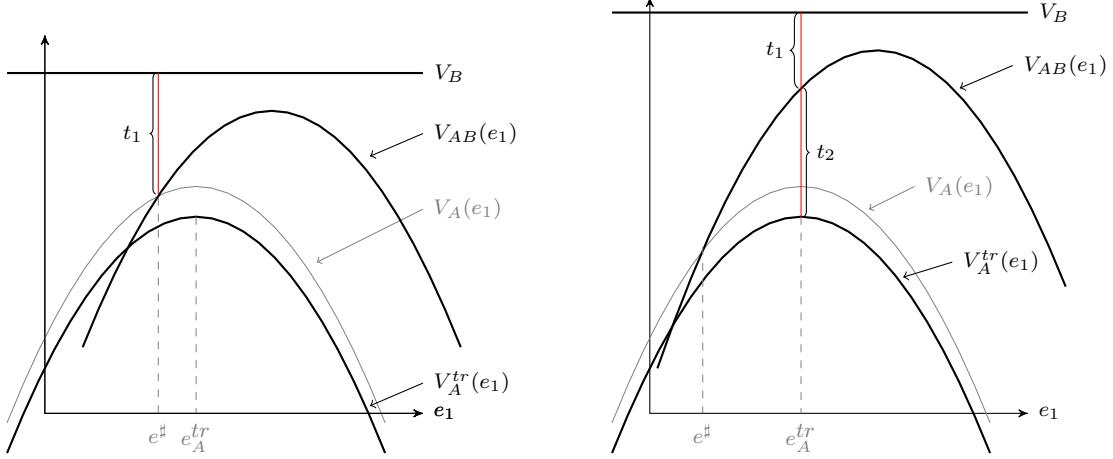


Figure 5: Optimal incentive schemes for intermediate π_B (left) and large π_B (right).

optimal first-period contract entails

$$e_1 = \begin{cases} e_A^o, & \text{if } \pi_B \leq \pi_B^\sharp, \\ e^\sharp, & \text{if } \pi_B^\sharp < \pi_B \leq \pi_B^{tr}, \\ e_A^{tr}, & \text{if } \pi_B > \pi_B^{tr}, \end{cases}$$

where e_A^{tr} is the unique maximizer of $V_A^{tr}(e) = \pi_A(e, a_{AB}(e)) - K(a_{AB}(e)) + \delta\pi_A^*(a_{AB}(e))$, and π_B^{tr} is such that $V_A(e^\sharp)$ takes on the same value as the resulting maximum when $\pi_B = \pi_B^{tr}$.³⁰ The associated first-period transfer is $t_1 = V_B - V_A(e_1)$ if $e_1 \leq e^\sharp$, and $t_1 = V_B - V_{AB}(e_1)$ otherwise. Second-period contracts are dependent on first-period emissions:

$$(t_2, e_2) = \begin{cases} (0, e^*(a_A(e_1))), & e_1 \leq e^\sharp \\ (\pi_B - \pi_A^*(a_{AB}(e_1)), e^*(a_{AB}(e_1))), & e_1 > e^\sharp. \end{cases}$$

Intuitively, whenever an optimal long-term contract can implement e_A^o without a positive second-period transfer (which holds if $\pi_B \leq \pi_B^\sharp$ – see Proposition 1), then this is also possible with short-term contracts and, thus, optimal.

Otherwise, the regulator faces the following dilemma. Either she implements a first-period emission level that leads to lock-in, i.e. for which no second-period transfer is required. This is optimally achieved by implementing $e_1 = e^\sharp$, which is the largest value that is still sufficiently small to create a lock-in in period 2. However, this is lower than e_A^o . Emissions are, thus, distorted (to trigger a larger investment), which implies a higher transfer payment than under full commitment. This case is depicted in the left panel of figure 5. The alternative is to implement a positive second-period transfer, which is

³⁰That is, $\pi_A(e^\sharp, a_A(e^\sharp)) - K(a_A(e^\sharp)) + \delta\pi_A^*(a_A(e^\sharp)) = \pi_A(e_A^{tr}, a_{AB}(e_A^{tr})) - K(a_{AB}(e_A^{tr})) + \delta\pi_A^*(a_{AB}(e_A^{tr}))$. Recall that e^\sharp depends on π_B , that relation pins down π_B^{tr} .

presented in the right panel of figure 5. To this end, the regulator adjusts the emissions target in period 1 (to the level e_A^{tr}), which induces a sufficiently small investment by the firm. In period 2, the regulator then pays a transfer to the firm to assure that it stays in country A also in period 2. The latter option has (potentially) a double inefficiency. Namely, the investment is inefficiently small, and emissions in period 1 are, in general, also inefficient.³¹

Note, that the implemented actions by the firm in the second alternative do *not* depend on the value of π_B , whereas in the first option they do because e^\sharp decreases with π_B . Therefore the cost of implementing e_A^{tr} does not depend on the firm's outside profit π_B . Implementing e^\sharp , on the other hand, is the more costly the higher π_B , because e^\sharp decreases with π_B . Overall, the regulator chooses to implement e_A^{tr} whenever π_B is larger than the critical value π_B^{tr} .

Lastly, observe that the first-period transfer from implementing e^\sharp is always larger than that of implementing e_A^{tr} , but the latter also requires a strictly positive second-period transfer. Overall the first-period transfer is non-monotone in π_B , it increases for $\pi_B \in (\pi_B^\sharp, \pi_B^{tr}]$ and then jumps to a lower level for $\pi_B > \pi_B^{tr}$. The total (expected) transfer, however, strictly increases with π_B .

4.2 Unobservable Investment

We now turn to the case where the firm's investment decision is not observable to the regulator. The second-period contract offer, therefore, cannot be conditioned on investment. We will show that the outcome identified in the case with observable investment that entails large first-period emissions (see Proposition 3, case $\pi_B > \pi_B^{tr}$), can no longer be implemented under unobservable investment.

The final stage, where a is fixed and the regulator already made the second-period contract offer (t_2, e_2) , is again characterized by (11). As indicated earlier, we treat the prior two stages (firm's choice of a and regulator's second-period contract offer (t_2, e_2)) as a simultaneous move game. Furthermore, for notational convenience, we focus on pure strategies here. We formally prove that this is indeed no restriction in Appendix B. To form an equilibrium, the following conditions must be satisfied:

$$a \in \arg \max_{\tilde{a}} t_1 + \pi_A(e_1, \tilde{a}) - K(\tilde{a}) + \delta(t_2 + \pi_A(e_2, \tilde{a})), \text{ and} \quad (16)$$

$$t_2 = \max\{0, \pi_B - \pi_A^*(a)\}, \quad e_2 = e^*(a). \quad (17)$$

Condition (16) states that the firm chooses her investment optimally, given the already accepted initial contract (t_1, e_1) , and correctly anticipating the second-period contract

³¹Whether emissions in period one are too high or too low depends on the specified functions. In our example we have $e_A^{tr} = e_A^o$.

offer (t_2, e_2) that she will accept. Condition (17) on the other hand gives the contract with the lowest transfer that is still accepted by the firm in equilibrium and, hence, averts relocation. As in the case of observable investment, the second-period emissions are chosen optimally and a transfer is only paid when the firm would strictly prefer to relocate in period 2.

