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Wolfgang Habla and Ralph Winkler

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Department of Economics
School of Business, Economics and Law at University of Gothenburg
Vasagatan 1, PO Box 640, SE 405 30 Göteborg, Sweden
+46 31 786 0000, +46 31 786 1326 (fax)
www.handels.gu.se   info@handels.gu.se

Strategic Delegation and Non-cooperative International Permit Markets*

Wolfgang Habla† and Ralph Winkler‡

† Department of Economics, University of Gothenburg and
Oeschger Centre for Climate Change Research, University of Bern
Vasagatan 1, SE-405 30 Gothenburg, Sweden; wolfgang.habla@gu.se
‡ Department of Economics and
Oeschger Centre for Climate Change Research, University of Bern
Schanzeneckstrasse 1, CH-3012 Bern, Switzerland; mail@ralph-winkler.de

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Abstract: We analyze a principal-agent relationship in the context of international climate policy in a two-country framework. First, the principals of both countries decide whether to link their domestic emission permit markets to an international market. Second, the principals select agents who then non-cooperatively determine the levels of emission permits. Finally, these permits are traded on domestic or international permit markets. We find that the principals in both countries have an incentive to select agents that care (weakly) less for environmental damages than the principals do themselves. This incentive is more pronounced under international permit markets, particularly for permit sellers, rendering an international market less beneficial to at least one country. Our results may explain why we do not observe international permit markets despite their seemingly favorable characteristics and, more generally, suggest that treating countries as atomistic players may be an over-simplifying assumption when analyzing strategic behavior in international policy making.

Keywords: non-cooperative climate policy, political economy, emissions trading, linking of permit markets, strategic delegation, strategic voting

JEL-Classification: D72, H23, H41, Q54, Q58

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1 Introduction

When analyzing international (environmental) policy, individual countries are usually represented by single benevolent decision makers, for example governments, that act in the best interest of the country as a whole. In this paper, we depart from this idealized abstraction by acknowledging that policies in modern democracies are typically shaped by hierarchical processes. All these decision-making procedures have in common that a principal first decides upon the rough orientation of the policy and then appoints an agent who elaborates on the details of this policy (and possibly implements it).

The particular environmental policy we investigate is the formation of an international emission permit market – which we will refer to as a "non-cooperative" international permit market – in which countries non-cooperatively choose emission permit levels (Helm 2003). Such a market may be preferable to purely domestic environmental policies (for example, domestic emission taxes) because it equalizes – by design – the marginal benefits of emissions across countries. This condition, while necessary for globally efficient emission reduction, is only accidentally satisfied in case of purely domestic policies. The reason that we focus on non-cooperative (in the game-theoretic sense) climate policies is twofold. On the one hand, the recent UNFCCC negotiations for a successor to the Kyoto Protocol have proven the difficulties of achieving international cooperation. As a consequence, the linking of existing national or regional permit markets has been discussed as a complementary building block for international climate policy (Flachsland et al. 2009; Jaffe et al. 2009; Green et al. 2014). On the other hand, Carbone et al. (2009) demonstrate that even non-cooperative permit markets exhibit substantial potential for greenhouse gas reductions. Despite their favorable characteristics, however, we have yet to observe the formation of many such markets. Only Liechtenstein, Iceland and Norway joined the European Union's Emissions Trading Scheme (EU-ETS), and California and Québec linked their cap-and-trade systems in 2014.[1]

We shed light on this puzzle by analyzing the typical principal-agent relationship outlined above in the context of international climate policy in a two-country framework. In a first step, the principals of both countries determine whether to link their domestic emission permit markets to an international market that is formed if and only if both principals agree to do so. Second, each principal selects one agent who is responsible for issuing emission permits. Then, the selected agents in both countries non-cooperatively determine the number of emission permits issued to domestic firms. Trading of permits – within or between countries – takes place in the final stage.

[1] While the EU-ETS is clearly an international permit market, we do not consider it "non-cooperative" because of the supranational authority that the European Union exerts on the national governments with respect to domestic emission permit levels.

We find that the hierarchical structure of the political process gives rise to strategic delegation. The principals of both countries appoint agents that care (weakly) less for environmental damages than do the principals. The reason is that emission permit levels are strategic substitutes: By delegating the emission permit choice to a less green agent who – ceteris paribus – issues more permits than the principal would do himself, the principal can – again, ceteris paribus – induce the other country's agent to reduce her emission permit issuance. However, as the principals in both countries face similar incentives, they end arrive at a prisoners' dilemma: Both would be better off if they selected agents who share their own preferences; yet, such self-representation is not an equilibrium of the game.

Moreover, the strategic delegation incentives are – for relevant parameter constellations – stronger under an international permit market than under domestic permit markets. The reason is that on an international market, there is an additional incentive to issue permits that is driven by the permit market's terms of trade. The principals of both the permit-buying and the permit-selling country may gain from the issuance of more permits, which can be achieved by delegating to a less green agent: Although total emissions and thus damages in both countries will rise, the permit-selling country may be able to sell more permits and realize the resulting revenues, whereas the permit-buying country benefits from a lower permit price. However, the resulting increase in total emissions and associated damages from delegating to less green agents renders linking less beneficial in many cases. Overall, we find that the conditions for the formation of an international non-cooperative permit market are less favorable than suggested by the standard permit market literature, which neglects the hierarchical structure of international environmental policy.

