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Unobservable investments, limited commitment, and the curse of firm relocation

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Abstract

Changes in market conditions or policies can induce firms to relocate. Countries may intervene by subsidizing domestic firms. We analyze a dynamic game where a regulator offers contracts to avert relocation of a firm in each of two periods. The firm can undertake an investment that is unobservable to the regulator, while contracts are contingent on an observable productive activity. Under limited commitment it is impossible to implement outcomes with positive transfers in the second period. To circumvent this problem, the regulator can tighten the regulation of the firm in the first period to induce a larger investment (lock-in effect).

Keywords: moral hazard; contract theory; limited commitment; firm mobility; abatement capital
JEL classification: D82, D86, L51

1   Introduction

In a globalized world economy, a firm's location is a strategic choice. Changes in tax regimes, market conditions, or regulations can render production more profitable in one country compared to another, and thus induce firms to relocate their production to other countries. Policy makers perceive firm relocation as particularly harmful, because it puts jobs and tax revenues at risk. For this reason, they take measures to prevent domestic firms from relocating, or design policies in a way that minimizes the relocation risk in the first place.[1]

The issue of firm relocation is inherently dynamic, because it involves location-specific investments, e.g., in buildings, equipment, technologies, etc.. These investment decisions crucially depend on the time horizon during which the firm is planning to operate in its current location, and investments are typically lower if the firm plans to relocate in the near future. A subsidy scheme designed to prevent relocation *permanently*, therefore, has to account for the intertemporal nature of the firm's investment decisions. This imposes strict requirements on the commitment power of regulators.[2] Lacking commitment to future subsidies and regulations exacerbates the relocation problem, because the firm may be unable to recoup sunk investment costs incurred in an earlier period.

This paper argues that averting relocation permanently often requires preempting any incentive to relocate in future periods already today, unless the regulator can credibly commit to future transfers. Underlying this result are two basic forces. On the one hand, the regulator needs to promise future rents to the firm, in order to avert (planned) relocation in later periods. On the other hand, the regulator's lack of commitment constrains any promises to be sequentially optimal. We show that these contradictory motives cannot be brought into balance, unless there is no conflict in future periods, i.e., if the firm

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[1] Various reasons led to the loss of competitiveness of the European steel sector, among others intensified environmental regulation. Recently (in spring 2015), the Italian government stepped in to save the country's loss-making Ilva steel plant. The plant is temporarily nationalized and a sum of two billion euros is unlocked for its rescue, see `http://www.industryweek.com/global-economy/italy-temporarily-nationalizes-ilva-steel-plant`.

[2] E.g., the European Union Emissions Trading System (EU ETS) both regulates emissions and incorporates compensation for firms in the form of free allowances. However, a single phase lasts for at most seven years, hence there is no long-term commitment to regulation, nor to firms' subsidization.

has no incentive to (plan to) relocate in the future even without future transfers. This can be achieved by tightening the firm's regulation at an early stage, which creates strong incentives for the firm to undertake location-specific investments. Once the investment costs are sunk, the firm is locked-in and relocation is averted also in the future.

We demonstrate this in a dynamic setting where a local regulator seeks to prevent the relocation of a firm to some other country in each of two periods. The firm can undertake a location-specific upfront investment that is not observable to the regulator. However, the regulator can make transfer payments to the firm contingent on other indicators of the firm's productive activity, such as its output or emissions. While the firm's optimal choice of these activities is *related* to the investment, they are not fully revealing – some activities remain unobservable to the regulator so that the firm's investment cannot be inferred. We further assume that the regulator cannot make commitments regarding transfers and regulations in the second period and, hence, can offer contracts only on a short-term basis.[3]

A prime example for the type of problem we have in mind is climate regulation, and the associated risks for a domestic economy in the absence of a globally harmonized regulation (such as a uniform carbon price). Past decades elapsed without reaching an effective global treaty to limit countries' emissions of greenhouse gases, which motivated some countries to step forward with unilateral climate policies. To reduce adverse effects on the international competitiveness of domestic industries, many of these unilateral efforts implicitly contain compensation schemes for domestic firms. E.g., the emissions trading scheme of the European Union (EU ETS) stipulates a free allocation of emission allowances for several years to come. Firms respond to the introduction of new environmental regulation by, e.g., investing in more environmentally friendly production processes.[4]

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[3]Such short-term contracting is especially relevant because with changing majorities and legislations, regulators or policy makers may not be able to commit to contractual obligations and future regulations for a sufficiently long period of time.

[4]E.g., in 2012 the Volkswagen Group announced to spend roughly € 40 billion over a span of five years "[...] in ever more efficient vehicles, new powertrains and technologies as well as environmentally compatible production at its plants [...]". Source: `http://www.volkswagenag.com/content/ vwcorp/info_center/en/news/2012/03/Volkswagen_Group_gives_go_ahead_for_fundamental_ ecological_restructuring.html`

Although we analyze the relocation issue in a very general setup that can be applied to various other issues[5], to foster intuition we chose to frame our analysis in the context of this environmental application. Starting point is a unilateral introduction of an emission price by a country (e.g., as a carbon tax or via a cap-and-trade scheme), that induces a polluting firm to relocate to a foreign country with less stringent environmental regulation, unless it is compensated (via transfers).[6] To reduce its operating costs in the light of the domestic emission price, the firm can invest in "abatement capital" or low-carbon technologies. While such investments are unobservable to the regulator, we assume that emissions are observable and verifiable.

In our model, the lack of commitment affects the relocation problem in two ways. First of all the regulator's parsimony in the usage of transfers creates a hold-up problem: With short-term contracts, the offer in the second period only averts relocation in that period, but does not account for earlier investment costs (that are sunk in the second period). In addition, also the firm is opportunistic: It can sack any transfers that take place in the first period and relocate in the second period – a strategy that we will refer to as 'take-the-money-and-run'.[7] To prevent the latter, the regulator could offer a reward to the firm in period 2, but the regulator's parsimony constrains credible promises to be sequentially optimal. We show that the resulting tension between the regulator's and the firm's incentives cannot be resolved in equilibrium, unless there is no need for a second-period transfer. To achieve this, the contract in the first period has to create sufficiently strong investment incentives so that the firm becomes "locked-in", i.e., it prefers not to (plan to) relocate in period 2 even without further transfers in that period.

Comparing the firm's investment to the benchmark of long-term contracting (i.e.,

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[5]E.g., consider a principal and an agent who engage in a project (such as the development of a new product). The agent's outside option (called "relocation" in our model) is then to terminate the project early. The model developed in this paper applies if the regulator cannot observe the firm's overall effort to develop the product, but can subsidize some investments in research equipment.

[6]Firm relocation is a channel of "carbon leakage", which implies that emissions go up elsewhere in response to a unilateral emissions control policy introduced by a country (see, e.g., Babiker (2005)).

[7]E.g., 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 conditioned upon a guarantee to maintain at least 2.856 full-time jobs. Nevertheless, in 2008 Nokia announced plans to shut down production and finally relocated to Romania. For more details see `www.spiegel.de/international/germany/the-world-from-berlin-nokia-under-attack-in-germany-a-529218.html`.

contracting under full commitment), our results point towards an over-investment under short-term contracting. In effect, the over-investment by the firm creates a "commitment" not to relocate that the regulator can utilize when he cannot commit to future regulations and transfers himself. A further implication of our analysis concerns the complexity of optimal contracts. In order to avert relocation with minimal transfers, the regulator prefers the firm to maximize its profits (given any constraints imposed by the regulator). The compensation, thus, only accounts for the difference between the maximized domestic profit of the firm, and the profit that it can achieve abroad. In this sense, the regulator's and the firm's incentives are partially aligned. With long-term contracting this implies that subsidy payments contingent only on the firm's location in each period are sufficient to avert relocation permanently with minimal (total) transfers; there is no need to interfere directly with the firm's productive decisions. By contrast, under limited commitment the regulator sets a tight target for the contractible productive activities of the firm in the first period, thus, *distorting* its productive choices in order to trigger a higher investment. From a policy perspective, our analysis indicates that transfers conditioned only on the location of a firm at a certain point in time may be less effective in averting relocation on a permanent basis than regulations that involve also binding targets for a firm's output, employment, or emissions.[8]

Related Literature

The relocation problem studied in this paper is a special case of dynamic moral hazard with short-term contracts. Fudenberg, Holmstrom and Milgrom (1990) and Chiappori, Macho, Rey and Salanié (1994) provide conditions under which the lack of commitment to future contractual obligations has no adverse effects, i.e., when short-term contracts are sufficient to implement the outcome of the optimal long-term contract. These conditions are not satisfied in our model, thus it falls into the class of models not considered in these

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[8]In the environmental context, such complex schemes are, e.g., applied in the emissions trading schemes of Australia, California, and New Zealand, that established *output-based updating* for allocating free emission permits. See Hood (2010) for further details. In other areas it is quite common that subsidies are subject to job guarantees – see the case of Nokia in Germany (discussed in footnote 7).

two papers.[9]

Only recently a growing body of literature studies dynamic problems of moral hazard where the use of short-term contracts is a severe restriction. Manso (2011) considers the problem of motivating an agent to innovate. Effort resembles choosing the arm of a bandit, where the agent has three options: take no arm at all (shirk), take a risk-less arm generating a known payoff, or take a risky arm generating an unknown payoff. Manso characterizes optimal long-term contracts that implement exploitation, where the agent is induced to take the risk-less arm, and exploration, inducing the risky arm. He further shows that with limited commitment implementing the latter is more costly, respectively impossible when the risky arm is sufficiently costly compared to the risk-less arm. The implementation failure arises from asymmetric beliefs about the risky arm, when the agent takes a different arm than the principal expects. The discrete effort structure, however, works in favor of implementability – as compared to our model with continuous effort, because continuity allows for small deviations towards both lower and higher effort.[10]

Bhaskar (2014) links a model similar to Manso's to the ratchet effect. In a richer information structure, where the agent's effort allows for stochastic learning of an ex-ante unknown state, Bhaskar studies the problem of implementing effort in the first place. As in Manso (2011), the crucial problem is the divergence of beliefs when the agent's action departs from the equilibrium path. When effort is continuous on a closed interval, Bhaskar shows that interior effort levels are not implementable at all. This result stems from the agent's possibility of adopting a 'take-the-money-and-run' strategy, which uses arguments similar to those applied in our paper.

The relation of Manso (2011) and Bhaskar (2014) to the ratchet effect is as follows: when the agent exerts effort there is some learning about an ex-ante unknown state. With short-term contracting, the principal seeks to exploit this new information in the next

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[9]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. The intuition behind their Example 2 is somewhat similar to the intuition for the implementation failure in our model.

[10]Bergemann and Hege (1998, 2005) study similar problems of inducing and agent to work on a risky project with unknown returns. These are 'good news' models, where a success perfectly reveals the state of the world, and no success makes parties more pessimistic. The simple structure substantially relaxes the problem of implementing effort.

period, which undermines the agent's incentives to exert effort in the first place. Traditionally, the ratchet effect, pioneered by Weitzman (1980), has been studied in models with adverse selection. Examples include Lazear (1986), Gibbons (1986), Freixas et al. (1985), and Laffont and Tirole (1988). Lazear (1986) studies piece rates in a competitive labor market. To overcome the ratchet effect, firms offer an inflated piece rate in the first period. However, notice that Lazear's argument for high-powered incentives crucially differs from the argument we provide, because of the competition between principals.

In a model with full bargaining power on the principal's side, Gibbons (1986) proves that a continuum of types cannot be separated in the first period when there is no commitment to second-period contracts. The same result is obtained by Laffont and Tirole (1988). These results can be interpreted as the impossibility of obtaining too precise information about the worker's characteristics from past interactions. A crucial assumption for obtaining these results is the worker's possibility to quit the job after the first period, i.e., the option of "taking the money and run". This feature is also a main driver in our paper and the works with pure moral hazard as outlined above. Freixas, Guesnerie and Tirole (1985) study a similar problem but with discrete types, where separation can be obtained but at some cost compared to the static counterpart.[11]

Dynamic moral hazard in combination with short-term contracting also gives rise to a hold-up problem, e.g. Hart and Moore (1988). The agent's incentives to exert effort in period 1 are undermined by the principal's reluctance to leave rents to the agent in period 2. Effectively, if effort is persistent the agent cannot recoup the complete rent from investing which creates the hold-up. Che and Sákovics (2004) study dynamic hold-up problems, the setting however differs from ours as there is some investment in each period and periods are independent, i.e., effort is not persistent. Hold-ups typically lead to under-investment, whereas we identify over-investment as a possible consequence of incomplete contracting. Joskow (1987) finds empirical evidence for a link between the contractual commitments to future trade and the importance of relationship-specific

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[11]Similar results are obtained by Laffont and Tirole (1987, 1990) and Battaglini (2007) for two-type versions of Laffont and Tirole (1988) and various assumptions on commitment power and persistency of types.

investment. Our paper provides a theoretical foundation: when the contract length falls short of the time in which investment costs are recouped, efficient investment cannot be implemented.