In addition to conditions (16) and (17), the firm's ability to plan relocation (and to choose a accordingly) adds another constraint. Given (t_1, e_1) , the maximal profit the firm could achieve with planned relocation is $t_1 + V_{AB}(e_1)$. Using the above conditions, on the equilibrium path the firm's profit is $t_1 + V_A(e_1) + \delta t_2$.³² A necessary condition for a subgame perfect equilibrium where the firm stays in country A in both periods is

$$V_A(e_1) + \delta t_2 \geq V_{AB}(e_1). \quad (18)$$

This condition is familiar from the full-commitment case, where it was used in the proof of Proposition 2. The argument there was, that the second period transfer necessary to satisfy equation (18) *exceeds* the sequentially optimal transfer that just averts relocation.³³ This argument carries over to the any sequence of short-term contracts, not only those with $e_1 = e_A^o$. In fact, the following lemma states a crucial result, namely that with short-term contracting and unobservable investment, it is impossible to implement strictly positive second-period transfers at all.

Lemma 5. *For any first-period contract (t_1, e_1) , there exists no equilibrium of the continuation game under short-term contracting with unobservable investment where the firm stays in country A in both periods, that entails a strictly positive second-period transfer payment.*

The result of Lemma 5 is a consequence of the regulator's limited commitment. Intuitively, if there was an equilibrium that entailed a strictly positive transfer t_2 , then the firm's second-period payoff on the equilibrium path would clearly be π_B . This is because the regulator would just pay a transfer that makes the firm indifferent towards relocation in period 2, given the equilibrium value of a chosen for 'location plan AA ' (see (16)). But then the firm would clearly be better off planning to relocate from the beginning, and hence, invest less in abatement capital than what (16) indicates. This reduces the firm's investment costs in period 1, and yields an identical payoff of π_B in period 2.

Underlying this result is the fact that – in contrast to the case of observable investment (see Section 4.1) – the regulator's second period contract offer (t_2, e_2) cannot respond to

³²The Envelope-theorem yields $\partial\pi_A^*/\partial a = \partial\pi_A/\partial a|_{e=e^*(a)}$. Consequently the first order condition of (16) corresponds to the one for $a_A(e_1)$, provided that $e_2 = e^*(a)$.

³³We have shown in section 3 that the optimal long-term contract seizes to be implementable with short-term contracts, whenever this requires $t_2 > 0$. The statement here goes far beyond that, in proving that *no* outcomes with $t_2 > 0$ can be implemented.

a *deviation* in the firm's investment choice. This creates a tension between planned relocation on the one hand, and the regulator's inclination to prevent this.

An immediate consequence of Lemma 5 is that certain first-period emission targets e_1 cease to be implementable. To see this, note that by Lemma 5, e_1 is implementable only if the continuation path entails an equilibrium with $t_2 = 0$, hence, where $\pi_A^*(a) \geq \pi_B$ holds. We have seen above, that on the equilibrium path, the firm realizes the payoff $V_A(e_1) + t_1$ (already respecting the new constraint $t_2 = 0$). Therefore, for e_1 to be implementable, this requires

$$V_A(e_1) \geq V_{AB}(e_1). \quad (19)$$

We are now ready to characterize the set of implementable³⁴ first-period emission levels.

Proposition 4. *Under short-term contracting with unobservable investment, a first-period emission level e_1 is implementable if and only if $e_1 \leq e^\sharp$.*

Only low emission targets for the first period can be implemented, because they enforce a sufficiently high abatement capital investment which renders the relocation option for period 2 unprofitable even in the absence of any further transfer. It is worth noting that the result of Lemma 4 is independent of the regulator's objective to minimize transfer payments.³⁵ It is rather a consequence of the firm's option to relocate after one period, and the regulator's desire to prevent relocation for both periods.

Recall that with long-term contracts or short-term contracts with observable investment, there was no such implementation problem: For any level of first-period emissions e_1 the regulator was able to implement an equilibrium where the firm never relocates. Also note, that for all levels $e_1 \leq e^\sharp$, 'location plan AB ' is already inferior. So in designing the optimal first-period contract, the regulator only has to make sure that the firm does not want to relocate immediately.

Finding the optimal first-period contract, i.e. the first-period emission level e_1 that implements an equilibrium where the firm stays for both periods in country A with the lowest (total) transfers, is now straightforward. Because $V_A(e)$ is strictly concave, the first-best emission level e_A^o can be implemented whenever $e_A^o \leq e^\sharp$, and is then also optimal. If, however, $e_A^o > e^\sharp$, then by concavity of $V_A(e)$, implementing $e_1 = e^\sharp$ leads to lowest transfers and is therefore optimal. The following Proposition summarizes.

Proposition 5. *With short-term contracting and unobservable investment, the regulator optimally sets $e_1 = \min\{e_A^o, e^\sharp\}$ and $t_1 = V_B - V_A(e_1)$. The second-period contract, then, entails $t_2 = 0$ and $e_2 = e^*(a_A(e_1))$.*

³⁴Implementability is understood to be under the constraint that the firm does not relocate in any period.

³⁵Adding a preference over emission levels or investment in abatement capital does not affect the implementation problem, i.e. does not change the set of implementable first-period emission levels as described in Lemma 4. But of course, adding such a preference may change the value of e_1 which is finally implemented.

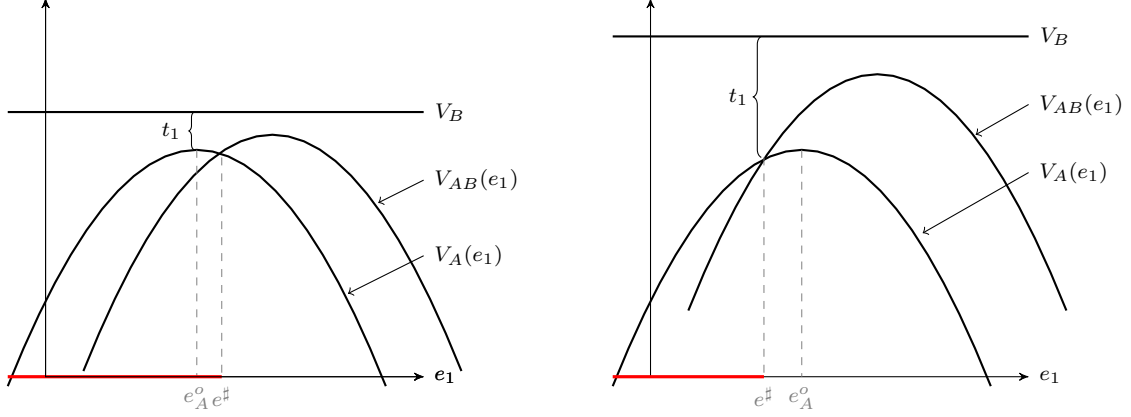


Figure 6: Optimal first-period contracts with short-term contracting and unobservable investment; left: $e_A^o < e^\sharp$, right: $e_A^o > e^\sharp$. Implementable levels of e_1 are shown in red.