Our paper contributes to several strands of literature. It builds on the literature on non-cooperative international permit markets, developed by Helm (2003), Carbone et al. (2009) and Helm and Pichler (2015). While these papers assume that countries are represented by one welfare-maximizing decision maker, we explicitly account for the principal-agent relationship between different bodies involved in international policy making within a single country, for example, an incumbent government or president and a selected executive or authority such as a ministry. In this regard, we draw on the strategic delegation literature (Jones 1989; Burtraw 1992; Segendorff 1998) and the strategic voting literature (Persson and Tabellini 1992), the two of which exhibit strong similarities when we interpret the electorate or, to be more precise, the median voter as the principal and the elected government as the agent. In this context "strategic" means that a principal is able to raise her payoff by misrepresenting her own preferences, i.e., delegating to an agent who does not share the same preferences. This result may occur either if the selected agents cooperatively (or via a bargaining procedure) determine the division or provision of a good or if they non-cooperatively decide on an issue with inter-agent spillovers such as environmental externalities.

In the context of environmental policy, Siqueira (2003), Buchholz et al. (2005), Roelfsema (2007) and Hattori (2010) analyze strategic voting. While the first three contributions focus on environmental taxation only, Hattori (2010) also examines the outcome of strategic voting under emissions caps. Siqueira (2003) and Buchholz et al. (2005) both find that voters' decisions are biased toward politicians who are less green than the median voter. By electing a more conservative politician, the home country commits itself to a lower tax on pollution, shifting the burden of a cleaner environment to the foreign country. By contrast, Roelfsema (2007) accounts for emissions leakage through shifts in production and finds that median voters may delegate to politicians who place greater weight on environmental damage than they do themselves, whenever their preferences for the environment relative to their valuation of firms' profits are sufficiently strong. This result, however, breaks down in the case of perfect pollution spillovers, such as the emission and diffusion of greenhouse gases. Hattori (2010) allows for different degrees of product differentiation and alternative modes of competition, i.e., competition on quantities but also on prices. His general finding is that when the policy choices are strategic substitutes (complements), a less (more) green policy maker is elected in the non-cooperative equilibrium. Using a very general principal-agent framework, Helm and Wirl (2014) find that an industrial country, as the principal, can ensure the participation of a developing country (the agent) in an international climate agreement by implementing a competitive permit market. As in Siqueira (2003) and Roelfsema (2007), the agents selected by the principals in our model do not engage in bargaining but rather set environmental policies according to their own preferences. In contrast to the aforementioned papers, however, we examine delegation not only under caps but also under international permit markets.[2]

The literature on linking offers several explanations for why "bottom-up" (or non-cooperative in our terminology) approaches to permit trading have not been successful. Among the obstacles identified by Green et al. (2014), for example, are different levels of ambition, competing domestic policy objectives, objections to financial transfers and the difficulty of regulatory coordination. We contribute to this literature by suggesting that the hierarchical structures underlying environmental policy may be a reason for the rejection of otherwise beneficial policies.

[2] Strategic delegation in the provision of public goods is examined by Harstad (2010), Christiansen (2013) and Kempf and Rossignol (2013). Harstad (2010) analyzes the incentives to delegate to more conservative or more progressive politicians. While delegation to the former increases their bargaining position, the latter are more likely to be included in majority coalitions and hence increase the political power of their jurisdiction. The direction of delegation in this model is found to depend on the design of the political system. Using a model of legislative bargaining, Christiansen (2013) shows that voters strategically delegate to public good lovers. In Kempf and Rossignol (2013), the electorates of two countries each delegate to an agent who then bargains with the delegate of the other country over the provision of a public good with cross-country spillovers. The choice of delegates is highly dependent on the distributive characteristics of the proposed agreement.

Finally, our paper is strongly related to a companion paper (Habla and Winkler 2013), in which we analyze the political economy of non-cooperative international emission permit markets under legislative lobbying in each country. We regard the common agency and strategic delegation models as complementary perspectives on the political process of modern democracies: Whereas the common agency framework assumes an *incumbent decision maker* who is swayed by interest groups to implement policies in their favor, the strategic delegation literature models the process of *bringing a decision maker into power*, in which the principal recognizes that she might be better off by empowering a decision maker who does not represent her own preferences because of strategic interactions between countries through the selected agents.[3]

2 The model

We consider two countries, indexed by $i = 1, 2$ and $-i = \{1, 2\} \setminus i$.[4] In each country i, emissions e_i imply country-specific benefits from the productive activities of a representative firm. In addition, global emissions $E = e_1 + e_2$ cause strictly increasing and convex country-specific damages.

2.1 Non-cooperative international climate policy

Both countries establish perfectly competitive domestic emission permit markets and determine, non-cooperatively, the number of permits ω_i issued to their representative domestic firm. As firms in all countries i require emission permits for an amount equal to the emissions they produce e_i, global emissions are given by the sum of emission permits issued $E = \omega_1 + \omega_2$. Countries may agree to link their domestic markets to an international market. Then permits issued by both countries are non-discriminatorily traded on a perfectly competitive international market.

Restricting emissions imposes a compliance cost on the representative firms and thus reduces profits. If permits are traded internationally, firms have an opportunity to either generate additional profits by selling permits or reduce the compliance cost by buying permits from abroad. Thus, the profits of the representative firm read:

$$\pi_i(e_i) = B_i(e_i) + p(\omega_i - e_i) , \qquad i = 1, 2 , \tag{1}$$

[3] In addition, although both approaches analyze principal-agent relationships, the common agency approach differs from strategic delegation to the extent that it includes competition among principals for political influence. A single principal, by contrast, never faces any competition.