In a model of repeated climate contracting between countries, Harstad (2012) finds results that are related to ours. Countries repeatedly negotiate climate contracts that specify emission levels. Between the contracting stages they invest in abatement technology. Harstad finds that shorter contract duration leads to tougher contracts and lower emission levels are agreed upon. However, investments remain inefficiently small, whereas in our model contracts are tougher *and* investments are inefficiently high.[12]

The interplay of policy-making and firm location has been studied in different strands of literature. Horstmann and Markusen (1992) study the impact of a trade policy on market structure. They study a two-stage game where first countries decide on their policies and second firms choose location and compete. They report that already small policy changes can have severe welfare effects. Also tax competition in general affects firm location, Wilson and Wildasin (2004) and Bucovetsky (2005) provide an overview.[13] The impact of unilateral environmental regulation on firms' location decisions was analyzed formally by Markusen, Morey and Olewiler (1993).[14] 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 (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.

The increasing relevance of the relocation issue under unilateral environmental policy is exemplified also by a recent contribution of Martin et al. (2014) who analyze compensation rules under the EU ETS. They find empirical evidence for substantial overcompensation for given risk of relocation, and argue that a more effective allocation of

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[12]Helm and Wirl (2014) and Martimort and Sand-Zantman (2015) adopt a mechanism design approach to analyze climate agreements. Our analysis focuses on a country that regulates emissions unilaterally.

[13]See also Haufler and Wooton (2010).

[14]See also Markusen et al. (1995). Other examples include 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.

permits could reduce the aggregate risk of job losses by more than half, without raising the implicit transfers. Our approach highlights that policy makers also need to take firms' investment opportunities into account when designing compensation schemes that reduce the risk of firm relocation on a permanent basis. Schmidt and Heitzig (2014) study the dynamics of 'grandfathering' schemes when firms can invest in abatement capital. They show that such transfer schemes can permanently avert firm relocation even when they terminate in finite time. In contrast to our paper, full contractual commitment by the regulator is assumed. Their findings conform with our results on long-term contracting. Meunier, Ponssard and Quirion (2014) consider the possibility that domestic firms can invest in capacity in a setting where demand for a tradeable good is uncertain. These authors do not consider firm relocation, but show that the domestic regulator may subsidize capacity investments to reduce leakage via the trade channel.

The remainder of the paper is organized as follows. Section 2 introduces the model and studies the relocation issue when the firm is not regulated. It also characterizes the benchmark case of full commitment (long-term contracting). Short-term contracting is investigated in Section 3. Extensions of the model, such as an observable but non-contractible investment, and an alternative objective function of the regulator are presented in Section 4. They serve us as a robustness check. Section 5 concludes. All formal proofs are relegated to the Appendix.

2   Model

2.1   The firm

We analyze the following two-period model: A firm is initially located in country A, where it earns per-period profits of $\pi_A(e, a)$. The variable $e \in \mathbb{R}$ reflects some productive activity, and $a \geq 0$ is the stock of capital available to the firm. For illustrative purposes, we will interpret these variables in terms of our environmental example (motivated in the introduction) throughout the paper. Then e stands for the firm's *emissions*, while a is the firm's stock of *abatement capital*. Note that the profit function $\pi_A(e, a)$ is

given in a *reduced form*. In particular, all other potential factors (e.g., input and output quantities, prices, etc.) are always chosen optimally by the firm, for any given values of e and a. Below, we show in a more specific example with functional forms how the firm's reduced profit $\pi_A(e, a)$ results from the firm's profit maximizing choice of other productive variables such as output and price.

Emission levels are chosen in each period, and we denote e_τ the firm's emission level in period $\tau \in \{1, 2\}$. The capital stock a is established at the beginning of period 1 and is thereafter available for both periods of production.[15] We further assume that abatement capital is immobile, i.e. it can only be utilized in country A.[16] The cost of installing the capital stock a is given by the increasing and strictly convex function $K(a)$, where we assume $K(0) = K'(0) = 0$,[17] and that there is an $\varepsilon > 0$ such that $K''(a) \geq \varepsilon > 0$ for all $a \geq 0$.[18] The firm's discounted profit from producing in country A in *both* periods, with emissions e_1 and e_2, and capital a is, therefore,

$$\pi_A(e_1, a) - K(a) + \delta\pi_A(e_2, a), \tag{1}$$

where $\delta > 0$ is the discount factor.[19]

At the beginning of each period, the firm has the possibility to relocate to some other country, in the following referred to as 'country B'. In country B, the firm earns a fixed profit of π_B per period.[20] Relocation is once and for all, and for simplicity assumed costless. If the firm relocates immediately (i.e. at the beginning of period 1) to country

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[15]In particular, we assume away depreciation. Allowing for a positive rate of depreciation would not affect our main results.

[16]Examples include investments in more energy-efficient production technologies, or investments in physical capital such as a building.

[17]We, thus, rule out any fixed cost from installing abatement capital. Our results continue to hold with a not too high fixed cost, but as fixed costs become large the regulator (and the firm) prefer implementing $a = 0$.

[18]The assumption on the second derivative obviously rules out linear cost functions. Relaxing this assumption would require stronger assumptions on the profit function. Loosely speaking, at least one of the involved functions should be non-linear to assure global concavity of target functions that are defined futher below.

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

[20]In the context of our environmental example, country B may, e.g., be a country that does not regulate emissions. Hence, even if abatement capital were mobile, the firm's prior investment does not affect its profit after relocation.

B, it earns a discounted profit of

$$V_B = (1 + \delta)\pi_B. \tag{2}$$

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, also referred to as 'location plan AB', amounts to a discounted profit of

$$\pi_A(e_1, a) - K(a) + \delta\pi_B. \tag{3}$$

We assume that for all $a \geq 0$ the firm's per-period profit function $\pi_A(e, a)$ is strictly concave in e and has a (unique) maximizer $e^*(a)$. Furthermore, we assume that $\partial^2\pi_A/\partial a^2 < 0$ and $\partial^2\pi_A/\partial e\partial a < 0$, where the latter implies that the firm prefers lower emissions when it has a larger abatement capital stock. We further assume that the Hessian of π_A is negative definite.[21] We also assume that a larger abatement capital stock is beneficial to the firm in terms of raising π_A (i.e., when the investment costs are neglected), whenever the firm is free to choose its own emissions.[22] More formally, we assume that $\partial\pi_A/\partial e = 0$ implies $\partial\pi_A/\partial a \in (m, M)$ for some bounds m and M that satisfy $0 < m < M < \infty$.[23] The upper bound on $\partial\pi_A/\partial a$ is sufficient to ensure finite levels of investment throughout the paper.[24] To guarantee positive and finite levels of investment, we finally assume $\partial\pi_A/\partial a \mid_{a=0} > K'(0) = 0$, as well as $\lim_{a\to\infty} \partial\pi_A/\partial a - K'(a) < -M$ for all values of e.

Example. Consider a polluting firm that produces an output quantity q (not observable to the regulator), emitting e units of greenhouse gases (observable and contractible). The firm faces the inverse demand $P(q) = 3 - q/2$ for its output. Marginal costs of

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[21]The negative Hessian yields concavity of implicitly defined functions, which we introduce later on.

[22]Note, that emissions are costly to the firm, e.g., due to a carbon tax implemented by the home country as an over-arching emissions control scheme. Hence, with a larger abatement capital stock the firm is able to produce the same amount of output at lower emissions costs.

[23]A strictly stronger condition to ensure profitable investments would be $\partial\pi_A/\partial a > 0$ for all e. Our weaker condition allows for investment to be detrimental in some cases when the firm's emissions are regulated. E.g., an overly large stock of abatement capital can lead to reduced profits when the firm has to raise production to an inefficiently high level in order to comply with a fixed emission target set by the regulator.

[24]A weaker yet still sufficient condition is $\partial\pi_A/\partial a - K'(a) + \partial\pi_A/\partial a \mid_{e^*(a)} < 0$ as $a \to \infty$.

production are constant and normalized to zero. The emission price in A is equal to 1 in both periods. Consequently, the firm's per-period profit in country A, gross of abatement capital installation cost, is $\widetilde{\pi}_A(e, q) = (3 - q/2)q - e$. Emissions depend on the firm's output as well as on its abatement capital stock. For simplicity, we assume that emissions are additive in q and a, i.e. $e(q, a) = q - a$. Inserting this into $\widetilde{\pi}_A(e, q)$, we obtain the firm's profit function in the *reduced form*:[25] $\pi_A(e, a) = 3a + 2e - (a + e)^2/2$. We will return to this example frequently throughout the paper, in order to illustrate our findings.

2.2 Regulation

In country A a regulator (or policy maker) is concerned with the firm's option to relocate. In particular, as soon as the firm relocates, welfare in country A is reduced by some fixed amount $L > 0$, e.g., due to job losses or lower tax revenues. The assumption that L is independent of whether the firm relocates in period 1 or in period 2 highlights the regulator's interest in averting relocation on a *permanent* basis (rather than on a temporary one). To this end, the regulator offers contracts to the firm in a take-it-or-leave-it manner. The firm's emissions in each period are contractible, while the investment in abatement capital is neither observable to the regulator nor verifiable. Contracts thus specify a location-specific transfer to the firm, denoted by t, and emission levels that the firm has to comply with (in order to obtain the transfer).

Furthermore, we assume that the firm can also reject any contract offer and continue to produce in country A at its own, un-subsidized expense (instead of relocating to B). This assumption limits the regulator's possibilities to extract rents from the firm via taxes. In particular, following a large investment in period 1, the firm may *strictly* prefer not to relocate to B in period 2 (lock-in effect). Because the regulator cannot force the firm into regulation, the firm is able to retain those rents from staying in country A.

Given these assumptions, the regulator's welfare over the two periods is

$$W = -\chi_1 t_1 - \chi_2 \delta t_2 - (1 - \chi_2) L, \tag{4}$$

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[25]It is straightforward to verify that the function $\pi_A(e, a)$ fulfills our earlier assumptions.

where $\chi_\tau = 1$ if the firm operates in country A in period τ (and accepts the contract offered in that period), and $\chi_\tau = 0$ otherwise.[26] The regulator and the firm use the same discount factor $\delta > 0$.[27]

Our implicit assumption that – apart from its location decision – the regulator has no direct preference over the firm's productive choices (in particular e), deserves some attention. In our leading example where e stands for the firm's emissions that lead to a negative externality, the assumption can be motivated as follows. Suppose, the government of country A implements a Pigouvian tax that applies to all emissions, including the emissions of the regulated firm. This over-arching emissions price creates the risk of firm relocation and calls for the (additional) regulation. However, even if the regulator manipulates the firm's level of emissions (e.g., in order to induce a lock-in), the distortion in e has no direct impact upon welfare, because the firm pays the Pigouvian tax to the government for each unit of its emissions. Hence, the social damages of its emissions are already covered by the firm's emissions costs. The regulator is, therefore, concerned with the firm's choice of e only in so far as it affects its incentives to relocate (and, thus, the amount of transfers needed to avert relocation).[28]

Throughout the paper, we distinguish between long-term and short-term contracts. Our main focus is on short-term contracting (limited commitment), while we use long-term contracting (full commitment) as a reference case.

Under short-term contracting, the regulator can make commitments that last only for a single period, i.e., a contract can only specify a transfer and a level of emissions for the current period. The timing of events is as follows (see Figure 1). In the first period the regulator offers a contract (t_1, e_1) to the firm. After observing the contract, the firm decides on its location and whether or not to accept the contract (if it does not relocate).

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[26]Because relocation is by assumption irreversible, $\chi_2 = 1$ requires $\chi_1 = 1$. Similarly $\chi_1 = 0$ implies $\chi_2 = 0$. A third realization is $\chi_1 = 1$ and $\chi_2 = 0$. The damage L is the same in the latter two cases.

[27]Allowing for different discount factors does not affect our main results, because discount factors are irrelevant for sequentially optimal second-period contracts. Only under full commitment (long-term contracting), differences in discount factors can induce the regulator to shift (part of) the transfers either to the first or to the second period (depending on whether the regulator's discount factor is higher or lower than the firm's), while emissions remain unaffected.