The two cases are illustrated in Figure 6. In the left panel the case $e_A^o \leq e^\sharp$ is shown. The regulator faces no dilemma, since the first-best emission level is implementable, and when the regulator implements it, the firm has no incentive to leave country A in the future, even though no second-period transfer is paid. In the right panel we illustrate a case where the region of implementable first-period emission levels does not contain the first-best level e_A^o . Then the regulator selects the largest implementable level, which is e^\sharp . The emissions target in the first period is, thus, stricter than the optimal one.

By comparing these results with the ones under long-term contracting, we can summarize:

Corollary 2. *The regulator implements the first-best emission levels with short-term contracting if and only if they can be implemented also under long-term contracting with zero transfers in period 2. Hence, under short-term contracting with unobservable investment, the first-period emission level is distorted downwards if and only if $\pi_B > \pi_B^\sharp$.*

Before continuing with some additional results, we briefly go back to our example.

Example 3. Consider again the setting introduced in example 1.

The value e^\sharp is given by $e^\sharp = 7 + \delta/2 - 2\pi_B$. Consequently, for $\pi_B > \pi_B^\sharp = 3 + \frac{3}{4}\delta$, the regulator always implements $e_1 = 7 + \delta/2 - 2\pi_B$ when investment is unobservable. The resulting first-period transfer is $t_1 = -(\pi_B - \pi_B^\sharp)^2 + 1/2(\delta^2 + 6\delta + 5)$. Clearly, t_1 unboundedly increases with π_B .

Under short-term contracting with observable investment, the regulator has the alternative to implement e_A^{tr} . In this example we have $e_A^{tr} = 1 - \delta$, which corresponds to e_A^o .³⁶ Because $a_{AB}(e_A^{tr}) = 1 + \delta/2$ the required transfers to implement e_A^{tr} are

³⁶Crucial for this seems that all third derivatives in the example equal zero, such that no higher order effects are present.

$t_1 = \pi_B - 7/2 - \delta$ and $t_2 = \pi_B - 3 - \delta/2$. The total transfer payment is therefore $t = (1 + \delta)\pi_B - 7/2 - 4\delta - \delta^2/2$.

Comparing the two yields $\pi_B^{tr} = 1/4(10 + \delta + 2 \cdot \sqrt{13 + 15\delta + \delta^2})$, which can be shown to always exceed π_B^\sharp . Thus, for $\pi_B > \pi_B^{tr}$ the regulator implements $e_1 = e_A^{tr} = 1 - \delta$ when investment is observable. Notice that, although first-period emissions are at their optimal level ($e_A^{tr} = e_A^o$) investment is not ($a_{AB}(e_A^{tr}) < a_A(e_A^{tr})$) and therefore second-period emissions are also sub-optimal.

4.3 Additional Results

So far we have argued in terms of implemented first-period emissions. The following Proposition restates the gained insights in terms of implemented investment. For this denote a_A^o the investment level the firm chooses under the optimal long-term contract. Because there $e_1 = e_2 = e_A^o$ independent of all other parameters the level of investment is indeed always given by a_A^o . The following holds for the implemented investment level under short-term contracting.

Proposition 6. *The investment level implemented, given the optimal sequence of short-term contracts, is*

- (observable investment): equal to a_A^o for $\pi_B \leq \pi_B^\sharp$, distorted upwards for $\pi_B \in (\pi_B^\sharp, \pi_B^{tr}]$ and distorted downwards for $\pi_B > \pi_B^{tr}$.
- (unobservable investment): equal to a_A^o for $\pi_B \leq \pi_B^\sharp$ and distorted upwards for $\pi_B > \pi_B^\sharp$.

The Proposition highlights the adverse effect limited commitment has on investment incentives. To grasp some intuition consider the case of unobservable investment first. Low levels of investment lead to $\pi_A^*(a) < \pi_B$, i.e. the firm has to be subsidized in order to not relocate in the second period. But then, marginal gains from investment can only be realized as long as they affect first period profits - investments are held up. On the other hand, the ratchet effect impedes implementation of a yet lower investment because the second period contract eventually offered *raises* investment incentives. The conflicting forces cannot be balanced out. Only in the case of observable investment this becomes possible and low investment are implemented.

5 Extensions

In this section we provide several extensions of our main model. First we discuss alternative objectives of the regulator. Second we introduce uncertainty regarding the second period profit.

5.1 Alternative objectives

Let us now assume the regulator receives a surplus $S > 0$ in each period the firm stays in the country. Consequently, the regulator does not seek to prevent relocation at any cost, but only unless the required transfers exceed $(1 + \delta)S$. In particular, the regulator maximizes the following objective:

$$\max x_1 \cdot (S - t_1) + x_2 \cdot \delta(S - t_2)$$

where $x_\tau \in \{0, 1\}$ indicates whether relocation is averted in period τ ($x_\tau = 1$) or not. Effectively this puts a cap on transfers and because transfer payments are typically larger with short-term contracting, relocation is prevented only for lower values of S compared to the case of long-term contracting. The fundamental underlying problems in terms of implementation, however, remain unaffected.

We characterize the optimal incentive contract in the following Proposition.

Proposition 7. *The optimal incentive contract is given by*

- (long-term contracting) $e_1 = e_2 = e_A^o$ and a total transfer of $t = V_B - V_A^o$ whenever $S \geq S^o := (V_B - V_A^o)/(1 + \delta)$. Otherwise no contract is offered and the firm relocates.³⁷

- (short-term contracting and observable investment)

(i) $e_1 = e_2 = e_A^o$ and a total transfer of $t = V_B - V_A^o$ whenever $\pi_B \leq \pi_B^\#$ and $S \geq S^o$

(ii) $e_1 = e^\#$ and $e_2 = e^*(a_A(e^\#))$ as well as $t_1 = V_B - V_A(e^\#)$ and $t_2 = 0$ whenever $\pi_B^{tr} \geq \pi_B > \pi_B^\#$ and $S \geq S^\# := (V_B - V_A(e^\#))/(1 + \delta)$.

(iii) $e_1 = e_A^{tr}$ and $e_2 = e^*(a_{AB}(e_A^{tr}))$ as well as $t_1 = V_B - V_{AB}(e_A^{tr})$ and $t_2 = \pi_B - \pi_A^*(a_{AB}(e_A^{tr}))$ whenever $\pi_B > \pi_B^{tr}$ and $S \geq S^{tr} := (V_B - V_A^{tr})/(1 + \delta)$

Otherwise no contract is offered and the firm relocates.