[4] All our results can be generalized to n countries in a straightforward manner.

where $B_i(e_i)$ denotes country-specific benefits from productive activities with $B_i(0) = 0$, $B_i' > 0$, $B_i'' < 0$ and p is the price of permits on an international market. If countries decide against linking, $\omega_i = e_i$ holds in equilibrium and the second term vanishes.

2.2 Political actors

In each country i there is a principal whose utility is given by:

$$V_i = \pi_i(e_i) - \theta_i^M D_i(E) \ , \tag{2}$$

where $D_i(E)$ denote convex country-specific damages $D_i(E)$ with $D_i(0) = 0$ and $D_i' > 0$, $D_i'' \geq 0$ for all $E > 0$ and $i = 1, 2$. Without loss of generality, we normalize θ_i^M to unity.

In addition, there is a continuum of agents j of mass one in each country i, whose utility is given by:

$$W_i^j = \pi_i(e_i) - \theta_i^j D_i(E) \ , \tag{3}$$

where θ_i^j is a preference parameter that is continuously distributed on the bounded interval $[0, \theta_i^{\max}]$. To ensure that, in both countries, the principal's preferences are represented in the continuum of agents, we impose $\theta_i^{\max} > 1$.

In each country, all agents and the principal thus have equal stakes in the profits of the domestic firm but differ with respect to environmental damage. This may be either because damages are heterogeneously distributed or because the monetary valuation of homogenous physical environmental damage differs. We assume that all political actors (principals and agents) are selfish in the sense that they make their decisions to maximize their respective utility, i.e., the principal in country i chooses her actions to maximize V_i, while agent j in country i makes decisions to maximize his utility W_i^j.

2.3 Structure and timing of the game

We model the hierarchical structure of environmental policy as a non-cooperative sequential game. In the first stage, the choice of regime, the principals in both countries simultaneously determine whether an international permit market is formed. As countries are sovereign, an international permit market only forms if the principals in both countries consent to doing so. In the second stage, the principals simultaneously select an agent from the continuum of available agents. In stage three, these selected agents simultaneously decide on the number of emission allowances that are distributed to the representative domestic firms. In the final stage, emission permits are traded. The complete structure and timing of the game is summarized as follows:

1. Choice of Regime:
   Principals in both countries simultaneously decide whether the domestic permit markets are linked to an international market.

2. Strategic Delegation:
   Principals in both countries simultaneously select an agent.

3. Emission Allowance Choices:
   Selected agents in both countries simultaneously choose the number of emission permits issued to the domestic firms.

4. Permit Trade:
   Depending on the regime established in the first stage, emission permits are traded on perfectly competitive domestic or international permit markets.

In essence, we analyze a standard non-cooperative international permit market as in Helm (2003), which we amend by a strategic delegation stage. We argue that this model, despite being highly stylized, captures essential characteristics of the hierarchical structure of domestic and international environmental policy. As we discuss in greater detail in Section 6, the structure of the model is compatible with various delegation mechanisms present in modern democratic societies. For example, the principal may be the median voter of the electorate while the agent represents the elected government. Alternatively, the principal could be the parliament of a representative democracy that delegates a decision to an agent, for example, to the minister of environment.

We solve the game by backward induction. Therefore, we first determine the equilibrium numbers of emission permits for the two different regimes, which depend on the preferences of the selected agents in both countries. Second, we determine the preferences of the agents whom the principals select. Finally, we analyze whether the principals in both countries consent to the formation of an international permit market.

3 Permit market equilibrium and delegated emissions permit choice

In the last stage and in the case of domestic emission permit markets, the market clearing condition implies that $\omega_i = e_i$ for both countries $i = 1, 2$. Profit maximization of the representative firm leads to an equalization of marginal benefits with the equilibrium permit price:

$$p_i(\omega_i) = B_i'(e_i) \ , \quad i = 1, 2 \ . \tag{4}$$

In the case of an international permit market, there is only one permit market price, which implies that in equilibrium, the marginal benefits of all participating countries are equalized:

$$p(E) = B_1'(e_1(E)) = B_2'(e_2(E)) \ . \tag{5}$$

In addition, the market clearing condition:

$$\omega_1 + \omega_2 = B_1'^{-1}(p(E)) + B_2'^{-1}(p(E)) = e_1(E) + e_2(E) = E \ , \tag{6}$$

implicitly determines the permit price $p(E)$ in the market equilibrium as a function of the total number of issued emission allowances E. Existence and uniqueness follow directly from the assumed properties of the benefit functions B_i. Equation (5) and $e_i(E) = B_i'^{-1}(p(E))$ imply:

$$p'(E) = \frac{B_i''(e_i(E))B_{-i}''(e_{-i}(E))}{B_i''(e_i(E)) + B_{-i}''(e_{-i}(E))} < 0 \ , \quad e_i'(E) = \frac{B_{-i}''(e_{-i}(E))}{B_i''(e_i(E)) + B_{-i}''(e_{-i}(E))} \in (0, 1) \ . \tag{7}$$

For the remainder of the paper, we impose the following on the benefit functions B_i:

Assumption 1 (Sufficient conditions for SOCs to hold: part I)
The benefit functions of both countries are almost quadratic*: $B_i'''(e_i) \approx 0$, $i = 1, 2$.*

By almost quadratic, we mean that $B_i'''(e_i)$ is so small that it is irrelevant for determining the sign of all expressions in which it appears. Note that $B_i'''(e_i) \approx 0$ for $i = 1, 2$ also implies that $p''(E) \approx 0$. These assumptions are sufficient (but not necessary) conditions for the second-order conditions in stage three of the game to hold.