[28]The assumption that the regulator has no preference over e is relaxed in Section 4, where we study a more general payoff function that depends on emissions, as well as on the timing of relocation (if the firm relocates).

The game ends immediately whenever the firm relocates. If the firm does not relocate in period 1, it invests in abatement capital and production takes place according to the terms specified in the contract (if accepted). At the end of period 1, the transfer is paid to the firm. Period 2 starts with a new contract offer (t_2, e_2) by the regulator. The firm again decides whether or not to relocate in period 2, and whether to accept the contract offer (if it does not relocate). If it stays in A, it produces according to the contractual terms (if accepted), or it produces without accepting the contract, in which case it does not receive any transfer payment in period 2.

Under long-term contracting, the initial contract offer specifies emissions and transfers for both periods. Hence, 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, retains an exit option, i.e., it can leave a long-term contract after period 1. This is the case if it wishes to relocate to country B in period 2, or if it prefers to produce at its own, un-subsidized expense in that period.[29] Compared with the timing of events under short-term contracting, the stages where the regulator offers the second-period contract (t_2, e_2) and where the firm decides whether or not to accept this offer, are skipped. However, before the firm decides on its location in period 2, a new stage is added where the firm decides whether or not to use its exit option.

Although we study a dynamic game with imperfect information, it turns out that we can use Subgame Perfect Nash Equilibrium (SPNE) as our solution concept. This is obvious in the case of long-term contracting where the regulator moves only once and all remaining decisions are taken by the firm.

Under short-term contracting, there is no proper subgame after the firm's choice of a (see Figure 1), because the regulator does not observe the firm's choice of a. However, the stages after the regulator's second-period contract offer (t_2, e_2) constitute a proper subgame, because the firm has perfect recall. Furthermore, the sequentiality of the firm's choice of a and the second-period contract offer (t_2, e_2) is inconsequential for the equilib-

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[29]The exit option under long-term contracting is not crucial. It merely forces the regulator to postpone some transfers to period 2, unless the optimized emissions level in the first period already induces a lock-in. The implemented allocation, i.e., emission levels and abatement, are not affected by the firm's exit option.

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rium outcome, because no information is revealed between these moves. Hence, we can effectively treat these stages as *simultaneous* moves.[30]

Furthermore, throughout the main part of the paper we focus on pure strategies. This is clearly without loss of generality when we analyze long-term contracts. With short-term contracting, randomization could be beneficial when the firm chooses its investment. However, as we formally prove in Appendix B, there are no additional equilibria in mixed strategies. Hence, focusing on pure strategy equilibria is without loss of generality also in the case of short-term contracting.

2.3   Preliminaries and the 'no-regulation' benchmark

In the following we consider the firm's problem in isolation and identify conditions under which relocation occurs. It is convenient to introduce the following short-hand notation. Let

$$\pi_A^*(a) = \max_e \pi_A(e, a) \tag{5}$$

be the firm's *maximal profit* in one period after having installed capital stock a. Denote $e^*(a)$ the corresponding level of emissions. Furthermore, let

$$V_A(e_1) = \max_a \left(\pi_A(e_1, a) - K(a) + \delta \pi_A^*(a) \right), \tag{6}$$

which represents the firm's discounted profit when staying in country A in both periods, with first-period emissions *fixed* (e.g., in a contract) at level e_1, while choosing e_2 optimally in period 2, and choosing a optimally in period 1. The corresponding optimal level of investment is denoted by $a_A(e_1)$. Similarly,

$$V_{AB}(e_1) = \max_a \left(\pi_A(e_1, a) - K(a) + \delta \pi_B \right) \tag{7}$$

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[30]The alternative would be to use Perfect Bayesian Nash Equilibrium. This requires specifying beliefs of the regulator in stage 4 about the firm's choice of investment. Because of the simple structure, these PBNE correspond to the SPNE.

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 can identify the following properties of these functions and their maximizers (see Lemma A1 in the Appendix for further details).

First of all, a firm that has installed a larger abatement capital stock optimally chooses lower emissions (i.e., $e^*(a)$ strictly declines in a). Furthermore, $\pi_A^*(a)$ strictly increases in a, beyond any bound. Hence, whenever the firm has invested enough in abatement capital, it is no longer tempted to relocate (lock-in effect). The functions V_A and V_{AB} are strictly concave and have unique maximizers. The functions $a_A(e_1)$ and $a_{AB}(e_1)$ are decreasing because in our model a stricter regulation in the first period corresponds to a *smaller* value of e_1 (emissions are regulated more tightly). Accordingly, the firm responds with a larger investment. And finally, it holds that $a_A(e_1) > a_{AB}(e_1)$ for any e_1. This is intuitive, because if the firm plans to stay in A in both periods, it benefits from the investment also in period 2.

Lemma 1. *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 formally establishes the *lock-in* effect, which plays a crucial role for our later results. Intuitively, whenever the firm prefers to stay in country A for one period (in the absence of transfers), undertaking a corresponding investment in abatement capital (i.e., $a = a_{AB}(e_1)$), then it is also willing to stay for the second period where the investment costs are already sunk. By raising its investment to the level $a_A(e_1)$, the firm can achieve an even higher profit. Hence, the option to relocate after one period is inferior to either immediate relocation or no relocation. Figure 2 illustrates the typical shape of the firm's payoff function $V_A(e_1)$ 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.

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

$$e_A^o = \arg\max_{e_1} V_A(e_1). \tag{8}$$

Because the firm uses the same capital stock in each period, given this optimal choice of first-period emissions, it holds that $e_2 = e_1 = e_A^o$ if the firm is free to choose its emissions in period 2. Define $V_A^o := V_A(e_A^o)$ and $a_A^o := a_A(e_A^o)$. The following lemma is an immediate consequence of the preceding derivations.

Lemma 2. *Absent regulatory intervention, the firm strictly prefers immediate relocation whenever $\pi_B > \pi_B^o$, and no relocation otherwise. The critical value π_B^o is given by*

$$\pi_B^o := \frac{V_A^o}{1 + \delta}. \tag{9}$$

Throughout the rest of the paper we maintain the assumption that $\pi_B > \pi_B^o$. Hence, in the absence of regulatory intervention the firm relocates immediately.

Example. Let us return to our example. Maximizing $\pi_A(e, a) = 3a + 2e - (a + e)^2/2$ over e, we find that the firm's optimal emissions (given a) are $e^*(a) = 2 - a$. Therefore, we have $\pi_A^*(a) = 2 + a$. Let the investment costs be given by $K(a) = a^2/2$. If the firm plans to stay in A in both periods, and is constrained to emit (no more than) e_1 units in period 1 (e.g., by the regulator), it thus maximizes the following expression over a: $3a + 2e_1 - (a + e_1)^2/2 - a^2/2 + \delta(2 + a)$. This yields $a_A(e_1) = (3 - e_1 + \delta)/2$ and $V_A(e_1) = \frac{1}{2}(5 + \delta)(1 + \delta) - \frac{1}{4}(e_1 - (1 - \delta))^2$. The latter implies $e_A^o = 1 - \delta$ and $V_A^o = \frac{1}{2}(5 + \delta)(1 + \delta)$. The critical level of π_B for relocation is $\pi_B^o = \frac{1}{2}(5 + \delta)$. If the firm plans to stay in A for only one period, it maximizes over a: $3a + 2e_1 - (a + e_1)^2/2 - a^2/2 + \delta\pi_B$. This yields $a_{AB}(e_1) = (3 - e_1)/2$, and $V_{AB}(e_1) = \frac{5}{2} - \frac{1}{4}(e_1 - 1)^2 + \delta\pi_B$. The firm's optimal choice of first-period emissions is $e_{AB} = 1$. Observe that the firm's emissions are higher and the abatement capital investment is smaller when it plans to relocate after one period (we find $a_A^o = 1 + \delta$ and $a_{AB} = 1$).

2.4 Long-term contracting

Given our earlier assumptions, the regulator's payoff from not offering a contract is $-L$ because the firm then relocates immediately. To prevent this, under full commitment the regulator can offer a long-term contract that incentivizes the firm to stay in country A for both periods.

In finding the optimal contract that permanently averts relocation, the regulator solves the following program

$$\min_{t_1, e_1, t_2, e_2, a} \quad t_1 + \delta t_2$$

$$\text{s.t.} \quad t_1 + \pi_A(e_1, a) - K(a) + \delta\big(t_2 + \pi_A(e_2, a)\big) \geq V_B, \tag{PC}$$

$$t_1 + \pi_A(e_1, a) - K(a) + \delta\big(t_2 + \pi_A(e_2, a)\big) \geq$$
$$t_1 + \pi_A(e_1, \widetilde{a}) - K(\widetilde{a}) + \delta\big(t_2 + \pi_A(e_2, \widetilde{a})\big) \quad \forall \widetilde{a}, \tag{MH-1}$$

$$t_2 + \pi_A(e_2, a) \geq \pi_B. \tag{EO}$$

The participation constraint (PC) ensures that the firm prefers accepting the contract (and not relocating) to immediate relocation. Constraint (MH-1) is a moral hazard constraint, that ensures the firm chooses the *intended* level of investment. Constraint (EO) ensures the firm does not exit the contract in period 2.[31]

Let us first ignore (EO). We later point out that appropriately distributing transfers across periods turns out sufficient to satisfy the constraint. The distribution of transfers across periods is, thus, inconsequential and we can substitute for the total transfer $t = t_1 + \delta t_2$. Obviously the participation constraint (PC) is binding. Together with the moral hazard constraint (MH-1) the minimal (total) transfer t that is required to avert relocation in both periods when emissions are chosen at levels e_1 and e_2 is

$$t = V_B - \max_a \big(\pi_A(e_1, a) - K(a) + \delta \pi_A(e_2, a)\big). \tag{10}$$

The regulator's minimization program given above, therefore, corresponds to minimizing (10) with respect to e_1 and e_2. This is equivalent to maximizing $V_A(e_1)$ over e_1,

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[31]Constraint (EO) has only π_B as reference profit, because any outcome where the firm does exit the contract in period 2 but nevertheless stays in A can equivalently be achieved by a contract that entails $t_2 = 0$ and $e_2 = e^*(a)$.

which yields $e_1 = e_A^o$ as defined in (8). Consequently, the minimal total transfer required to avert relocation is $t^o := V_B - V_A^o$, and the regulator, accounting for the welfare loss from relocation, offers a contract that averts relocation if and only if this transfer does not exceed L. Finally we can show that t^o always exceeds the minimal transfer that has to be delayed to period 2, in order to incentivize the firm not to exit the contract (in order to relocate).

Proposition 1. *The regulator offers a contract that averts relocation if and only if* $L \geq t^0$. *The optimal long-term contract specifies* $e_1 = e_2 = e_A^o$ *and pays the firm a total transfer* $t^o := V_B - V_A^o$, *which can be paid entirely in period 2 to prevent relocation in period 2.*

Notice the following alternative way of implementing the optimal long-term contract: the regulator can simply offer the lump-sum subsidy t^o (paid in period 2) under the condition that the firm has not relocated in period 1, and does not relocate in period 2. This leaves the optimal choices of e_1 and e_2 at the firm's discretion. The firm then chooses emissions and investment so as to maximize its discounted profit. But this implies $e_1 = e_2 = e_A^o$ and $a = a_A^o$, as we have shown in Section 2.3. Hence, under full commitment, a simple location-based subsidization is sufficient to avert firm relocation with minimal transfers; the regulator does not need to interfere directly with the firm's productive activities.

Example. Applying Proposition 1, the optimal long-term contract specifies emission targets $e_1 = e_2 = e_A^o = 1 - \delta$. The firm's discounted profit in A is $V_A^o = \frac{1}{2}(1 + \delta)(5 + \delta)$, and a total transfer of $t^o = V_B - V_A^o = (1+\delta)\left[\pi_B - \frac{1}{2}(5+\delta)\right]$ is required to avert relocation. From the expression for t^o we also get $\pi_B^o = \frac{1}{2}(5 + \delta)$.

3 Short-term contracting

We now move on to the analysis of short-term contracting, which is the main focus of this paper. Hence, we assume that the regulator cannot commit to a contract that specifies emissions and transfers for both periods and instead resorts to a sequence of short-term contracts. We will show that an implementation problem arises that makes it difficult to

avert relocation on a permanent basis. However, we also demonstrate that the regulator can still achieve this goal by offering more high-powered incentives in the first period.