- (short-term contracting and unobservable investment)

(i) $e_1 = e_2 = e_A^o$ and a total transfer of $t = V_B - V_A^o$ whenever $\pi_B \leq \pi_B^\#$ and $S \geq S^o$

(ii) $e_1 = e^\#$ and $e_2 = e^*(a_A(e^\#))$ as well as $t_1 = V_B - V_A(e^\#)$ and $t_2 = 0$ whenever $\pi_B > \pi_B^\#$ and $S \geq S^\#$.

Otherwise no contract is offered and the firm relocates.

³⁷The inter-temporal allocation of transfers is as described in Proposition 1.

For all parameter values we have $S^o > S^{tr}$. Furthermore $S^o > S^\#$ whenever $\pi_B > \pi_B^\#$ and $S^\# > S^{tr}$ if and only if $\pi_B < \pi_B^{tr}$.

The Proposition essentially collects the results from Propositions 1, 3 and 5. The only difference is, that we now state a new condition, involving the value S , for when a contract is offered at all. Notice that for attractive outside options, i.e. $\pi_B > \pi_B^\#$, relocation is prevented for strictly lower values of S when the regulator's commitment is limited. Furthermore, it is straightforward to verify that for $S \rightarrow \infty$ the contract from the above Proposition coincides with the contracts in the main part of this paper.

Additionally we may add a preference over e and/or a for the regulator. Notice, however, that this does not affect the underlying implementation problems. Hence, what changes is only which of the implementable outcomes the regulator wishes to implement. For instance in the case of short-term contracting with unobservable investment, the set of implementable first-period emissions remains to be constrained by $e_1 \leq e^\#$.

To summarize, the hold-up problem, present in the model studied in this paper, does not depend on details of the regulators objective. The problem is more fundamental in that it severely constrains the set of implementable outcomes, whereas the precise objective of the regulator merely influences the regulator's choice among the set of implementable outcomes.

5.2 Uncertainty

Adding uncertainty to the model only complicates the regulator's program. Consider for instance uncertainty about the firm's outside profit π_B in period two. In particular let π_B^2 be distributed on $[\underline{\pi}_B, \bar{\pi}_B]$ with mean π_B^1 , i.e. on average the outside profit is the same in both periods. Then, to avert relocation with certainty, the regulator has to choose e_1 such that the lock-in-effect already bites at the value $\underline{\pi}_B$. Otherwise the intuition of Proposition 4 can be applied to rule out any strictly positive transfer payment in period two.

Similarly, uncertainty about the capital stock or depreciation make the implementation problem only harder.

6 Discussion / Conclusion

This paper studies optimal incentive contracts to avert firm relocation. A local policy maker is aimed at averting a firm's relocation in two subsequent periods. The firm, if staying for at least the first period, undertakes some location specific investment, which is not contractible. Contracts consist of transfers and targets for a observable and contractible productive activity, such as output, price or employment.

If contracts are long-term, i.e. the regulator can fully commit to both periods, contracts are simple subsidy payments. In particular these optimal contracts do not need to specify anything beyond the transfers in the two periods. The structure is that plain because regulator's and firm's interests are aligned.

With short-term contracts the outcome from long-term contracting seems to be implementable whenever relocation is very attractive. The second period, that the optimal long-term contract promises, is too large and therefore not sequentially optimal. As a consequence, when investment is not observable contracts are tougher and implemented investment is larger. The more attractive relocation becomes, the tougher the contract and the larger the first-period transfer gets. Second period transfers are never paid with observable investment, they cannot be implemented.

When investment is observable, the implementation cost dynamic can be stopped. Lower investments and positive second-period contracts can be implemented via a seemingly time inconsistent pattern. The first-period target is mild and investments are low. In the second period a positive transfer is paid. Local deviations are unprofitable, because they only affect the transfer, not the gross profit, because transfers are such that the firm is indifferent to relocation. With this pattern, first-period transfers are bounded, which is why they turn optimal when relocation is very attractive.

Our model has an important application in the area of climate policy. When countries unilaterally introduce prices for emissions, the competitiveness of energy intensive industries is harmed. In response, firm's may be tempted to relocate to other countries with less stringent environmental regulation. As a response, in many countries that already initiated emission trading schemes, firms's were initially allocated free permits. In the light of our model these can be understood as simple subsidies. What we argue however, is that given a dynamic pattern these subsidies may not prevent relocation on a permanent basis. The subsidies, in order to be effective, have to include for instance emission targets. This becomes necessary as soon as the policy maker is not able to commit to a long future.

A Proofs

Proof of Lemma 1. The following Lemma turns out helpful in the analysis.

Lemma A.1. π_A^* is strictly concave in a and $e^*(a)$ is strictly decreasing in a .

Proof. $e^*(a)$ is implicitly defined by $(\partial\pi_A)/(\partial e) = 0$. Differentiating w.r.t. a and rearranging yields

$$\frac{\partial e^*}{\partial a} = -\frac{\frac{\partial^2 \pi_A}{\partial e \partial a}}{\frac{\partial^2 \pi_A}{\partial e^2}} < 0. \quad (20)$$

This proves the second claim. For the first differentiate π_A^* , using the envelope-theorem, to get

$$\frac{\partial \pi_A^*}{\partial a} = \frac{\partial \pi_A}{\partial a} \Big|_{(e^*(a), a)}.$$

Differentiating again yields (suppressing the arguments for simplicity)

$$\frac{\partial^2 \pi_A^*}{\partial a^2} = \frac{\partial^2 \pi_A}{\partial a \partial e} \cdot \frac{\partial e^*}{\partial a} + \frac{\partial^2 \pi_A}{\partial a^2},$$

which, making use of (20), can be reformulated as

$$\frac{\partial^2 \pi_A^*}{\partial a^2} = -\frac{\left(\frac{\partial^2 \pi_A}{\partial e \partial a}\right)^2}{\frac{\partial^2 \pi_A}{\partial e^2}} + \frac{\partial^2 \pi_A}{\partial a^2} = \frac{\frac{\partial^2 \pi_A}{\partial a^2} \cdot \frac{\partial^2 \pi_A}{\partial e^2} - \left(\frac{\partial^2 \pi_A}{\partial e \partial a}\right)^2}{\frac{\partial^2 \pi_A}{\partial e^2}} < 0$$

The nominator is the Hessian of π_A , which by assumption is positive. The denominator is negative, hence the entire expression is negative. \square

Now consider the function $V_A(e)$. The value $a_A(e)$ is implicitly defined by the first-order condition

$$\frac{\partial \pi_A}{\partial a} - \frac{\partial K}{\partial a} + \delta \frac{\partial \pi_A^*}{\partial a} = 0. \quad (21)$$

Differentiating this expression w.r.t. e and rearranging yields

$$\frac{\partial a_A(e)}{\partial e} = \frac{\frac{\partial^2 \pi_A}{\partial e \partial a}}{\frac{\partial^2 K}{\partial a^2} - \frac{\partial^2 \pi_A}{\partial a^2} - \delta \frac{\partial^2 \pi_A^*}{\partial a^2}} < 0. \quad (22)$$