3.1 Delegated permit choice under a domestic permit market

We first assume that no international permit market has been formed in the first stage of the game. Then, the selected agent from country i sets the level of emission permits ω_i to maximize:

$$W_i^D = B_i(\omega_i) - \theta_i D_i(E) \ , \tag{8}$$

subject to equation (4) and given the permit choice ω_{-i} of the other country. Then, the reaction function of the selected agent i is implicitly given by:

$$B_i'(\omega_i) - \theta_i D_i'(E) = 0 \ , \tag{9}$$

implying that the selected agent in country i trades off the marginal benefits of issuing more permits against the corresponding environmental damage costs. The following proposition holds:

Proposition 1 (Unique Nash equilibrium on domestic permit markets)
For any given vector $\Theta = (\theta_1, \theta_2)$ of preferences of the selected agents under domestic permit markets, there exists a unique subgame perfect Nash equilibrium of the subgame beginning in stage three in which all countries $i = 1, 2$ simultaneously set emission permit levels ω_i to maximize (8) subject to (4) and for a given permit level ω_{-i} of the other country.

The proofs of all propositions and corollaries are relegated to the Appendix.

We denote the subgame perfect Nash equilibrium of the subgame beginning in stage three by $\Omega^D(\Theta) = \big(\omega_1^D(\Theta), \omega_2^D(\Theta)\big)$ and the total emission level of this equilibrium by $E^D(\Theta)$. For later use, we analyze how the equilibrium emission levels change with a marginal change in the preferences of the selected agent in country i.

Corollary 1 (Comparative statics on domestic permit markets)
The following conditions hold for the levels of national emissions ω_i^D, ω_{-i}^D and total emissions E^D in the Nash equilibrium $\Omega^D(\Theta)$:

$$\frac{d\omega_i^D(\Theta)}{d\theta_i} < 0 \ , \qquad \frac{d\omega_{-i}^D(\Theta)}{d\theta_i} \geq 0 \ , \qquad \frac{dE^D(\Theta)}{d\theta_i} < 0 \ . \tag{10}$$

Corollary 1 states that domestic emission levels ω_i^D of country i and global emissions E^D are lower in equilibrium the higher is the preference parameter θ_i, i.e., the more country i's selected agent cares for the environment. Moreover, emission levels are strategic substitutes. If country i decreases emission levels in response to a change in the preference parameter θ_i, then country $-i$ increases its emissions and vice versa. This does not hold for linear damages, in which case emission choices are dominant strategies and thus $d\omega_{-i}^D(\Theta)/d\theta_i = 0$. In any case, the direct effect outweighs the indirect effect, and total emissions E^D follow the domestic emission level ω_i^D in equilibrium.

3.2 Delegated permit choice under an international permit market

If an international permit market is formed in the first stage, country i's selected agent chooses ω_i to maximize:

$$W_i^I = B_i(e_i(E)) + p(E)\left[\omega_i - e_i(E)\right] - \theta_i D_i(E) \ , \tag{11}$$

subject to equations (5), (6) and given ω_{-i}. Taking into account that $p(E) = B_i'(e_i(E))$, the reaction function of the agent in country i is given by:

$$p(E) + p'(E)\left[\omega_i - e_i(E)\right] - \theta_i D_i'(E) = 0 \ . \tag{12}$$

By summing the reaction functions for both countries, the equilibrium permit price is equal to the average marginal environmental damage costs of the selected agents:

$$p(E) = \frac{1}{2}\left[\theta_i D_i'(E) + \theta_{-i} D_{-i}'(E)\right] \ . \tag{13}$$

Inserting equation (13) back into the reaction function (12) reveals that, in equilibrium, the country whose agent exhibits above-average marginal damages is the permit buyer, whereas the country whose agent's marginal damages are below average is the permit seller. Again, there exists a unique subgame perfect Nash equilibrium of the subgame beginning at stage three:

Proposition 2 (Unique Nash equilibrium on international permit markets)
For any given vector $\Theta = (\theta_1, \theta_2)$ *of preferences of the selected agents under an international permit market, there exists a unique subgame perfect Nash equilibrium of the subgame beginning at stage three in which both countries simultaneously set the levels of emission permits* ω_i *to maximize* (11) *subject to equations* (5), (6) *and taking the permit level* ω_{-i} *of the other country as given.*

Denoting the Nash equilibrium by $\Omega^I(\Theta) = \left(\omega_1^I(\Theta), \omega_2^I(\Theta)\right)$ and the total equilibrium emissions by $E^I(\Theta)$, we analyze the influence of the selected agents' preferences on the equilibrium permit choices:

Corollary 2 (Comparative statics on international permit markets)
The following conditions hold for the levels of emission allowances ω_i^I, ω_{-i}^I *and total emissions* E^I *in the Nash equilibrium* $\Omega^I(\Theta)$*:*

$$\frac{d\omega_i^I(\Theta)}{d\theta_i} < 0 \ , \qquad \frac{d\omega_{-i}^I(\Theta)}{d\theta_i} > 0 \ , \qquad \frac{dE^I(\Theta)}{d\theta_i} < 0 \ . \tag{14}$$

As before, an increase in θ_i decreases the equilibrium permit level ω_i^I and overall emissions but increases the equilibrium allowance choice ω_{-i}^I of the other country. In the case of an international permit market, domestic emissions are not equal to the domestic allowance choices. In fact, equilibrium emissions decrease in both countries if θ_i increases in one of the countries, as a reduction in total emission permits increases the equilibrium permit price.