As compared to the case of full commitment (long-term contracting), the regulator faces two additional constraints.[32] First of all, the contract offered by the regulator in the second period has to be sequentially optimal, which means that the firm is just compensated for not relocating within that period (if a positive transfer takes place in period 2). Formally, *given* that the firm has an abatement capital stock of a, the second-period contract (t_2, e_2) is sequentially optimal whenever

$$t_2 = \max\{0, \pi_{\text{B}} - \pi_{\text{A}}^*(a)\}, \qquad e_2 = e^*(a). \tag{SO}$$

The firm accepts the contract whenever $t_2 + \pi_{\text{A}}(e_2, a) \geq \max\{\pi_{\text{B}}, \pi_{\text{A}}^*(a)\}$.[33] As in the case of long-term contracting, the regulator's and the firm's interests are to some extent aligned: minimizing the transfer payment, the regulator seeks to maximize the firm's profit over e_2, which implies the choice of $e_2 = e^*(a)$. What is crucial is that whenever $t_2 > 0$, the transfer just compensates the firm for not relocating in period 2. However, if $\pi_{\text{A}}^*(a) \geq \pi_{\text{B}}$, then no second-period transfer is required.[34]

The second additional constraint concerns the firm's possibility to (secretely) plan relocation in period 2, and investing less in abatement capital accordingly. Having accepted the first-period contract (t_1, e_1) and following the location plan AB stipulates the investment $a_{\text{AB}}(e_1)$, and the firm earns a discounted profit of $t_1 + V_{\text{AB}}(e_1)$.[35] To incentivize the firm not to adopt such a "take-the-money-and-run" strategy, the regulator needs to assure that the following condition holds:

$$t_1 + \pi_{\text{A}}(e_1, a) - K(a) + \delta\big(t_2 + \pi_{\text{A}}(e_2, a)\big) \geq t_1 + V_{\text{AB}}(e_1). \tag{MH-2}$$

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[32]Since the firm needs no exit option under short-term contracting, the constraint (EO) becomes obsolete. However, the same constraint is now contained in a new condition which assures that the firm accepts the second-period contract (and does not relocate); see below.

[33]Recall that the firm has the option to produce in A at its own, un-subsidized expense, earning a maximal profit of $\pi_{\text{A}}^*(a)$.

[34]We assume that when $\pi_{\text{A}}^*(a) \geq \pi_{\text{B}}$, the firm still accepts a contract offer with $t_2 = 0$ and emissions at the level $e_2 = e^*(a)$ without loss of generality.

[35]Of course this requires the firm to actually reject the second-period contract. Because $a_{\text{AB}}(e_1) < a_{\text{A}}(e_1)$ this is indeed the case.

The condition states that the firm obtains a larger profit from accepting both contracts (t_1, e_1) and (t_2, e_2) and investing in a accordingly (as desired by the regulator) than under the take-the-money-and-run strategy. Furthermore, the regulator has to respect conditions (PC) and (MH-1), introduced in the last section. The regulator's problem of finding the minimal transfer(s) that permanently avert relocation can, therefore, be stated as follows:

$$\min_{t_1, e_1, t_2, e_2, a} t_1 + \delta t_2, \qquad \text{subject to (PC), (MH-1), (MH-2), (SO).} \qquad (\mathcal{P}_S)$$

To solve problem $\mathcal{P}_S$, let us first fix a contract offer (t_1, e_1). The regulator thus seeks to implement an equilibrium where the firm invests a and accepts also the second-period contract offer (t_2, e_2), i.e., does not relocate in any period. As explained above, the sequentially optimal second-period contract does not distort the firm's emissions in period 2, that is, the regulator imposes the profit-maximizing emissions on the firm in period 2, for the *anticipated* investment a. Similarly, the firm chooses its investment, anticipating that it will produce with the profit-maximizing level of emissions in period 2. In sum, conditions (MH-1) and (SO) imply that the firm's discounted profit *in equilibrium* is $t_1 + V_A(e_1) + \delta t_2$. Using this to rewrite the left-hand side of (MH-2) yields

$$\delta t_2 + V_A(e_1) \geq V_{AB}(e_1). \qquad (\text{MH-2}')$$

Condition (MH-2$'$) reflects the dual role of the second-period transfer t_2. When deciding upon the investment, the firm faces two options: Either it invests little and relocates in period 2, rejecting the second-period contract offer. Or it invests more, planning to stay in A in both periods and accepting the second-period contract offer. To avoid the former "take-the-money-and-run" strategy, the regulator has to '*promise*' a sufficiently large transfer t_2. However, in the second period the regulator is only willing to compensate the firm for not relocating in that period. Any other promises become void.

More formally, condition (MH-2$'$) puts a lower bound on the second-period transfer, namely $\delta t_2 \geq V_{AB}(e_1) - V_A(e_1)$. On the other hand, condition (SO) requires that the

same transfer satisfies $t_2 = \max\{0, \pi_B - \pi_A^*(a)\}$.

We are now ready to formally state the central result of this paper regarding the implementability of equilibrium outcomes that do not involve relocation in any period.

Proposition 2. *For any first-period emission level e_1, there exists a second-period contract (t_2, e_2) and an investment level a such that constraints* (MH-1), (MH-2), *and* (SO) *are satisfied if and only if* $V_A(e_1) \geq V_{AB}(e_1)$.

In other words: if a sequence of short-term contracts $(t_1, e_1), (t_2, e_2)$ permanently averts the firm's relocation in equilibrium, then it must necessarily hold that $t_2 = 0$. Outcomes where the firm never relocates and that involve positive transfers in the second period are, thus, not implementable if the regulator cannot commit to future transfers. Hence, under short-term contracting an equilibrium with no relocation requires a situation where the firm is *locked-in* after the first period.

If the condition in the Proposition is met, constraint (MH-2) has no bite. This can be seen best from its reformulation into (MH-2′). Provided that $V_A(e_1) \geq V_{AB}(e_1)$, any non-negative transfer t_2 satisfies the constraint. If, however, $V_A(e_1) < V_{AB}(e_1)$, constraint (MH-2′) imposes a lower bound on t_2, as argued above. Intuitively, in order to satisfy constraint (MH-2′), the second-period transfer not only has to account for the difference in second-period profits between staying (having invested $a_A(e_1)$) and relocating in period 2 (having invested $a_{AB}(e_1)$ accordingly), but also for the resulting difference in *first-period* profits (as $a_A(e_1) > a_{AB}(e_1)$). In particular, first-period profits are strictly higher with planned relocation because the firm then incurs lower investment costs, and the second-period transfer – serving as reward – has to compensate the firm also for this difference. However, the regulator does not have the commitment power to promise such a future reward from the start, and offering it ex-post is not sequentially optimal. Any sequentially optimal second-period transfer (i.e., any t_2 that satisfies (SO)) only compensates the firm for not relocating within that period, and fails to take into account investment costs that were incurred prior to this period.

Proposition 2 also allows us to determine when the optimal *long-term* contract is implementable via a sequence of short-term contracts:

Corollary 1. *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 is equivalent to $\pi_B \leq \pi_B^\sharp$, where*

$$\pi_B^\sharp := \tfrac{1}{\delta}\left(V_A^o - \pi_A(e_A^o, a_{AB}(e_A^o)) + K(a_{AB}(e_A^o))\right) > \pi_B^o.$$

The respective sequence of contracts entails $(t_1, e_1) = (t^o, e_A^o)$, and $(t_2, e_2) = (0, e_A^o)$.

Let us now characterize short-term contracts that permanently avert relocation in equilibrium although $\pi_B > \pi_B^\sharp$, thereby taking into account the implementation problem that we identified above. The following result makes the analysis more transparent, by mapping the condition $V_A(e_1) \geq V_{AB}(e_1)$ from Proposition 2 to a line segment.

Lemma 3. *Assume $\pi_B > \pi_B^\sharp$. Then there exists a unique value $e^\sharp$, with $e^\sharp < e_A^o$, such that $V_A(e_1) \geq V_{AB}(e_1)$ holds if and only if $e_1 \leq e^\sharp$. The level $e^\sharp$ decreases with π_B.*

Hence, only sufficiently tight (i.e., low) emission targets for the first period can be utilized to implement an outcome without relocation in any period (in equilibrium). By offering more high-powered incentives in the first period, the regulator can, thus, enforce a sufficiently high abatement capital investment, which renders location plan AB unprofitable.

Let us now determine 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. Because $V_A(e_1)$ is strictly concave, this value is simply given by $e_1 = e^\sharp$ when $\pi_B > \pi_B^\sharp$. Regarding the cost of implementing such an outcome, the total transfer required is $t_1 = t^\sharp := V_B - V_A(e^\sharp)$, and the regulator prefers this to immediate relocation whenever $t^\sharp \leq L$.

Proposition 3. *To implement an equilibrium where the firm stays for both periods in country A with minimal transfers, the regulator offers the first-period contract*

- $(t_1, e_1) = (t^o, e_A^o)$, *if $\pi_B \leq \pi_B^\sharp$ and $L \geq t^o$, and*

- $(t_1, e_1) = (t^\sharp, e^\sharp)$, *if $\pi_B > \pi_B^\sharp$ and $L \geq t^\sharp$, with $t^\sharp = V_B - V_A(e^\sharp) > t^o$.*

The respective second-period contract is $(t_2, e_2) = (0, e^*(a_A(e_1)))$. *If the involved trans-fers are too high (i.e.,* $L < t^o$ *if* $\pi_B \leq \pi_B^\sharp$, *resp.* $L < t^\sharp$ *if* $\pi_B > \pi_B^\sharp$*) then the regulator prefers not to offer any contract to the firm, and the firm relocates immediately.*

The implications of Proposition 3 are as follows: For moderate relocation profits π_B, the lack of commitment has no consequence for the optimal contract. Both with long-term and with short-term contracting, paying all transfers in period 1 does not trigger relocation in the future. Subsidizing the firm only for one period is sufficient to induce the firm to stay also in period 2. This case is depicted in the left panel of Figure 3. Observe that at $e_1 = e_A^o$, it holds that $V_{AB}(e_1) < V_A(e_1)$. Hence, as the firm has to comply with the emission target e_1 in order to obtain the transfer t_1 in the first period, the option to relocate in period 2 is effectively ruled out.

However, when the outside option 'relocation' is more attractive, limited commitment restricts the set of outcomes that can be implemented in equilibrium. A tension arises between the regulator's parsimony, i.e., offering a sequentially optimal second-period contract that minimizes transfer payments in that period, and the firm's opportunism, i.e., considering a 'take-the-money-and-run' strategy (sacking first-period transfers and relocating in period 2). This tension can be resolved by tightening regulation in the first period. However, this amounts to a downward-distortion in e_1, that is costly to the regulator because it necessitates larger (total) transfers. In particular, the transfer t_1 required to induce the firm to accept the first-period contract (rather than to relocate immediately) is then larger than the total discounted transfer under the optimal long-term contract. This case is depicted in the right panel of Figure 3. An implication of Proposition 3 is, therefore, that with short-term contracting, the regulator prefers *not* to avert relocation already for lower values of the welfare loss L. In this sense, limited commitment leads to *more* relocation.

Figure 4 shows combinations of the parameters π_B and L for which relocation is averted under the short-term contracts characterized in Proposition 3, in comparison with the respective results under optimal long-term contracting. As the figure illustrates, the implementation problem that is underlying the results of Proposition 3 becomes more

severe when the relocation option becomes more attractive (i.e., for larger values of π_{B}). By contrast, when $\pi_{\text{B}} \leq \pi_{\text{B}}^{\sharp}$, there is no implementation problem, because offering a contract in period 1 is already sufficient to avert relocation in both periods. If $\pi_{\text{B}} \leq \pi_{\text{B}}^{\circ}$ then no transfers are needed to avert relocation.

As a consequence of limited commitment also investments are distorted. In particular, the tougher first-period emission target e_1 leads to an over-investment in abatement capital by the firm.

Corollary 2. *Under the sequence of short-term contracts characterized in Proposition 3, the implemented investment level is a_{A}° for $\pi_{\text{B}} \leq \pi_{\text{B}}^{\sharp}$ (and $L \geq t^{\circ}$), and distorted upwards for $\pi_{\text{B}} > \pi_{\text{B}}^{\sharp}$ (and $L \geq t^{\sharp}$).*

We close this section by illustrating the above findings in our earlier example.