Provided that π_A^* is concave, which is proven in Lemma A.1, the latter derivative is negative. Now differentiate $V_A(e)$, using the envelope-theorem, to get

$$\frac{\partial V_A}{\partial e} = \frac{\partial \pi_A}{\partial e} \Big|_{(e, a_A(e))}.$$

Differentiating this expression once more and suppressing the arguments yields

$$\begin{aligned} \frac{\partial V_A^2}{\partial e^2} &= \frac{\partial^2 \pi_A}{\partial e^2} + \frac{\partial^2 \pi_A}{\partial e \partial a} \cdot \frac{\partial a_A(e)}{\partial e} = \frac{\partial^2 \pi_A}{\partial e^2} + \frac{\left(\frac{\partial^2 \pi_A}{\partial e \partial a}\right)^2}{\frac{\partial^2 K}{\partial a^2} - \frac{\partial^2 \pi_A}{\partial a^2} - \delta \frac{\partial^2 \pi_A^*}{\partial a^2}} \\ &= \frac{\frac{\partial^2 K}{\partial a^2} \cdot \frac{\partial^2 \pi_A}{\partial e^2} - \left[\frac{\partial^2 \pi_A}{\partial a^2} \cdot \frac{\partial^2 \pi_A}{\partial e^2} - \left(\frac{\partial^2 \pi_A}{\partial e \partial a}\right)^2\right] - \delta \frac{\partial^2 \pi_A^*}{\partial a^2} \cdot \frac{\partial^2 \pi_A}{\partial e^2}}{\frac{\partial^2 K}{\partial a^2} - \frac{\partial^2 \pi_A}{\partial a^2} - \delta \frac{\partial^2 \pi_A^*}{\partial a^2}} < 0. \end{aligned}$$

To get the correct sign of the latter derivative, we again use the positive Hessian, the concavity of π_A^* and Assumption 1.

Proving concavity of $V_{AB}(e)$ is a simple repetition of the above steps and therefore

skipped. Lastly, $a_{AB}(e)$ is defined by the first-order condition

$$\frac{\partial \pi_A}{\partial a} - \frac{\partial K}{\partial a} = 0. \quad (23)$$

Comparing this to (21), noticing that π_A^* is strictly increasing and by concavity of the respective objectives, we find that $a_A(e) > a_{AB}(e)$ for all e . \square

Proof of Lemma 2. Assume $V_{AB}(e_1) \geq V_B$, which can be written as

$$V_{AB}(e_1) = \pi_A(e_1, a_{AB}(e_1)) - K(a_{AB}(e_1)) + \delta\pi_B \geq \pi_B + \delta\pi_B = V_B.$$

But this implies $\pi_A(e_1, a_{AB}(e_1)) > \pi_B$ and therefore

$$\begin{aligned} V_A(e_1) &= \max_a \pi_A(e_1, a) - K(a) + \delta\pi_A^*(a) \\ &\geq \pi_A(e_1, a_{AB}(e_1)) - K(a_{AB}(e_1)) + \delta\pi_A(e_1, a_{AB}(e_1)) \\ &> \pi_A(e_1, a_{AB}(e_1)) - K(a_{AB}(e_1)) + \delta\pi_B \\ &= V_{AB}(e_1). \end{aligned}$$

This proves our claim. \square

Proof of Proposition 1. Follows from the arguments in the main text. Observe that $e_1 = e_2$ because the same stock of investment is available in each period. \square

Proof of Proposition 2. A necessary condition for implementation is that

$$t_1 + V_A(e_A^o) + \delta t_2 \geq t_1 + \max_a \pi_A(e_A^o, a) - K(a) = t_1 + V_{AB}(e_A^o). \quad (24)$$

Thus, $\delta t_2 \geq V_{AB}(e_A^o) - V_A(e_A^o)$. Sequential optimality of the second-period contract requires

$$t_2 = \max \{0, \pi_A^*(a_A^o)\}.$$

Now suppose $t_2 > 0$, which implies $\pi_A^*(a_A^o) + t_2 = \pi_B$ and consequently

$$\begin{aligned} t_1 + V_A(e_A^o) + \delta t_2 &= t_1 + \pi_A(e_A^o, a_A^o) - K(a_A^o) + \delta\pi_B \\ &< t_1 + \max_a \pi_A(e_A^o, a) - K(a) + \delta\pi_B = t_1 + V_{AB}(e_A^o). \end{aligned}$$

Therefore, implementation requires that no second-period transfer is necessary.

When is this the case? The first period contract must be (t_1, e_A^o) and (24) implies that $V_A(e_A^o) \geq V_{AB}(e_A^o)$ is necessary. To prove sufficiency, assume that the latter holds and

$\pi_A^*(a_A^o) < \pi_B$. Then we have

$$V_A(e_A^o) = \pi_A(e_A^o, a_A^o) - K(a_A^o) + \delta\pi_A^*(a_A^o) < \pi_A(e_A^o, a_A^o) - K(a_A^o) + \delta\pi_B \leq V_{AB}(e_A^o)$$

- a contradiction.

For the critical π_B notice that $V_A^o > V_{AB}(e_A^o)$ for $\pi_B = \pi_B^0$ by Lemma 2. Because $V_{AB}(e_A^o)$ strictly increases with π_B we get $\pi_B^\# > \pi_B^0$. \square

Proof of Lemma 3. From the arguments given in the text we have $e_2 = e^*(a)$. The transfer t_2 must be such that the firm is willing to stay in country A in period 2. Because $\pi_A^*(a)$ is strictly increasing in a , there exists a value \bar{a} such that $\pi_A^*(a) \geq \pi_B$ for all $a \geq \bar{a}$, and $\pi_A^*(a) < \pi_B$ otherwise. This completes the proof. \square

Before we proceed with the proof of Lemma 4, we first state a useful result. Define $e^\#$ as the solution of $V_A(e) = V_{AB}(e)$.

Lemma A.2. *The value $e^\#$ exists and is unique, and $V_A(e) < V_{AB}(e)$ holds for all $e > e^\#$ while $V_A(e) > V_{AB}(e)$ for all $e < e^\#$. Furthermore, $a_{AB}(e^\#) < \bar{a} < a_A(e^\#)$.*

Proof. By the Envelope Theorem we have

$$\frac{\partial V_A}{\partial e_1} \Big|_{e_1} = \frac{\partial \pi_A}{\partial e_1} \Big|_{e_1, a_A(e_1)}, \text{ and } \frac{\partial V_{AB}}{\partial e_1} \Big|_{e_1} = \frac{\partial \pi_A}{\partial e_1} \Big|_{e_1, a_{AB}(e_1)}. \quad (25)$$

Because $\partial^2 \pi_A / \partial e \partial a < 0$ and $a_{AB}(e) < a_A(e)$ we have that

$$\frac{\partial V_A}{\partial e_1} \Big|_{e_1} < \frac{\partial V_{AB}}{\partial e_1} \Big|_{e_1}, \quad (26)$$

which proves uniqueness, while existence follows from the concavity of the two functions. By continuity, if $V_A(e_1) = V_{AB}(e_1)$ it has to hold that $V_A(e) < V_{AB}(e)$ for all $e > e_1$ and $V_A(e) > V_{AB}(e)$ for all $e < e_1$.