4 Strategic delegation

We now turn to the selection of agents by the principals in the second stage of the game. As all agents living in country i are potential candidates to be selected, and the principals can always find a delegate for preference parameters in the interval $\theta_i \in [0, \theta_i^{\max}]$. We shall see that principals will select agents who have (weakly) less concern for the environment than they have themselves, i.e., they wish to select agents with $\theta_i \leq 1$. Thus, the assumption $\theta_i^{\max} > 1$ ensures that principals can always appoint their preferred agent. In addition, we impose:

Assumption 2 (Sufficient conditions for SOCs to hold: part II)
The damage functions of both countries are almost quadratic*:* $D_i'''(e_i) \approx 0,\ i = 1, 2.$

Together with Assumption 1, this assumption ensures that the utility V_i of the principals in both countries is strictly concave under both permit market regimes $R \in \{D, I\}$, as we show in the proofs of Propositions 3 and 4.

4.1 Strategic delegation under domestic permit markets

First, assume a domestic permit markets regime. Then, the principal in country i selects an agent with preferences θ_i such that:

$$V_i^D = B_i(\omega_i^D(\Theta)) - D_i(E^D(\Theta)) \tag{15}$$

is maximized given the Nash equilibrium $\Omega^D(\Theta)$ of the subgame beginning in the third stage and the preferences θ_{-i} of the selected agent in the other country. We derive the following first-order condition:

$$B_i'(\omega_i^D(\Theta))\frac{d\omega_i^D(\Theta)}{d\theta_i} - D_i'(E^D(\Theta))\frac{dE^D(\Theta)}{d\theta_i} = 0\ , \tag{16}$$

which implicitly determines the best-response function $\theta_i^D(\theta_{-i})$. Taking into account the equilibrium outcome of the third stage, in particular equation (9), we can re-write the first-order condition to yield:

$$(1-\theta_i)D_i'(E^D(\Theta))\frac{dE^D(\Theta)}{d\theta_i} = -B_i'(\omega_i^D(\Theta))\frac{d\omega_{-i}^D(\Theta)}{d\theta_i}\ . \quad (17)$$

It states that in equilibrium, the marginal costs of strategic delegation have to equal its marginal benefits. The costs of choosing an agent with lower environmental preferences (left-hand side) are given by the additional (compared to $\theta_i = 1$) marginal damage caused by the increase in total emissions. The benefits from strategic delegation (right-hand side) depend on how much of the abatement effort can be passed on to the other country due to the strategic substitutability of emission permit choices. This passed-on abatement effort is given by the marginal production benefits (of having to abate less) times the decrease in the number of permits that the other country issues. In particular, there is no incentive for strategic delegation if emission permit choices are dominant strategies, i.e., $d\omega_{-i}^D(\Theta)/d\theta_i = 0$.

The subgame beginning in stage two exhibits a unique subgame perfect Nash equilibrium:

Proposition 3 (Unique Nash equilibrium under domestic permit markets)
Given a domestic permit markets regime, there exists a unique subgame perfect Nash equilibrium of the subgame beginning at stage two in which the principals of both countries $i = 1, 2$ simultaneously select agents with preferences θ_i to maximize (15) *subject to* $\Omega^D(\Theta)$ *and given the choice θ_{-i} of the principal in country $-i$.*

The following corollary characterizes this equilibrium, the outcome of which we denote by $\Theta^D = (\theta_1^D, \theta_2^D)$:

Corollary 3 (Properties of the NE under domestic permit markets)
For the equilibrium Θ^D, the following conditions hold:

1. *For both countries, $0 < \theta_i^D \leq 1$ holds.*
2. *Self-representation ($\theta_i^D = 1$) is an equilibrium strategy if and only if the permit choice at stage three is a dominant strategy ($d\omega_{-i}(\Theta)/d\theta_i = 0$).*

Corollary 3 states that the principals in both countries solve the trade-off mentioned above by delegating the choice of emission permits to agents who are (weakly) less green ($\theta_i^D \leq 1$) than they are themselves.[5] The intuition for this result is that emission permit choices in stage three of the game are – for strictly convex damages – strategic substitutes. By increasing the level of domestic emission permits, the other country can be induced to reduce its issuance of permits. Thus, abatement costs can be partly shifted to the other country. For linear damages, this shifting of the burden of abatement to the other country

[5] This result is in line with the findings of Segendorff (1998), Siqueira (2003) and Buchholz et al. (2005).

is not possible because the permit choices in the third stage are dominant strategies. As a consequence, self-representation will prevail in equilibrium.