Example. The firm's profit when following location plan 'AB' with first-period emissions e_{A}° is given by $V_{\text{AB}}(e_{\text{A}}^{\circ}) = \frac{5}{2} - \frac{1}{4}\delta^2 + \delta\pi_{\text{B}}$. We have $V_{\text{A}}^{\circ} \geq V_{\text{AB}}(e_{\text{A}}^{\circ})$ if and only if $\pi_{\text{B}} \leq \pi_{\text{B}}^{\sharp} = 3 + \frac{3}{4}\delta$. Notice that $a_{\text{A}}^{\circ} = 1 + \delta$ and hence $\pi_{\text{A}}^{*}(a_{\text{A}}^{\circ}) = 3 + \delta > \pi_{\text{B}}$ whenever $\pi_{\text{B}} \leq \pi_{\text{B}}^{\sharp}$. This demonstrates the lock-in effect, which renders relocation unprofitable even absent any second-period transfer payment. If, however, $\pi_{\text{B}} > \pi_{\text{B}}^{\sharp}$ a transfer of $t_2 \geq \frac{1}{\delta}\{V_{\text{AB}}(e_{\text{A}}^{\circ}) - V_{\text{A}}^{\circ}\} = \pi_{\text{B}} - \pi_{\text{B}}^{\sharp}$ is required to implement the long-term contract. Provided the firm indeed chooses investment a_{A}°, the sequentially rational second-period transfer is $\max\{0, \pi_{\text{B}} - \pi_{\text{A}}^{*}(a_{\text{A}}^{\circ})\} = \max\{0, \pi_{\text{B}} - (3 + \delta)\}$. Implementation fails, because the latter is strictly lower than $\pi_{\text{B}} - \pi_{\text{B}}^{\sharp}$, which mirrors the finding of Corollary 1. The critical value $e^{\sharp}$ is given by $e^{\sharp} = e_{\text{A}}^{\circ} - 2(\pi_{\text{B}} - \pi_{\text{B}}^{\sharp}) = 7 + \frac{\delta}{2} - 2\pi_{\text{B}}$. Consequently, for $\pi_{\text{B}} > \pi_{\text{B}}^{\sharp}$, the regulator specifies first-period emissions $e_1 = e^{\sharp} < e_{\text{A}}^{\circ}$. The resulting first-period transfer is $t^{\sharp} = V_{\text{B}} - V_{\text{A}}^{\circ} + (\pi_{\text{B}} - \pi_{\text{B}}^{\sharp})^2 > V_{\text{B}} - V_{\text{A}}^{\circ}$ (if $L \geq t^{\sharp}$). Investment in this case is $a_{\text{A}}^{\sharp} = a_{\text{A}}^{\circ} + \pi_{\text{B}} - \pi_{\text{B}}^{\sharp} > a_{\text{A}}^{\circ}$.

4 Extensions

In this section we consider extensions of our main model, and analyze to what extent they have an impact on the central result of the previous section, regarding the implementabil-

ity of outcomes under short-term contracting. First, we consider a situation where the firm's investment is *observable* to the regulator, but remains non-contractible.[36] Second, we focus on a more general objective function of the regulator, that (apart from the firm's location decision) also depends on the firm's emissions, and allows for a benefit to the regulator from averted relocation also in case the firm stays for only one period in A.

4.1 Observable Investment

Observability of the firm's investment relaxes the implementation problem studied in the previous section to some extent. The reason is, that the regulator can now make the second-period contract offer dependent on the level of investment actually *chosen* by the firm (and not just the anticipated level of a, as in the previous section). As a result, also emission levels $e_1 > e^\sharp$ can now be used to implement SPNE without relocation when $\pi_B > \pi_B^\sharp$. Nevertheless, there is a distortion, and we will show that the optimal long-term contract can only be implemented when $V_A^o \geq V_{AB}(e_A^o)$ (as in the case with an unobservable investment).

Because the regulator now observes the firm's investment level a, the second-period contract entails $e_2 = e^*(a)$ and $t_2 = \max\{0, \pi_B - \pi_A^*(a)\}$, unless the stated t_2 exceeds L (in this case no second-period contract is offered and the firm relocates). Let $\overline{a}$ be the investment level that is just sufficiently large to create a lock-in situation in period 2. Hence, it is implicitly defined by the condition $\pi_A^*(\overline{a}) = \pi_B$.[37] For $a \geq \overline{a}$ no second-period transfer is required to avert relocation and the firm's second-period profit is $\pi_A^*(a)$. Otherwise (for $a < \overline{a}$), the firm is either offered a contract and does not relocate, or there is no second-period contract offer and the firm relocates; in both cases, the firm's profit

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[36] Bergemann and Hege (2005) show in a model of project-financing with an infinite time horizon that non-observability of effort may actually be beneficial because it leads to a form of implicit commitment. In our model with a finite horizon, observability is always preferable. Nonetheless, short-term contracting still has severe consequences on implementation.

[37] Existence of $\overline{a}$ follows from Lemma A1, result (2).

in period 2 is π_B. Overall, the firm's discounted profit at the investment stage is thus

$$t_1 + \pi_A(e_1, a) - K(a) + \delta \begin{cases} \pi_A^*(a), & a \geq \bar{a}, \\ \\ \pi_B, & a < \bar{a}. \end{cases} \tag{11}$$

After having accepted the first-period contract, the firm chooses its investment to maximize (11). The corresponding investment level depends only on e_1. For low values of e_1, namely $e_1 \leq e^\sharp$, the firm invests $a_A(e_1)$. Intuitively, the optimal investment when the firm plans to stay for only one period in country A is, then, already fairly large. The firm then prefers to invest even more, planning to stay also in period 2, even without a second-period transfer. This leads to an optimal investment of $a = a_A(e_1)$. On the other hand, less stringent first-period emission levels $e_1 > e^\sharp$ render large investments unprofitable, so that the firm ends up requiring a transfer in period 2.

Paradoxically, although the regulator can now implement equilibrium outcomes where such transfers are paid in period 2 (because the firm's actual investment a is now observable), the regulator is unable to induce the firm to invest optimally in a (optimal for a permanent stay in A) whenever the second-period transfer is strictly positive. The reason for this is a hold-up problem: given the second-period transfer that averts relocation in that period, the firm's second-period profit is always π_B. Hence, all rents from a higher investment are captured by the regulator. As a result, the firm optimally chooses $a = a_{AB}(e_1)$ even when it does *not* plan to relocate. The regulator thus often prefers to induce a lock-in (as in the case with an unobservable investment), despite the possibility to implement outcomes with positive transfers in the second period.

Plugging the optimal investment level back into the firm's discounted profit, (11), its profit is $t_1 + V_A(e_1)$ whenever $e_1 \leq e^\sharp$, and $t_1 + V_{AB}(e_1)$ whenever $e_1 > e^\sharp$. The first-period transfer that is necessary to implement some first-period emission level e_1 is thus given by $t_1 = V_B - V_A(e_1)$ if $e_1 \leq e^\sharp$, and $t_1 = V_B - V_{AB}(e_1)$ if $e_1 > e^\sharp$. In the latter case, also a positive second-period transfer of $t_2 = \pi_B - \pi_A^*(a_{AB}(e_1))$ is paid. The total (discounted) transfer needed to implement a first-period emission level of $e_1 > e^\sharp$ is then $t = V_B - V_{AB}(e_1) + \delta(\pi_B - \pi_A^*(a_{AB}(e_1)))$. Denote the minimizer of this expression by e_A^{tr}

and the minimized value of the expression by t^{tr}.

Proposition 4. *Assume* $a_{AB}(e)$ *is concave in* e.[38] *To implement an equilibrium where the firm stays for both periods in country* A *with minimal transfers in the case of an observable investment, the regulator offers the first-period contract*

- $(t_1, e_1) = (t^o, e_A^o)$, *if* $\pi_B \leq \pi_B^\sharp$ *and* $L \geq t^o$,

- $(t_1, e_1) = (t^\sharp, e^\sharp)$, *if* $\pi_B^\sharp < \pi_B \leq \pi_B^{tr}$ *and* $L \geq t^\sharp$, *and*

- $(t_1, e_1) = (V_B - V_{AB}(e_A^{tr}), e_A^{tr})$, *if* $\pi_B > \pi_B^{tr}$ *and* $L \geq t^{tr}$.

In all other cases the regulator prefers not to offer any contract to the firm and the firm relocates immediately. $\pi_B^{tr} > \pi_B^\sharp$ *is the critical value for* π_B *for which* $t^\sharp = t^{tr}$. *The second-period contract in the third case is* $(t_2, e_2) = (\pi_B - \pi_A^*(a_{AB}(e_A^{tr})), e^*(a_{AB}(e_A^{tr})))$.

Hence, in contrast to the case with unobservable investment, the regulator now has an alternative way to avert relocation, using the possibility to implement a positive second-period transfer. 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 that just averts relocation. However, this option creates a (potential) double inefficiency. Namely, the firm's investment is inefficiently small (given e_1), because the firm does not incur the full returns on investing in abatement capital (as in the second period a higher value of a leads to lower transfers). In addition, the emissions in period 1 may also be distorted.[39] Since the actions implemented by the firm in this case do *not* depend on the value of π_B, whereas the distortions in the case with a lock-in (second case in Proposition 4) are increasing in π_B, the regulator implements e_A^{tr} whenever π_B is sufficiently large (larger than π_B^{tr}).

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[38]This assumption is sufficient to establish existence and uniqueness of the value e_A^{tr}. Only mild assumptions are required to establish concavity of a_{AB}. E.g., in our illustrative example, $a_{AB}(e)$ is always concave.

[39]Whether emissions in period 1 are distorted depends on the specified functions. It turns out that in our illustrative example we have $e_A^{tr} = e_A^o$.

4.2 Alternative objective function

In our model as presented so far the regulator's preference only varies in the location of the firm and not directly in the firm's productive choices. Adding a preference over the contractible productive choices of the firm[40] slightly complicates the analysis, but does not reverse the major result of the paper concerning the implementability of outcomes. In addition, we will also allow for positive benefits of averting relocation only in period 1. We will show that also this modification does not alter the main results. Unlike in the previous subsection, we again assume that a is *not* observable to the regulator.

Suppose, the regulator's payoff can be written as follows:

$$-\chi_1 \left(t_1 + D(e_1)\right) - (1 - \chi_1) L_1 - \chi_2 \delta(t_2 + D(e_2)) - (1 - \chi_2) \delta L_2, \qquad (12)$$

where $\chi_\tau = 1$ if the firm operates in country A in period τ (and accepts the contract offered in that period), and $\chi_\tau = 0$ otherwise. If the firm relocates in the second period the regulator incurs a loss of L_2 in that period, and if it relocates already in period 1 the regulator incurs an additional loss of $L_1 \geq 0$. In other words, L_1 is the regulator's *benefit* of averting relocation only in period 1. We assume $L_2 \geq L_1$, so that the same payoff structure as in (4) is obtained when $L_1 = 0$, while the regulator has an identical interest in averting relocation in each of the two periods when $L_1 = L_2$. $D(e)$ is a penalty function, capturing the domestic damages from the firm's emissions.[41] We assume that $D(e)$ is weakly increasing in e, and that $D(e) = 0$ if $e \leq 0$.

With this payoff structure it is not obvious that the regulator always prefers either immediate relocation or no relocation, because the regulator benefits also from averting relocation only in period 1. However, we argue in the following that due to the sunk costs associated with abatement capital investments, such an outcome is less preferable

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[40]We have argued in Section 2 that the regulator has no direct preferences over the firm's choice of e when a Pigouvian tax internalizes environmental externalities. Such a preference may arise if the tax on emissions falls short of the marginal external damages of emissions, or when other choices of the firm (such as output or the level of employment) are also part of the regulator's targets.

[41]When the firm relocates, it may increase its emissions abroad. If pollution is transboundary, the regulator will take these emissions into account as well. However, they effectively only raise the fixed welfare loss of relocation and, hence, can be embedded in the parameters L_1 and L_2.

to either immediate relocation or no relocation and, hence, cannot arise in equilibrium.

Lemma 4. *Under an optimal sequence of short-term contracts the firm either relocates immediately or stays for both periods.*

The intuition is straightforward. If the firm stays for one period, it has to receive a transfer that compensates it for not relocating in that period. Because investments are made in the first period, this transfer has to take the investment cost into account. Because these costs are sunk, in period 2 a lower transfer is sufficient to discourage the firm from relocating. This implies that whenever the regulator prefers to avert the firm's relocation in period 1, then he strictly prefers to avert it also in period 2.

Under limited commitment, the regulator thus seeks to find a sequence of short-term contracts that permanently averts relocation with minimal discounted transfers, taking into consideration also the damages of emissions. If this is too costly, the regulator offers no contract and implements the outcome where the firm relocates immediately.