The last claim is proven by contradiction. Suppose $\bar{a} \leq a_{AB}(e^\#)$. Then $\pi_B \leq \pi_A(a_{AB}(e^\#))$ and

$$V_{AB}(e^\#) \leq \pi_A(e^\#, a_{AB}(e^\#)) - K(a_{AB}(e^\#)) + \delta\pi_A^*(a_{AB}(e^\#)) < V_A(e^\#)$$

which contradicts the definition of $e^\#$.

On the other hand, if $\bar{a} \geq a_A(e^\#)$, then $\pi_B \geq \pi_A(a_A(e^\#))$ and

$$V_A(e^\#) \leq \pi_A(e^\#, a_{AB}(e^\#)) - K(a_{AB}(e^\#)) + \delta\pi_B < V_{AB}(e^\#)$$

which again contradicts the definition of $e^\#$. This completes the proof. \square

Proof of Lemma 4. We distinguish the three cases, already indicated in the main text.

Case (i): $\bar{a} \leq a_{AB}(e_1)$. By Assumption 1, the function $\pi_A(e, a) - K(a) + \delta\pi_B$ is strictly concave with the unique maximizer $a_{AB}(e_1)$. Thus, for all $a \leq \bar{a}$ we have

$$\pi_A(e_1, a) - K(a) + \delta\pi_B \leq \pi_A(e_1, \bar{a}) - K(\bar{a}) + \delta\pi_B = \pi_A(e_1, \bar{a}) - K(\bar{a}) + \delta\pi_A^*(\bar{a}), \quad (27)$$

where the latter equality follows from the definition of \bar{a} . Furthermore, because $\bar{a} \leq a_{AB}(e_1) < a_A(e_1)$, we have $V_A(e_1) \geq \pi_A(e_1, a) - K(a) + \delta\pi_A^*(a)$ for all $a \geq \bar{a}$. Consequently, $a = a_A(e_1)$ maximizes the firm's profit in this case and this maximal profit is $V_A(e_1)$.

Case (iii): $a_A(e_1) \leq \bar{a}$. By Assumptions 1 and 2, the function $\pi_A(e, a) - K(a) + \delta\pi_A^*(a)$ is strictly concave with the unique maximizer $a_A(e_1)$. Thus, for all $a \geq \bar{a}$ we have

$$\pi_A(e_1, a) - K(a) + \delta\pi_A^*(a) \leq \pi_A(e_1, \bar{a}) - K(\bar{a}) + \delta\pi_A^*(\bar{a}) = \pi_A(e_1, \bar{a}) - K(\bar{a}) + \delta\pi_B. \quad (28)$$

Furthermore, because $a_{AB}(e_1) < a_A(e_1) \leq \bar{a}$, we have $V_{AB}(e_1) \geq \pi_A(e_1, a) - K(a) + \delta\pi_B$ for all $a \leq \bar{a}$. Consequently, $a = a_{AB}(e_1)$ maximizes the firm's expected profit in this case and this maximal profit is $V_{AB}(e_1)$.

Case (ii): $a_{AB}(e_1) < \bar{a} < a_A(e_1)$. By the above arguments the firm's profit has two local maxima: at $a = a_A(e_1)$, and at $a = a_{AB}(e_1)$. Consequently the maximal profit is either $V_A(e_1)$ or $V_{AB}(e_1)$. By Lemma A.2 and the fact that $V_A(e) > V_{AB}(e)$ holds if and only if $e < e^\sharp$, we find that the firm's maximal profit, given $a_{AB}(e_1) < \bar{a} < a_A(e_1)$, is thus $V_A(e_1)$ if $e_1 \leq e^\sharp$, and $V_{AB}(e_1)$ if $e_1 > e^\sharp$. This completes the proof. \square

Proof of Corollary 1. By Lemma A.2 and because $a_A(e)$ decreases with e , we have $a_A(e_1) > \bar{a}$ for all $e_1 \leq e^\sharp$. Consequently, the associated second-period transfer is zero. On the other hand, $a_{AB}(e_1) < \bar{a}$ for all $e_1 > e^\sharp$ and, therefore, a strictly positive second-period transfer is required to avoid relocation. By Lemma 3, this transfer has to satisfy $t_2 + \pi_A^*(a_{AB}(e_1)) = \pi_B$. \square

Proof of Proposition 3. The regulator chooses e_1 in order to minimize (15). If $e_A^o \leq e^\sharp$, we have $t(e_A^o) = V_B - V_A(e_A^o) = V_B - V_A^o$. Furthermore, for all $e_1 \leq e^\sharp$

$$t(e_1) = V_B - V_A(e_1) \geq V_B - V_A(e_A^o) = t(e_A^o),$$

and also for all $e_1 > e^\sharp \geq e_A^o$

$$\begin{aligned} t(e_1) &= V_B - (\pi_A(e_1, a_{AB}(e_1)) - K(a_{AB}(e_1)) + \delta\pi_A^*(a_{AB}(e_1))) \\ &> V_B - \max_{e, a} (\pi_A(e, a) - K(a) + \delta\pi_A^*(a)) = t(e_A^o). \end{aligned}$$

Thus, $e_1 = e_A^o$ is optimal, whenever $e_A^o \leq e^\sharp$. By Proposition 1 this is the case whenever $\pi_B \leq \pi_B^\sharp$.

Now suppose $e_A^o > e^\sharp$. Then by strict concavity of $V_A(e)$ we have

$$t(e_1) = V_B - V_A(e_1) > V_B - V_A(e^\sharp) = t(e^\sharp) \quad \forall e_1 < e^\sharp.$$

Considering $t(e_1)$ for $e_1 > e^\sharp$, we find

$$\min_{e_1 > e^\sharp} t(e_1) = \max_{e_1 > e^\sharp} \pi_A(e_1, a_{AB}(e_1)) - K(a_{AB}(e_1)) + \delta \pi_A^*(a_{AB}(e_1)). \quad (29)$$

The above objective can be stated as $V_{AB}(e_1) - \delta \pi_B + \delta \pi_A^*(a_{AB}(e_1))$. By Lemma 1 the function $V_{AB}(e_1)$ is strictly concave. Furthermore, because π_A^* is strictly concave by Lemma A.1 and increasing by Assumption 2, the composition with the concave function $a_{AB}(e_1)$ is also concave. Therefore the entire objective is concave. Using once more the envelope-theorem, the first-order condition for a maximizer of (29) is

$$\frac{\partial \pi_A}{\partial e} + \delta \frac{\partial \pi_A^*}{\partial a} \frac{\partial a_{AB}}{\partial e}. \quad (30)$$

Concavity of a_{AB} and of the remaining functions yields existence of a solution e_A^{tr} to (30). Uniqueness follows directly from strict concavity of the objective.