More generally, delegating the emission allowance choice to an agent with less green preferences is a commitment device for principals to signal a high issuance of emission allowances (thereby, ceteris paribus, inducing a smaller issuance of emission allowances by the other country). The signal is credible, as agents choose an emission permit level that is in their own best interest but is inefficiently low from the principals' point of view.[6]

4.2 Strategic delegation under an international permit market

Now assume an international permit market regime. Then, the principal in country i selects an agent with preferences θ_i to maximize:

$$V_i^I = B_i(e_i(E^I(\Theta))) + p(E^I(\Theta))\left[\omega_i^I(\Theta) - e_i(E^I(\Theta))\right] - D_i(E^I(\Theta)) \ , \tag{18}$$

given the Nash equilibrium $\Omega^I(\Theta)$ of the subgame beginning in the third stage and the preferences θ_{-i} of the selected agent in the other country. Now, the first-order condition reads:

$$p(E^I(\Theta))\frac{d\omega_i^I(\Theta)}{d\theta_i} + \left\{p'(E^I(\Theta))\left[\omega_i^I(\Theta) - e_i(E^I(\Theta))\right] - D_i'(E^I(\Theta))\right\}\frac{dE^I(\Theta)}{d\theta_i} = 0 \ , \tag{19}$$

which implicitly defines the best-response function $\theta_i^I(\theta_{-i})$. Compared to the case of domestic permit markets, an additional term enters the principals' trade-off due to the terms of trade on the international permit market. Again, we can re-write the first-order condition by taking into account the equilibrium in the third stage, in particular equation (12):

$$(1-\theta_i)D_i'(E^I(\Theta))\frac{dE^I(\Theta)}{d\theta_i} = -p(E^I(\Theta))\frac{d\omega_{-i}^I(\Theta)}{d\theta_i} \ . \tag{20}$$

Similar to equation (17), this equation says that in equilibrium, the marginal costs of strategic delegation have to equal its marginal benefits. The only difference is that the marginal benefits of having to abate less due to the strategic substitutability of permit choices are now equal across countries and given by the uniform permit price p.

There exists a subgame perfect Nash equilibrium of the subgame beginning at stage two:

Proposition 4 (Nash equilibrium under international permit market)
Given an international permit market regime, there exists a subgame perfect Nash equilib-

[6] On delegation and commitment, see also Perino (2010).

rium of the subgame beginning at stage two in which the principals of both countries $i = 1, 2$ simultaneously select agents with preferences θ_i to maximize (18) *subject to $\Omega^I(\Theta)$ and given the choice θ_{-i} of the principal in country $-i$.*

A unique *interior Nash equilibrium exists if and only if the following condition holds:*

$$\frac{(B_i''(.))^2 B_{-i}''(.)\left[3B_{-i}''(.)+2B_i''(.)\right]-2D_i''(E)\left[B_i''(.)+B_{-i}''(.)\right]^3}{B_i''(.)B_{-i}''(.)\left[3B_{-i}''(.)+2B_i''(.)\right]^2} < \frac{D_{-i}'(E^I(\Theta^I))}{D_i'(E^I(\Theta^I))}$$
$$< \frac{B_i''(.)B_{-i}''(.)\left[3B_i''(.)+2B_{-i}''(.)\right]^2}{B_{-i}''(.)(B_{-i}''(.))^2\left[3B_i''(.)+2B_{-i}''(.)\right]-2D_{-i}''(E^I(\Theta^I))\left[B_i''(.)+B_{-i}''(.)\right]^3}\;. \tag{21}$$

In contrast to Propositions 1–3, even Assumptions 1 and 2 do not guarantee a unique subgame perfect Nash equilibrium. However, as we shall see in the numerical exercise in Section 5, the game has a unique (although not necessarily interior) Nash equilibrium for empirically relevant parameter constellations.

Denoting the vector of Nash equilibria $\vec{\Theta}^I$, where $\Theta^I = (\theta_1^I, \theta_2^I)$, the following corollary characterizes the properties of each of its elements:

Corollary 4 (Properties of NE under an international permit market)
For any Nash equilibrium Θ^I, the following conditions hold:

1. *For both countries, $\theta_i^I < 1$ holds.*
2. *The Nash equilibrium Θ^I may be a corner solution, i.e., $\theta_i^I = 0$, $\theta_{-i}^I = \theta_{-i}^I(0)$.*
3. *The reaction function of the principal from the permit-selling country i lies strictly below the reaction function of the principal from the permit-buying country $-i$ if $|B_i''(\cdot)| < |B_{-i}''(\cdot)|$.*

Corollary 4 implies that in the case of an international permit market, self-representation ($\theta_i^I = 1$) can never be an equilibrium strategy, even for constant marginal damages, as the interaction through the permit market ensures that permit choices in stage three of the game are strategic substitutes. In other words, the principals in both countries attempt to shift the burden of emissions abatement to the other country by delegating the choice of emission permits to agents who value environmental damages strictly less than they do themselves ($\theta_i^I < 1$). However, under an international permit market regime, the incentive for strategic delegation may be so strong for one country that the principal would prefer to empower an agent with a negative preference parameter θ_i, which would imply that the agent perceives environmental damages as a benefit. As the distribution of preference parameters among the agents has a lower bound at zero, the best the principal can do under these circumstances is to select an agent who does not care about environmental damages.

The last part of Corollary 4 states that the principal of the permit-selling country, i.e., the one exhibiting the relatively lower $\theta_i D_i'(E^I(\Theta^I))$ compared with the other country, has a higher incentive for strategic delegation than the principal in the permit-buying country if the permit-selling country also has the lower carbon efficiency, respectively abatement costs, measured by $|B_i''(\cdot)|$. We will see in the numerical illustration in Section 5 that the latter condition is not restrictive, as (at least under self-representation) the formation of an international permit market is most likely to be mutually beneficial if we match a country with high environmental damages (and, therefore, the permit-buying country) and high carbon efficiency with a country with low environmental damages (and, therefore, the permit-selling country) and low carbon efficiency.