In the following we derive necessary and sufficient conditions for the implementability of such an outcome in equilibrium, that parallel the results in Section 3. To form an equilibrium where the firm does not relocate, the quintuple (t_1, e_1, t_2, e_2, a) again has to satisfy the constraints (PC), (MH-1), and (MH-2). The constraint of sequential optimality now reads as follows

$$(t_2, e_2) \in \arg\min_{\widetilde{t}_2, \widetilde{e}_2} \widetilde{t}_2 + D(\widetilde{e}_2), \quad \text{s.t.} \quad \widetilde{t}_2 + \pi_A(\widetilde{e}_2, a) \geq \max\{\pi_B, \pi_A^*(a)\}. \qquad \text{(SO')}$$

Because the regulator may now prefer a different level of emissions than the firm also in period 2, a further constraint emerges. Namely, the firm should not choose a different investment and thereafter stay in country A also in period 2 without accepting the second-period contract. This leads us to the following additional moral hazard constraint:[42]

$$t_1 + \pi_A(e_1, a) - K(a) + \delta(t_2 + \pi_A(e_2, a)) \geq t_1 + V_A(e_1). \qquad \text{(MH-3)}$$

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[42]For the sake of brevity we did not write down this constraint under the original payoff structure (see Section 3), because there it is automatically satisfied given the constraint (SO). This is no longer true under the modified constraint (SO').

We can now extend our central result regarding the implementability of outcomes under short-term contracting (see Proposition 2) to the generalized payoff structure.

Proposition 5. *For a first-period emission level e_1, there exists a second-period contract (t_2, e_2) and an investment level a such that constraints* (MH-1), (MH-2), (SO'), *and* (MH-3) *are satisfied if and only if $V_A(e_1) \geq V_{AB}(e_1)$ and $D'(e^*(a_A(e_1))) = 0$.*

Hence, our result on implementability, which is the central result of this paper, carries over to the more general payoff function of the regulator. However, the implementation of outcomes becomes even harder. The second condition in Proposition 5 requires that given the firm's equilibrium investment a, the regulator's and the firm's interests in the second period are fully aligned. Hence, the regulator must have no incentive to distort the firm's emissions e_2 away from the level that the firm would optimally choose (given a) in the absence of regulation in that period.

The underlying reason for this result is similar as before. Namely, whenever the regulator has an incentive to distort the firm's emissions in period 2, this is anticipated by the firm, and leads to an adjustment in the firm's investment in abatement capital. The regulator, in turn, anticipates this adjustment, and is only willing to compensate the firm for the distortion in second-period emissions, taking this adjustment into account. This shifts the reference point for transfers in the second period, so that the firm is always better off when it plans to reject the second-period contract offer from the start, and invests in abatement capital accordingly (i.e., $a = a_A(e_1)$).[43]

A way to escape this dilemma is for the regulator to implement an emission level e_1 that preempts the conflict between the regulator's and the firm's interests in period 2. Given the above specification of the regulator's payoff, this holds whenever $e^*(a_A(e_1)) \leq 0$, which implies $D'(e^*(a_A(e_1))) = 0$.[44] Hence, first-period emissions must be set at a sufficiently low level in order to induce a lock in, *and* fulfill the above constraint.[45]

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[43]This reasoning also applies if the regulator has an incentive to distort the firm's emissions upwards (e.g., in order to trigger a higher choice of output). Anticipating this distortion in the second period, the firm reduces its investment, so that its optimal (un-distorted) emissions are higher in period 2. The regulator then only compensates the difference in the firm's profit when choosing its optimal emissions in period 2, given this investment, and the emission level preferred by the regulator.

[44]Depending on the value of the outside option π_B, either the constraint $V_A(e_1) \geq V_{AB}(e_1)$, or the constraint $D'(e^*(a_A(e_1))) = 0$ is binding.

[45]There are also possible modifications of the model that can alleviate the implementation problem.

5 Conclusion

This paper identifies a general implementation problem associated with persistent investments by an agent, that yield returns over more than one period. It arises when the principal cannot commit to contractual obligations for the full period of time in which the returns on the investments are incurred. The agent has an outside option, and realizes that in the future, the principal will compensate her only for forgone profits (due to not using the outside option) within a period, and not for her prior investment costs. Hence, the agent is unable to recover the full investment cost, and is better off when she plans to use the outside option in a future period from the start, which implies lower investment costs. We show that the principal is unable to implement outcomes where the agent never uses the outside option *and* requires a strictly positive transfer in a future period. To circumvent this implementation problem, the principal can distort the contract offered to the agent in the first period, where the investment takes place. In particular, by offering more high-powered incentives, the agent is induced to invest more. The outside option, then, becomes less attractive, so that the agent no longer requires a positive transfer in the future and yet refrains from using the outside option.

We frame this general idea in a more specific context. Namely, we analyze the problem of designing optimal incentive contracts that avert firm relocation. A local regulator aims to avert a firm's relocation in each of two periods. The firm, if staying for at least one period, undertakes some location-specific investment, which is not observable to the regulator. Contracts consist of transfers and targets for an observable productive activity, such as the firm's emissions, output, or employment.

If contracts are long-term, they specify simple subsidy payments, conditional on the firm's location. Optimal long-term contracts do not interfere directly with the firm's

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E.g., suppose that in addition to the variable cost of installing an abatement capital stock of a, there is a fixed cost that arises only if a is strictly larger than zero. In that case, the regulator can always induce an investment of zero by setting a sufficiently high emission target for the first period, because this reduces the firm's benefit from investing in abatement capital. But as long as $a = 0$ holds, the local effects from a distortion in the second-period emission target upon the firm's investment vanish. This suggests that – similarly as in the case with an observable investment (see Section 4.1) – the regulator has an alternative way to circumvent the implementation problem, by setting a sufficiently loose emission target in the first period.

operative decisions. This simple structure results because the interests of the regulator and the firm are to some extent aligned. Averting relocation with minimal transfers requires maximal profits of the firm. Therefore, the regulator has no incentive to distort the firm's operative decisions.

With limited commitment an implementation problem arises whenever relocation is sufficiently attractive. To avert relocation of the firm in equilibrium with minimal transfers, first-period contracts are more stringent than under optimal long-term contracts, and implement an inefficiently high investment. This creates a 'lock-in' situation where the firm no longer finds it optimal to relocate in period 2, despite the absence of transfers in that period. The more attractive the relocation option is, the tougher the first-period contract needs to be to achieve this. This leads to greater distortions and larger transfers.

Our model has an important application in the area of climate policy. When some countries unilaterally introduce prices for greenhouse gas emissions, the international competitiveness of their emission-intensive industries is harmed. In response, firms may be tempted to relocate to other countries with less stringent environmental regulation. This may be one of the reasons why the EU initially decided to allocate allowances for free in the EU ETS. Our results indicate that such simple subsidies may not prevent relocation on a *permanent* basis. In order to be effective in this respect, subsidies should be conditioned upon the fulfillment of binding criteria such as firm-specific emission levels, output or employment targets. Such policies can help to resolve the relocation problem on a permanent basis when regulators or policy makers cannot make binding commitments that last for a sufficiently long period of time.

A   Proofs

A.1   Proofs of Section 2

We first establish the following properties of the functions defined in Section 2.3 and their respective maximizers.

Lemma A1. *(1)* $e^*(a)$ *is strictly decreasing,*

(2) $\pi_A^*(a)$ *is strictly increasing, concave, and satisfies* $\lim_{a \to \infty} \pi_A^*(a) = +\infty$,

(3) $a_A(e_1)$ *and* $a_{AB}(e_1)$ *are unique and strictly decreasing,*

(4) $V_A(e_1)$ *and* $V_{AB}(e_1)$ *are strictly concave and have unique maximizers,*

(5) $a_A(e_1) > a_{AB}(e_1)$ *for all* $e_1 \in \mathbb{R}$.

Proof of Lemma A1. Claim (1): $e^*(a)$ exists by assumption and is unique since $\partial^2 \pi_A / \partial e^2 < 0$. Differentiating $\partial \pi_A / \partial e = 0$ w.r.t. a and rearranging yields

$$\frac{\partial e^*}{\partial a} = -\frac{\frac{\partial^2 \pi_A}{\partial e \partial a}}{\frac{\partial^2 \pi_A}{\partial e^2}} < 0. \tag{13}$$

Claim (2): By the envelope-theorem we have

$$\frac{\partial \pi_A^*}{\partial a} = \frac{\partial \pi_A}{\partial a}\bigg|_{(e^*(a),a)} > m > 0.$$

Consequently π_A^* is strictly increasing and $\lim_{a \to \infty} \pi_A^*(a) = +\infty$. To prove concavity of π_A^* differentiate twice, using the envelope-theorem, to get

$$\frac{\partial^2 \pi_A^*}{\partial a^2} = \frac{\partial^2 \pi_A}{\partial a \partial e} \cdot \frac{\partial e^*}{\partial a} + \frac{\partial^2 \pi_A}{\partial a^2} \stackrel{(13)}{=} -\frac{\left(\frac{\partial^2 \pi_A}{\partial e \partial a}\right)^2}{\frac{\partial^2 \pi_A}{\partial e^2}} + \frac{\partial^2 \pi_A}{\partial a^2} = \frac{\frac{\partial^2 \pi_A}{\partial a^2} \cdot \frac{\partial^2 \pi_A}{\partial e^2} - \left(\frac{\partial^2 \pi_A}{\partial e \partial a}\right)^2}{\frac{\partial^2 \pi_A}{\partial e^2}}$$

Finally, the last expression's denominator is strictly negative because π_A is strictly concave in e. Its numerator is the Hessian of π_A, which we assumed non-negative. We

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conclude that π_A^* is concave.

Claim (3): $a_A(e)$ is implicitly defined by the first-order condition

$$\frac{\partial \pi_A}{\partial a} - K'(a) + \delta \frac{\partial \pi_A^*}{\partial a} = 0. \tag{14}$$

At $a = 0$ the expression one the left-hand side is strictly positive, because $K'(0) = 0$ and $\partial \pi_A/\partial a \mid_{a=0} > 0$ as well as π_A^* strictly increases with a. Furthermore, as $a \to \infty$ we have $\partial \pi_A/\partial a - K'(a) < -\delta M < -\delta \, \partial \pi_A^*/\partial a$. This yields existence of $a_A(e)$. Uniqueness follows from strict concavity of $\pi_A(e, a) - K(a) + \delta \pi_A^*(a)$, which we conclude from strict concavity of its components. Differentiating (14) w.r.t. e and rearranging yields

$$\frac{\partial a_A}{\partial e} = \frac{\frac{\partial^2 \pi_A}{\partial e \partial a}}{\frac{\partial^2 K}{\partial a^2} - \frac{\partial^2 \pi_A}{\partial a^2} - \delta \frac{\partial^2 \pi_A^*}{\partial a^2}} < 0. \tag{15}$$

For $a_{AB}(e)$ just repeat the above steps.

Claim (4): Following claim (3) both $V_A(e)$ and $V_{AB}(e)$ are well defined. Differentiating $V_A(e)$ twice, using the envelope-theorem, yields

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

To show existence of a maximizer of $V_A(e)$ define the function $\mathcal{F}(e, a) := (e^*(a), a_A(e))$. Suppose $(\bar{e}, \bar{a})$ is a fixed-point of $\mathcal{F}$, then

$$\frac{\partial V_A}{\partial e}\bigg|_{\bar{e}} = \frac{\partial \pi_A}{\partial e}\bigg|_{(\bar{e}, a_A(\bar{e}))} = \frac{\partial \pi_A}{\partial e}\bigg|_{(e^*(\bar{a}), \bar{a})} = 0.$$

Hence a fixed-point of $\mathcal{F}$ is a maximizer of the function $V_A(e)$. To prove existence of the fixed-point, note that the Jacobian of $\mathcal{F}$ satisfies

$$|\mathcal{J}_\mathcal{F}| = \begin{vmatrix} 0 & \frac{\partial e^*}{\partial a} \\ \frac{\partial a_A}{\partial e} & 0 \end{vmatrix} = \frac{\frac{\partial^2 \pi_A}{\partial e \partial a}}{\frac{\partial^2 \pi_A}{\partial e^2}\left(\frac{\partial^2 \pi_A}{\partial a^2} - K''(a)\right)}$$

Because $K''(a) \geq \varepsilon > 0$ we conclude that there exists $\kappa < 1$ such that $|\mathcal{J}_{\mathcal{F}}| \leq \kappa$. Hence, $\mathcal{F}$ is a contraction and existence of the fixed-point follows from Banach's fixed-point theorem. Finally, uniqueness is implied by strict concavity of $V_A(e)$.