If $e_A^{tr} \leq e^\sharp$, the regulator minimizes transfer payments for $e_1 = e^\sharp$. Otherwise, there are two potential optima: e^\sharp or e_A^{tr} . Notice that $t(e_A^{tr})$ is independent of π_B , whereas $t(e^\sharp)$ strictly increases with π_B , because e^\sharp strictly decreases with π_B . Consequently there exists a unique cut-off π_B^{tr} such that $t(e_A^{tr}) < t(e^\sharp)$ if and only if $\pi_B > \pi_B^{tr}$.

It remains to show, that $\pi_B^{tr} > \pi_B^\sharp$. To see this, notice that $\pi_A(e_1, a_{AB}(e_1)) - K(a_{AB}(e_1)) + \delta \pi_A^*(a_{AB}(e_1)) < V_A(e_1)$ for all e_1 . In particular this is true for $e_1 = e^\sharp$, from which the claimed follows immediately. \square

Proof of Lemma 5. Suppose to the contrary that a subgame perfect equilibrium exists that entails $t_2 > 0$. As argued in the main text, the expected profit of the firm is thus $t_1 + V_A(e_1) + \delta t_2$. Furthermore, in order to have $t_2 > 0$ we must have $\pi_B > \pi_A^*(a_A(e_1))$. But then

$$\begin{aligned} t_1 + V_A(e_1) + \delta t_2 &= t_1 + \pi_A(e_1, a_A(e_1)) - K(a_A(e_1)) + \delta \pi_A^*(a_A(e_1)) + \delta t_2 \\ &= t_1 + \pi_A(e_1, a_A(e_1)) - K(a_A(e_1)) + \delta \pi_B \\ &< t_1 + V_{AB}(e_1), \end{aligned}$$

where the latter inequality follows from $a_A(e_1) > a_{AB}(e_1)$. Hence, condition (18) is violated, the firm is, thus, strictly better off when it plans to relocate in period 2 from

the beginning and invests in a accordingly. \square

Proof of Proposition 4. Because the regulator seeks to implement an equilibrium with the firm staying in A for both periods, only first-period emission levels e_1 that allow for a corresponding subgame perfect equilibrium are implementable. By Lemma 5 and the discussion in the text, this is the case only if $V_A(e_1) \geq V_{AB}(e_1)$. This proves our claim. \square

Proof of Proposition 5. That the second-period contract entails $t_2 = 0$ follows from Lemma 5 and the argument for the value of e_2 was given in the main text. The function $V_A(e_1)$ is maximized for $e_1 = e_A^o$, therefore, whenever $e_A^o \leq e^\sharp$ the optimal solution takes exactly this value. Otherwise, by concavity of $V_A(e_1)$, the optimal value in the set of implementable levels is e^\sharp . Finally, t_1 is set such that immediate relocation becomes unprofitable from the firm's perspective. \square

Proof of Corollary 2. We have argued in Section 3 as well as in the proof of Proposition 1 that with long-term contracting, the second-period transfer is strictly positive if and only if $V_A(e_A^o) < V_{AB}(e_A^o)$. But this is equivalent to $e_A^o > e^\sharp$. Consequently we have $t_2 = 0$ under long-term contracting if and only if $e_A^o \leq e^\sharp$, which implies $e_1 = e_A^o$ under short-term contracting with unobservable investment. \square

Proof of Proposition 7. For long-term contracting the result is straightforward. The regulator seeks to avert relocation if and only if $(1 + \delta)S \geq t$. This condition can be solved for S^o .

Now consider the case of observable investment. In the second period a contract that averts relocation is offered if and only if $S \geq \pi_B - \pi_A^*(a)$. The contracts coincide to the ones given in section 4.1. Consequently, the firm's expected payoff from choosing investment level a remains to be given by (14). Thus, Lemma 4 remains valid. The case $\pi_B \leq \pi_B^\sharp$ is now straightforward. For the remaining two cases notice that it is never optimal to avert relocation in period one, but allow relocation in period two.³⁸ Thus relocation is averted if and only if $t(e_1) \leq (1 + \delta)S$. Plugging in $e_1 = e^\sharp$, resp. $e_1 = e_A^{tr}$, completes the proof.

Lastly consider the case of unobservable investment. For $\pi_B \leq \pi_B^\sharp$ the result is trivial. Thus, assume for the remainder that $\pi_B > \pi_B^\sharp$. Implementing $e_1 \leq e^\sharp$ is done as illustrated in section 4.2. In this range, $e_1 = e^\sharp$ remains optimal. It is straightforward to verify that the regulator offers such a contract whenever $S \geq S^\sharp$ and $\pi_B > \pi_B^\sharp$.

³⁸ To see this: Relocation in period two occurs whenever $S < \pi_B - \pi_A^*(a)$. But then also $S < \pi_B - \pi_A(e_1, a) - K(a)$ for all e_1 and consequently it is not worth preventing relocation already in period one.

However, the regulator can now also implement contracts that entail $e_1 > e^\sharp$. Consider the following cases for the (pure) level of investment a that the regulator seeks to implement with a first period contract (t_1, e_1) :

1. $\pi_A^*(a) \geq \pi_B$. Then the regulator, without offering any second period contract, averts relocation. The firm always stays and therefore $a = a_A(e_1)$. Her equ. profit is $t_1 + V_A(e_1)$ and we have already seen several times that this requires $e_1 \leq e^\sharp$ to form an equilibrium.³⁹
2. $\pi_A^*(a) < \pi_B$ and $S + \pi_A^*(a) > \pi_B$. In this case the regulator always offers a second-period contract that averts relocation. The firm's second-period profit is π_B and, hence, she chooses $a = a_{AB}(e_1)$. On the other hand, sequential optimality requires that $e_2 = e^*(a)$ which then yields $a = a_A(e_1)$ - a contradiction.⁴⁰
3. $\pi_A^*(a) < \pi_B$ and $S + \pi_A^*(a) = \pi_B$. In this case the regulator, in period two, potentially randomizes between offering a contract that averts relocation or allowing the firm to relocate. But then, because $\pi_A(e_1, a) - K(a) + S < \pi_A^*(a) + S = \pi_B$, the regulator does not want to avert the firm's relocation in period one.
4. $S + \pi_A^*(a) < \pi_B$. Similar to the last point, the regulator does not find it optimal to avert the firm's relocation already in period one.

The argument can be extended to mixed strategies of the firm along the lines of appendix B. □

B Restriction to pure strategies

We want to argue that also with mixed equilibria the regulator cannot avert relocation in the setting of section 4.2 with unobservable investment. For this assume $e_1 > e^\sharp$, for the other case we have already shown that and how the regulator can avert relocation.