4.3 Comparison of delegation choices under the two regimes

Comparing the principals' incentives to delegate to less green agents under the two regimes, we can show that these are – under rather weak conditions – stronger in the international permit market regime than in a regime with domestic permit markets:

Proposition 5 (Comparison of delegation incentives)
For the reaction function of the principal of country i, $\theta_i^I(\theta_{-i}) < \theta_i^D(\theta_{-i}) \leq 1$ holds for any $0 \leq \theta_{-i} \leq 1$ if the following condition holds:

$$\frac{D_{-i}'(E)}{D_i'(E)} > -\left[1 + \frac{D_{-i}''(E)\left[(B_i''(.))^2 - (B_{-i}''(.))^2\right]}{B_i''(.)(B_{-i}''(.))^2}\right] \ . \tag{22}$$

Proposition 5 implies that whenever $B_i''(.)$ and $B_{-i}''(.)$ are sufficiently close, the principals of both countries will – for any given choice of the other principal – select an agent under the international permit market regime who is less green compared with their choice under domestic permit markets. The intuition for this result is best understood by the following thought experiment. Assume that both countries are perfectly symmetric with respect to all exogenously given parameters and that damages are strictly convex. This implies that without strategic delegation, i.e., $\theta_i = 1$, the allowance choices would be the same under both regimes. In particular, under an international permit market regime, both countries would issue emission permits equal to the volume of domestic emissions and no permit trading would occur.

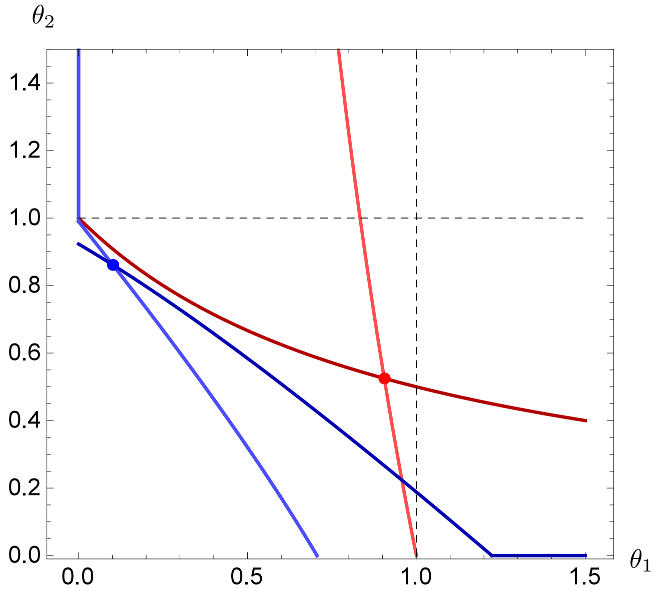

Figure 1: Reaction functions for the delegation stage for the principals in country 1 (light) and country 2 (dark) under the regimes $R = D$ (red) and $R = I$ (blue).

Now consider the Nash equilibrium Θ^D for this situation. Obviously it would also be symmetric, but as $\theta_i^D < 1$, the emission permit levels in both countries are higher than in the case of self-representation. To see that Θ^D cannot be an equilibrium under an international permit market regime, recall that the country whose agent exhibits the smaller marginal environmental damages $\theta_i D_i'(E^I(\Theta^I))$ is the seller of permits. Beginning from the symmetric equilibrium of the domestic permit market regime, the principals in both countries have an incentive to drive down θ_i to become the seller of emission permits and realize the resulting revenues. Ultimately, this race to the bottom leads again to a symmetric equilibrium, in which both countries are neither buyers nor sellers but overall emissions are higher, i.e., $E^I > E^D$.

Yet, even if the reaction functions of both principals shift inward under $R = I$ relative to $R = D$ for sufficiently similar curvatures of the benefit functions, i.e., $\theta_i^I(\theta_{-i}) < \theta_i^D(\theta_{-i})$ for all i, this does *not* imply that both countries will also delegate to a less green agent in *equilibrium*. The point of intersection of the two reaction functions under $R = I$ could still lie to the upper left or lower right of the respective point under $R = D$ (or be a corner solution). This is illustrated in Figure 1.[7] In this example, both countries exhibit identical damage functions, but for any given level of domestic emissions $\bar{e}$, the marginal benefits from emissions are higher and decrease to a greater extent in country 2 (i.e., $B_2'(\bar{e}) > B_1'(\bar{e})$ and $|B_2''(\bar{e})| >$

[7] Details on all numerical illustrations are given in the Appendix.

$|B_1''(\bar{e})|$). Thus, country 2 has a higher carbon efficiency, respectively higher abatement costs of emissions. Under self-representation, both countries would produce emissions exactly equal to the number of permits they issue and, thus, no trade in permits would occur between the countries under an international permit market regime. In the case of strategic delegation, the country with higher abatement costs (here, country 2) has less incentive to abate under a domestic permit market regime and, therefore, chooses an agent with a lower preference parameter θ_2. Under an international permit market regime, the country whose marginal benefits decrease less strongly (here, country 1), profits more from an increase in the total number of issued permits and, therefore, chooses an agent with a lower preference parameter θ_1. Thus, although both reaction functions under $R = I$ lie strictly below those under $R = D$, the principal of country 2 chooses in equilibrium an agent under $R = I$ that exhibits higher environmental awareness than her delegated agent under $R = D$, and vice versa for country 1.