Repeating the above steps proves the claimed also for the function $V_{AB}(e)$ (not shown).

Claim (5): $a_{AB}(e)$ is defined by the first-order condition

$$\frac{\partial \pi_A}{\partial a} - \frac{\partial K}{\partial a} = 0. \tag{16}$$

Comparing this to (14), 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. $\qquad \square$

Proof of Lemma 1. 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. $\qquad \square$

Proof of Lemma 2. As is discussed in the main text, the optimal profit from not relocating is V_A°. The profit from immediate relocation is V_B. As a consequence of Lemma 1 we have $V_{AB}(e_1) < \max\{V_A^\circ, V_B\}$ for all e_1. Therefore, the firm prefers immediate relocation whenever $V_B > V_A^\circ$ and no relocation otherwise. Solving $V_A^\circ = V_B$ for π_B leads to the definition of π_B°. $\qquad \square$

Proof of Proposition 1. As is argued in the main text, the regulator's problem is to minimize (10) over e_1 and e_2. This is equivalent to maximizing $\pi_A(e_1, a) - K(a) + \delta \pi_A(e_2, a)$ over a, e_1, and e_2. Maximizing first over e_2 and a yields $V_A(e_1)$. Maximizing this over e_1 yields $e_1 = e_A^\circ$. By comparing the respective first-order conditions we get $e_2 = e_1$. The total transfer required is $t^\circ = V_B - V_A^\circ$. The regulator offers this contract whenever $t^\circ \leq L$. $\qquad\square$

A.2 Proofs of Section 3

Proof of Proposition 2. When (SO) is satisfied, the firm's second-period profit is $t_2 + \pi_A^*(a)$. By the envelope-theorem, (MH-1) then implies that the firm's total profit is $t_1 + \delta t_2 + V_A(e_1)$. This justifies constraint (MH-2′), as a replacement for (MH-2).

Now first assume $V_A(e_1) \geq V_{AB}(e_1)$, which can be stated as

$$\max_a \ \pi_A(e_1, a) - K(a) + \delta \pi_A^*(a) \geq \max_a \ \pi_A(e_1, a) - K(a) + \delta \pi_B. \qquad (17)$$

This implies $\pi_A^*(a_A(e_1)) > \pi_B$, where $a_A(e_1)$ denotes the maximizer of the left-hand side. Hence, the second-period contract $(t_2, e_2) = (0, e^*(a_A(e_1)))$ satisfies (SO), given $a = a_A(e_1)$. By construction, (MH-1) and (MH-2) are satisfied, given (t_2, e_2).

Next assume $V_A(e_1) < V_{AB}(e_1)$. Constraints (MH-1) and (SO) imply $a = a_A(e_1)$ and the second-period contract offer entails $t_2 = \max\{0, \pi_B - \pi_A^*(a_A(e_1))\}$ and $e_2 = e^*(a_A(e_1))$. As indicated above, (MH-2) can be replaced by (MH-2′). Therefore, necessary for all three constraints to hold is $\delta t_2 \geq V_{AB}(e_1) - V_A(e_1) > 0$. Further, note that

$$
\begin{aligned}
\delta t_2 \ &\geq \ V_{AB}(e_1) - V_A(e_1) \\
&= \ \max_a \left\{ \pi_A(e_1, a) - K(a) + \delta \pi_B \right\} - \max_a \left\{ \pi_A(e_1, a) - K(a) + \delta \pi_A^*(a) \right\} \\
&> \ \delta \left(\pi_B - \pi_A^*(a_A(e_1)) \right).
\end{aligned}
$$

Therefore $t_2 > \pi_B - \pi_A^*(a_A)$ and together with $t_2 > 0$, as shown above, we get $t_2 > \max\{0, \pi_B - \pi_A^*(a_A)\}$ – this contradicts (SO). $\qquad\square$

Proof of Corollary 1. The result on implementability follows from Proposition 2. Regarding $\pi_B^\sharp$ notice that $V_A^\circ > V_{AB}(e_A^\circ)$ for $\pi_B = \pi_B^\circ$ by Lemma 1. Because $V_{AB}(e_A^\circ)$ strictly increases with π_B, while V_A° is independent of π_B, we get $\pi_B^\sharp > \pi_B^\circ$. $\qquad\square$

Proof of Lemma 3. By the envelope-theorem $\partial V_A/\partial \pi_B = 0 < \delta = \partial V_{AB}/\partial \pi_B$. Furthermore, using $a_A(e) > a_{AB}(e)$, it holds that

$$\frac{\partial V_A}{\partial e} = \frac{\partial \pi_A}{\partial e}(e, a_A(e)) < \frac{\partial \pi_A}{\partial e}(e, a_{AB}(e)) = \frac{\partial V_{AB}}{\partial e}. \tag{18}$$

Together with $V_A(e_A^\circ) = V_{AB}(e_A^\circ)$ for $\pi_B = \pi_B^\sharp$ (from Corollary 1) this yields $e^\sharp < e_A^\circ$ and $e^\sharp$ strictly decreases with π_B. Finally, because V_{AB} is linear in π_B, the implicit function theorem guarantees existence of $e^\sharp$, implicitly defined by $V_A(e^\sharp) = V_{AB}(e^\sharp)$, for all π_B. $\qquad\square$

Proof of Proposition 3. We determine the cost of implementing an equilibrium with no relocation. Recall from the proof of Proposition 2 that there is no second-period transfer. As long as $\pi_B \leq \pi_B^\sharp$, by Corollary 1, e_A° is implementable and minimizes the cost over the set of implementable first-period emission levels; the required (total) transfer is $t^\circ = V_B - V_A^\circ$. If $\pi_B > \pi_B^\sharp$, we have $e_A^\circ > e^\sharp$. Therefore, the regulator cannot use e_A° to implement an outcome with no relocation. By the concavity of V_A, implementing $e^\sharp$ requires the smallest transfer, which is equal to $t^\sharp = V_B - V_A(e^\sharp)$. $\qquad\square$

Proof of Corollary 2. Trivial for $\pi_B \leq \pi_B^\sharp$. For $\pi_B > \pi_B^\sharp$ recall that $a_A(e)$ decreases in e (Lemma A1), and $e^\sharp < e_A^\circ$. The result follows. $\qquad\square$

A.3 Proofs of Section 4

Proof of Proposition 4. We first characterize the firm's optimal investment decision, i.e. the maximizer of (11). We distinguish three cases:

i) $\overline{a} \leq a_{AB}(e_1)$. By concavity of $\pi_A(e, a) - K(a) + \delta\pi_B$ (see the proof of Lemma A1), we have for all $a \leq \overline{a}$:

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

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

ii) $a_A(e_1) \leq \overline{a}$. Similar to the previous case we have for all $a \geq \overline{a}$:

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

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

iii) $a_{AB}(e_1) < \overline{a} < a_A(e_1)$. By the above arguments the firm's profit has two local maxima: at $a = a_A(e_1)$ and at $a = a_{AB}(e_1)$, such that the maximal profit is either $V_A(e_1)$ or $V_{AB}(e_1)$. Because $V_A(e) > V_{AB}(e)$ holds if and only if $e < e^\sharp$, we find that the firm's maximal profit, given $a_{AB}(e_1) < \overline{a} < a_A(e_1)$, is thus $V_A(e_1)$ if $e_1 \leq e^\sharp$, and $V_{AB}(e_1)$ if $e_1 > e^\sharp$.

Therefore, the firm's profit after having accepted a first-period contract offer (t_1, e_1) is

$$t_1 + \begin{cases} V_A(e_1), & e_1 \leq e^\sharp, \\ V_{AB}(e_1), & e_1 > e^\sharp. \end{cases} \tag{19}$$

We here implicitly assume that the firm always chooses $a_A(e_1)$ when $e_1 = e^\sharp$, although it is indifferent. This is without loss of generality, because the regulator chooses the equilibrium, in case there are multiple, and it is obvious that the first-period transfer to implement $e_1 = e^\sharp$ is unaffected by the continuation, but in case the firm chooses $a_{AB}(e^\sharp)$

the regulator has to pay a strictly positive second-period transfer to avert relocation in period 2.

The total transfer to avert relocation is given by

$$t(e_1) = \begin{cases} V_B - V_A(e_1), & e_1 \leq e^\sharp, \\ V_B - V_{AB}(e_1) + \delta\big(\pi_B - \pi_A^*(a_{AB}(e_1))\big), & e_1 > e^\sharp. \end{cases} \tag{20}$$

In case $e_1 \leq e^\sharp$ this is trivial, because it implies $a = a_A(e_1) > \overline{a}$ and therefore a first-period transfer is sufficient (this already follows from Lemma 3). Now consider $e_1 > e^\sharp$, and suppose $\pi_A^*(a_{AB}(e_1)) \geq \pi_B$. This would imply

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

which yields $e_1 < e^\sharp$ – a contradiction. Thus, $\pi_A^*(a_{AB}(e_1)) < \pi_B$, so that the minimal second-period transfer required to implement an outcome with no relocation is $t_2 = \pi_B - \pi_A^*(a_{AB}(e_1))$.

The regulator now chooses e_1 in order to minimize (20). The first case ($\pi_B \leq \pi_B^\sharp \Leftrightarrow e_A^\circ \leq e^\sharp$) follows readily from Corollary 1. For the remainder, assume $e_A^\circ > e^\sharp$, i.e. $\pi_B > \pi_B^\sharp$. By strict concavity of $V_A(e)$ we have

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

So it cannot be optimal to implement some $e_1 < e^\sharp$. For $e_1 > e^\sharp$, the required transfer is $\widetilde{t}(e_1) = V_B - V_{AB}(e_1) + \delta\big(\pi_B - \pi_A^*(a_{AB}(e_1))\big)$. Denote e_A^{tr} the minimizer of $\widetilde{t}(e_1)$. By Lemma A1, the function $V_{AB}(e_1)$ is strictly concave. Furthermore, because π_A^* is concave and strictly increasing by Lemma A1, the composition with the concave function $a_{AB}(e_1)$ is also concave. Therefore, $\widetilde{t}(e_1)$ is strictly convex for *all* $e_1 \in \mathbb{R}$, and existence of a minimizers follows from our assumptions on π_A. Now suppose $e_A^{tr} \leq e^\sharp$. Then $t(e^\sharp) \geq \widetilde{t}(e^\sharp) > \widetilde{t}(e_1)$ for all $e_1 > e^\sharp$ so that $e_1 = e^\sharp$ leads to minimal (total) transfers.

Hence the relevant cases are where $e_A^{tr} > e^\sharp$. Notice, that $\widetilde{t}(e_A^{tr})$ does not depend on π_B, and that for $\pi_B = \pi_B^\sharp$ we have $V_A^{tr}(e_A^{tr}) < V_A(e^\sharp)$. Because $t(e^\sharp)$ strictly increases with π_B and converges to $+\infty$, there exists a level π_B^{tr} such that $t(e_A^{tr}) < t(e^\sharp)$ if and only if $\pi_B > \pi_B^{tr}$. This completes the proof. $\qquad\square$

Proof of Lemma 4. Suppose the regulator offers (t_1, e_1) in the first period, which is accepted by the firm and relocation in period 2 occurs. Denote $\hat{a}$ the equilibrium value of the firm's investment. Because the firm relocates in period 2, we must have $\pi_A^*(\hat{a}) \leq \pi_B$. Regarding the first-period transfer, it has to hold that $t_1 \geq V_B - V_{AB}(e_1)$, in order to be accepted by the firm. Furthermore, we must have $L_1 \geq t_1 + D(e_1)$, otherwise the regulator prefers not to offer the contract at all. But then we have

$$
\begin{aligned}
0 \leq\ & L_1 - t_1 - D(e_1) \ \leq\ L_1 - V_B + V_{AB}(e_1) - D(e_1) \\
=\ & L_1 - \pi_B + \pi_A(e_1, \hat{a}) - K(\hat{a}) - D(e_1) \ <\ L_2 - \pi_B + \pi_A(e_1, \hat{a}) - D(e_1).
\end{aligned}
$$

Now, because $\pi_A^*(\hat{a}) \leq \pi_B$, the optimal contract to keep the firm in country A in period 2 is the solution to

$$
\min_{t_2, e_2} t_2 + D(e_2) \quad \text{s.t.} \quad t_2 + \pi_A(e_2, \hat{a}) \geq \pi_B. \tag{21}
$$

Clearly, the solution to this is $e_2 = \arg\max_e \pi_A(e, \hat{a}) - D(e)$ and $t_2 = \pi_B - \pi_A(e_2, \hat{a})$. Together with the above, the regulator's benefit from offering this contract is

$$
L_2 - t_2 - D(e_2) = L_2 - \pi_B + \pi_A(e_2, \hat{a}) - D(e_2) > L_2 - \pi_B + \pi_A(e_1, \hat{a}) - D(e_1) > 0,
$$

where the first inequality holds because e_2 maximizes $\pi_A(e, \hat{a}) - D(e)$, and the second inequality was shown above to hold. Hence, the regulator strictly prefers offering a contract in period 2 that averts relocation.