A mixed equilibrium is characterized by a randomized strategy of the firm, i.e. a distribution on a subset A of the real line, and a mechanism that the regulator offers in period 2. By the revelation principle, the latter mechanism can be assumed to be direct, incentive compatible and truth-telling.⁴¹

For simplicity we focus in our analysis on the discrete case, i.e. where the firm randomizes over the discrete set of investment levels $\mathcal{A} = \{a^1, \dots, a^n\}$. Clearly, there must

³⁹Otherwise the firm again does better with planned relocation. But then the second-period contract is not sequentially optimal unless $\pi_A^*(a) + S \leq \pi_B$. This contradicts $\pi_A^*(a) \geq \pi_B$.

⁴⁰The argument of Proposition 4 can as well be applied to this case.

⁴¹Because only allocations matter for providing investment incentives to the firm, replacing an arbitrary mechanism that leads to a particular allocation with its direct and incentive compatible counterpart is indeed without loss of generality.

exist $\hat{a} \in \mathcal{A}$ which receives no positive rent. Denote the contract this types accepts in equilibrium as (\hat{t}_2, \hat{e}_2) . Then it must hold that

$$\hat{t}_2 + \pi_A(\hat{e}_2, \hat{a}) = \pi_B. \quad (31)$$

Now consider the firm's investment choice. First of all, \hat{a} must maximize the following expression

$$t_1 + \pi_A(e_1, a) - K(a) + \delta(\hat{t}_2 + \pi_A(\hat{e}_2, a)). \quad (32)$$

Second, because of (31), \hat{a} also maximizes

$$t_1 + \pi_A(e_1, a) - K(a) + \delta\pi_B. \quad (33)$$

Using the first order-conditions for (32) and (33), \hat{a} has to satisfy

$$\frac{\partial \pi_A}{\partial a}(\hat{e}_2, \hat{a}) = 0. \quad (34)$$

Because the function π_A is strictly concave in a for any value e , we conclude that

$$\pi_A(\hat{e}_2, a) < \pi_A(\hat{e}_2, \hat{a}), \quad \forall a \neq \hat{a}. \quad (35)$$

Together with (31) this implies

$$\hat{t}_2 + \pi_A(\hat{e}_2, a) < \pi_B, \quad \forall a \in \mathcal{A} \setminus \{\hat{a}\}. \quad (36)$$

Thus, no other type has the incentive to mimic type \hat{a} , because any type is guaranteed a profit of at least π_B . But this implies that there exists a second type $a' \neq \hat{a}$ that also receives no rent, because otherwise we could reduce all transfers to types $a \neq \hat{a}$ without violating any incentive constraint. This type a' also has to maximize (33). Because (33) has a unique maximizer, namely $a_{AB}(e_1)$, this leads to a contradiction.

References

- Babiker, Mustafa H**, "Climate change policy, market structure, and carbon leakage," *Journal of International Economics*, 2005, 65 (2), 421–445.
- Bergemann, Dirk and Ulrich Hege**, "Venture capital financing, moral hazard, and learning," *Journal of Banking & Finance*, 1998, 22 (6), 703–735.
- **and** –, "The financing of innovation: learning and stopping," *RAND Journal of Economics*, 2005, pp. 719–752.

- Bhaskar, V**, “Learning and the Ratchet Effect: An Impossibility Result,” 2014.
- Bucovetsky, Sam**, “Public input competition,” *Journal of Public Economics*, 2005, *89* (9), 1763–1787.
- Chiappori, Pierre-Andre, Ines Macho, Patrick Rey, and Bernard Salanié**, “Repeated moral hazard: The role of memory, commitment, and the access to credit markets,” *European Economic Review*, 1994, *38* (8), 1527–1553.
- Freixas, Xavier, Roger Guesnerie, and Jean Tirole**, “Planning under incomplete information and the ratchet effect,” *Review of Economic Studies*, 1985, *52* (2), 173–191.
- Fudenberg, Drew, Bengt Holmstrom, and Paul Milgrom**, “Short-term contracts and long-term agency relationships,” *Journal of Economic Theory*, 1990, *51* (1), 1–31.
- Gibbons, Robert**, “Piece-Rate Incentive Schemes,” *Journal of Labor Economics*, 1986, *5* (4), 413–29.
- Harstad, Bård**, “Climate Contracts: A Game of Emissions, Investments, Negotiations, and Renegotiations,” *Review of Economic Studies*, 2012, *79* (4), 1527–1557.
- Hart, Oliver and John Moore**, “Incomplete contracts and renegotiation,” *Econometrica*, 1988, pp. 755–785.
- Haufler, A. and I. Wooton**, “Competition for firms in an oligopolistic industry: The impact of economic integration,” *Journal of International Economics*, 2010, *80*, 239–248.
- Horstmann, Ignatius J and James R Markusen**, “Endogenous market structures in international trade (natura facit saltum),” *Journal of International Economics*, 1992, *32* (1), 109–129.
- Joskow, Paul L**, “Contract duration and relationship-specific investments: Empirical evidence from coal markets,” *American Economic Review*, 1987, *77* (1), 168–185.
- Laffont, Jean-Jacques and Jean Tirole**, “The Dynamics of Incentive Contracts,” *Econometrica*, 1988, *56* (5), 1153–75.
- Lazear, Edward P**, “Salaries and Piece Rates,” *Journal of Business*, 1986, *59* (3), 405–431.
- Manso, Gustavo**, “Motivating innovation,” *Journal of Finance*, 2011, *66* (5), 1823–1860.

- Markusen, James R., Edward R. Morey, and Nancy Olewiler**, “Environmental policy when market structure and plant locations are endogenous,” *Journal of Environmental Economics and Management*, 1993, 24 (1).
- , – , and – , “Competition in regional environmental policies when plant locations are endogenous,” *Journal of Public Economics*, 1995, 56 (1), 55–77.
- Motta, Massimo and Jacques-Francois Thisse**, “Does environmental dumping lead to delocation?,” *European Economic Review*, 1994, 38 (3), 563–576.
- Rey, Patrick and Bernard Salanie**, “Long-term, short-term and renegotiation: on the value of commitment in contracting,” *Econometrica*, 1990, pp. 597–619.
- Schmidt, Robert C. and Jobst Heitzig**, “Carbon leakage: Grandfathering as an incentive device to avert firm relocation,” *Journal of Environmental Economics and Management*, 2013.
- Segal, Ilya and Michael D. Whinston**, “Property Rights,” in “Handbook of Organizational Economics,” R. Gibbons and J. Roberts (eds), 2010.
- Ulph, Alistair**, *Environmental policy, plant location and government protection*, Springer, 1994.
- and **Laura Valentini**, “Plant location and strategic environmental policy with intersectoral linkages,” *Resource and Energy Economics*, 1997, 19 (4), 363–383.
- Weitzman, Martin L.**, “The ‘Ratchet Principle’ and Performance Incentives,” *Bell Journal of Economics*, 1980, 11 (1), 302–308.
- Wilson, John Douglas and David E Wildasin**, “Capital tax competition: bane or boon,” *Journal of Public Economics*, 2004, 88 (6), 1065–1091.