Notice that the method of proof also rules out random relocation in period 2. Hence, either immediate relocation or no relocation can be optimal. $\qquad\square$

Proof of Proposition 5. Let (t_1, e_1, t_2, e_2, a) be the outcome to be implemented.

Assume first that $V_A(e_1) \geq V_{AB}(e_1)$ and the second-period contract entails $e_2 \neq e^*(a)$. Because $D' \geq 0$ this implies $e_2 < e^*(a)$ and thus (MH-1) implies $a > a_A(e_1)$. But then $\pi_A^*(a) > \pi_A^*(a_A(e_1)) > \pi_B$. The firm's second-period profit, including the transfer $t_2 = \pi_A^*(a) - \pi_A(e_2, a)$, is therefore $\pi_A^*(a)$, but then (MH-3) is clearly violated because $a \neq a_A(e_1)$ is not the maximizer of $\pi_A(e_1, \tilde{a}) - K(\tilde{a}) + \delta\pi_A^*(\tilde{a})$.

Next assume $V_A(e_1) \geq V_{AB}(e_1)$ and the second-period contract entails $e_2 = e^*(a)$. Then (MH-3) is trivially satisfied. Also (MH-2) holds, by the arguments used in proving Lemma 2. Constraint (SO') is only satisfied when the regulator indeed prefers to keep the firm without distorting its second-period emissions, for which the second condition from the Proposition is both necessary and sufficient.

Lastly, assume $V_A(e_1) < V_{AB}(e_1)$. If $\pi_A^*(a) \geq \pi_B$ the firm's equilibrium payoff is $t_1 + \pi_A(e_1, a) - K(a) + \delta\pi_A^*(a) \leq t_1 + V_A(e_1) < t_1 + V_{AB}(e_1)$, hence (MH-2) is violated. If on the other hand $\pi_A^*(a) < \pi_B$ the firm's equilibrium payoff is $t_1 + \pi_A(e_1, a) - K(a) + \delta\pi_B$. Because $D' \geq 0$ we must have $e_2 \leq e^*(a)$ and, therefore, $\partial\pi_A/\partial a \mid_{e_2, a} > 0$, because $\partial\pi_A/\partial a \geq m > 0$ at $e_2 = e^*(a)$ and $\partial^2\pi_A/\partial e\partial a < 0$. This implies $a \neq a_{AB}(e_1)$, and consequently (MH-2) is violated because a is not the maximizer of $\pi_A(e_1, \tilde{a}) - K(\tilde{a}) + \delta\pi_B$. $\quad\square$

B Restriction to pure strategies

Here we argue that allowing for mixed strategies does not soften the regulator's implementation problem identified in Proposition 2.

We her take the sequential structure into consideration and apply the concept of Perfect Bayesian Equilibrium. In the second-period, the regulator holds a belief about the firm's type, which is just the level of investment the firm took in period one. For simplicity let us focus on the case where the firm randomizes over at most finitely many actions, i.e., investments are taken from the finite set $\mathcal{A} = \{a^1, \ldots, a^n\}$. Denote $\alpha = (\alpha^1, \ldots, \alpha^n)$ the regulator's belief, that is α^i is the probability the firm did choose investment a^i.

The second-period is then equivalent to a static contracting problem where the prin-

cipal's prior is α and the agent has finitely many types from the set $\mathcal{A}$. Invoking the revelation principle, the principal offers a menu of contracts $((t_2^1, e_2^1), \dots, (t_2^n, e_2^n))$ and type a^i picks contract (t_2^i, e_2^i) with certainty.

Without loss we can focus on equilibria where the firm never relocates, i.e., each type a^i accepts some contract and stays in country A also for period two.[46]

The equivalent of condition (MH-2) requires

$$t_1 + \pi_A(e_1, a^i) - K(a^i) + \delta(t_2^i + \pi_A(e_2^i, a^i)) \geq t_1 + \max_a \pi_A(e_1, a) - K(a) + \delta\pi_B \quad \forall i$$

Because the right-hand side has a unique maximizer, there can be at most one $a^k \in \mathcal{A}$ such that $t_2^k + \pi_A(e_2^k, a^k) = \pi_B$, for all other that must be a strict inequality. Consider two cases:

Case I: $t_2^i + \pi_A(e_2^i, a^i) > \pi_B$ for all $i = 1, \dots, n$. By sequential optimality $t_2^i \equiv 0$, and $e_2^i = e^*(a^i)$ for all i. Because $t_1 + \pi_A(e_1, a) - K(a) + \delta\pi_A^*(a)$ has a unique maximizer, only one of the values a^i can be an optimal choice of the firm in period one, which brings us back to pure strategy case discussed in the paper.

Case II: There is a^k such that $t_2^k + \pi_A(e_2^k, a^k) = \pi_B$. Then, obviously, $a^k = a_{AB}(e_1)$, otherwise the firm would strictly increase its (expected) profit by choosing that $a_{AB}(e_1)$ and refusing any contract offered in period two. $a^k = a_{AB}(e_1)$ implies

$$\left.\frac{\partial \pi_A}{\partial a}\right|_{e_1, a^k} - K'(a^k) = 0. \tag{22}$$

Furthermore it has to hold that the (equilibrium-) profit of type a^k cannot be increases by the firm choosing *any* other level of investment but still accepting the contract (t_2^k, e_2^k) in period two. This requires

$$t_1 + \pi_A(e_1, a^k) - K(a^k) + \delta(t_2^k + \pi_A(e_2^k, a^k)) \geq t_1 + \pi_A(e_1, a) - K(a) + \delta(t_2^k + \pi_A(e_2^k, a)) \tag{23}$$

---

[46]Because every type stayed for period one, we have $t_1 + \pi_A(e_1, a^i) - K(a^i) \geq \pi_B$ for all i and $t_1 \leq L$, since otherwise the regulator preferred immediate relocation. Therefore $L \geq t_1 > \pi_B - \pi_A(e_1, a^i)$ for all i, which implies $L > \pi_B - \pi_A^*(a^i)$ and the regulator strictly prefers to avert any types' relocation also in period two.

for all $a \geq 0$. Together with (22) this yields $\partial \pi_A / \partial a = 0$ at $(e, a) = (e_2^k, a^k)$, and strict concavity of π_A further yields $t_2^k + \pi_A(e_2^k, a^i) < \pi_B$ for all $i \neq k$. Hence no other $a^i \neq a^k$ has an incentive to pick the contract (t_2^k, e_2^k). But then, the regulator can save transfers in period two by moving e_2^k towards $e^*(a^k)$, which increases $\pi_A(e_2^k, a^k)$, without violating any of the other types' incentive constraints. This contradicts optimality of the regulator's second-period contract offer.

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Figures:
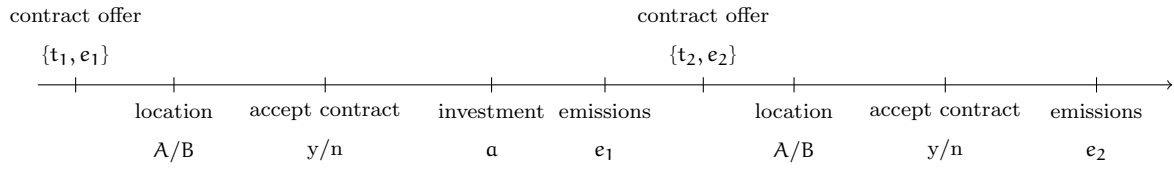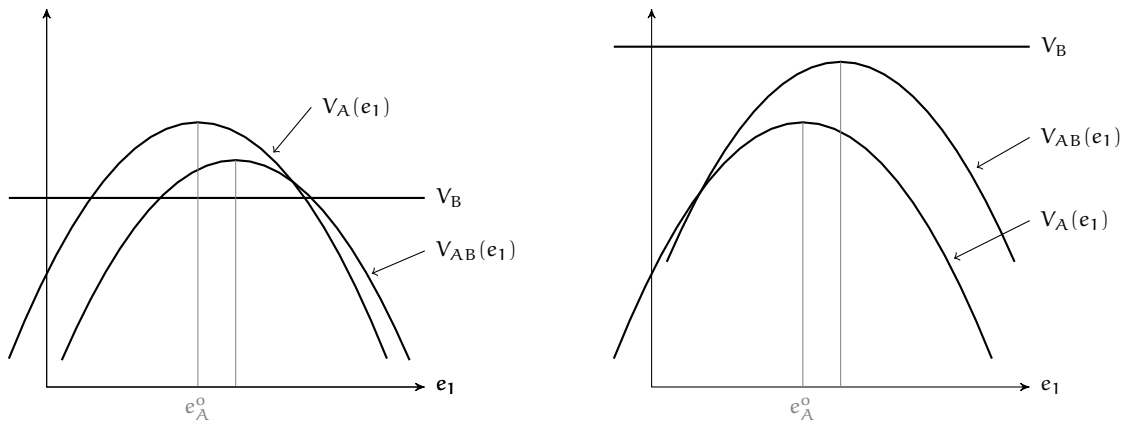

Figure 1: Timing with short-term contracting.

Figure 2: Payoff functions $V_A(e_1)$, $V_{AB}(e_1)$, and V_B for low π_B (left) and high π_B (right).
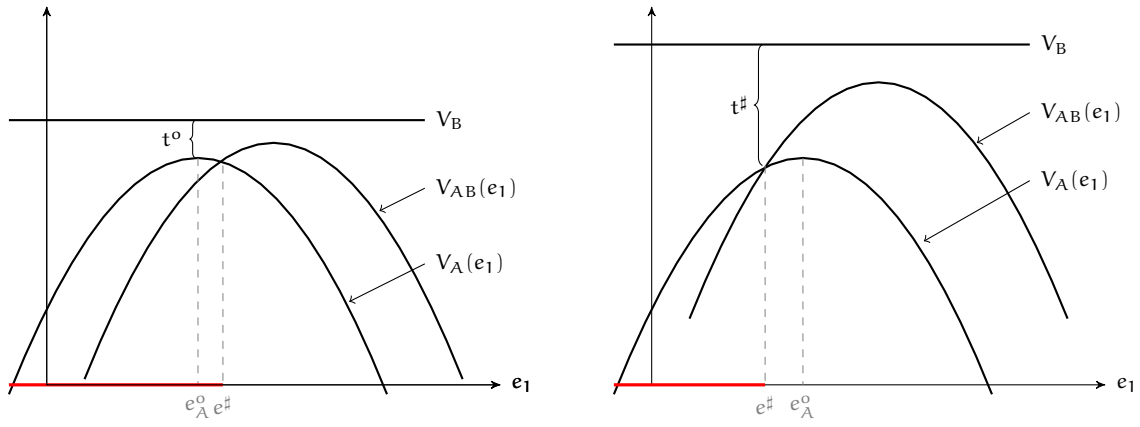
Figure 3: Optimal first-period contracts with short-term contracting; left: $e_A^o < e^\sharp$, right: $e_A^o > e^\sharp$. Implementable levels of e_1 are shown in red.
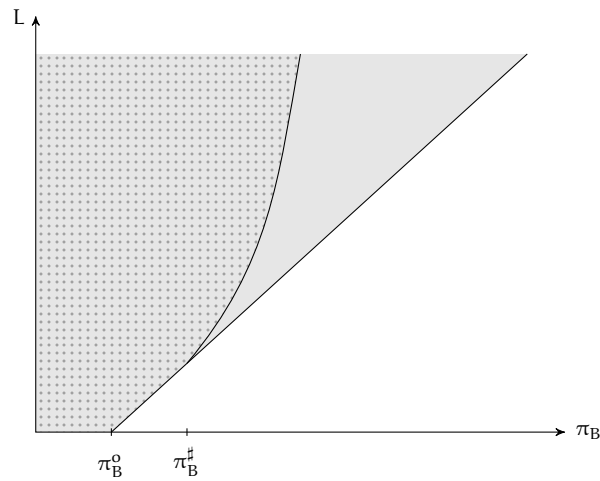

Figure 4: (π_B, L) - combinations for which relocation is averted; grey-shaded area: long-term contracting, dotted area: short term.