5 Formation of international emission permit markets

We now turn to the question of which permit market regime $R \in \{D, I\}$ will be established in the first stage of the game. To this end, we first examine the circumstances under which the principals in both countries consent to the formation of an international permit market. Then, we discuss how strategic delegation induces less favorable circumstances for an international emission permit market to form.

5.1 The choice of regime

Recall that an international permit market only forms in the first stage if the principals in both countries consent to doing so. Thus, an international permit market only forms if this is in the best interest of the principals in both countries. In considering their preferred regime choices, the principals in both countries anticipate the influence of the regime choice on the outcomes of the following stages. Thus, principals are aware that the regime choice $R \in \{D, I\}$ in the first stage induces preference parameters for the selected agents given by Θ^R and emission allowance choices of $\Omega^R(\Theta^R)$. As a consequence, the principal in country i prefers an international emission permit market if:

$$\begin{aligned}\Delta V_i \equiv\; & B_i(e_i(E^I(\Theta^I))) - B_i(\omega_i^D(\Theta^D)) + p(E^I(\Theta^I))\left[\omega_i^I(\Theta^I) - e_i(E^I(\Theta^I))\right] \\ & - \theta_i^M \left[D_i(E^I(\Theta^I)) - D_i(E^D(\Theta^D))\right] > 0 \;,\end{aligned} \tag{23}$$

which denotes the utility difference of the principal in country i between the international and the domestic permit market regime given the subgame perfect Nash equilibria of the second and third stages of the game under the respective regime.

Then, an international permit market forms if and only if it is a Pareto improvement for the principals over domestic permit markets:[8]

$$\Delta V_i > 0 \quad \wedge \quad \Delta V_{-i} > 0 \; . \tag{24}$$

Helm (2003) shows that for the standard non-cooperative international permit market (in our notation, this implies that $\Theta^D = \Theta^I$ is exogenously given) global emissions may be smaller or larger under an international permit market relative to a situation with domestic permit markets. In addition, it is possible that global emissions are lower under an international emission permit market regime but at least one country does not consent to it. Finally, global emissions may be higher under an international permit market regime, but both countries may nevertheless consent to linking domestic permit markets to an international market. These results also hold for our setting. Which of the different cases applies depends on the set of exogenously given parameters, in particular on the distribution of benefits from local and damages from global emissions.

5.2 Strategic delegation and the formation of international permit markets

In the following, we show that strategic delegation may hinder the formation of an international permit market in the sense that under strategic delegation, an international permit market may not be Pareto superior to domestic permit markets from the principals' point of view, while it would have been without strategic delegation, i.e., if the principals in both countries had themselves decided on the issuance of emission permits.

Proposition 6 (International permit markets under strategic delegation)
Under strategic delegation, the formation of an international emission permits market may not be in the best interest of both principals, i.e., $\Delta V_i \leq 0$ for at least one $i = 1, 2$, even if it would have been in the case of self-representation.

[8] We implicitly assume that country i's principal only favors an international permit market over domestic permit markets if ΔV_i is strictly positive. The intuition behind this tie-breaking rule is the assumption that domestic permit markets represent the status quo. If linking domestic permit markets to an international market induces some positive costs ϵ, then $\Delta V_i > \epsilon > 0$ has to hold for an international permit market to be favorable. However, this tie-breaking rule does not qualitatively affect our results, and any other tie-breaking rule is permissible.

Without strategic delegation

Regime	θ_1^R	θ_2^R	ω_1^R	ω_2^R	e_1^R	e_2^R	E^R	V_1^R	V_2^R
$R = D$	1	1	0.95	0.82			1.77	0.40	0.34
$R = I$	1	1	1.02	0.68	0.80	0.90	1.70	0.44	0.37

With strategic delegation

Regime	θ_1^R	θ_2^R	ω_1^R	ω_2^R	e_1^R	e_2^R	E^R	V_1^R	V_2^R
$R = D$	0.91	0.97	0.95	0.83			1.78	0.40	0.34
$R = I$	0	0.86	1.08	0.70	0.85	0.93	1.78	0.43	0.33

Table 1: Overview of the outcomes in the subgame perfect Nash equilibria without and with strategic delegation for the numerical example detailed in the Appendix.

We illustrate Proposition 6 with a numerical example (the details of which can be found in the Appendix). To this end, we choose parameter constellations such that one country (or country block) exhibits a *low* carbon efficiency (which is equivalent to low abatement costs) and its principal a *low* willingness to pay (WTP) to prevent environmental damages, and the second country has a *high* carbon efficiency and its principle a *high* WTP to prevent environmental damages. One can think of country 1 as a country in transition, while country 2 represents a developed country. This constellation is known to render the most favorable conditions for the formation of an international emission permits market (Carbone et al. 2009) and for reductions in aggregate emissions relative to domestic permit markets. The example also demonstrates that we obtain unique (although not necessarily interior) Nash equilibria for plausible and empirically relevant parameter constellations.

We calibrate the example to China (country 1) and the European Union (country 2), using relative energy productivities taken from the OECD Green Growth Indicators database as a proxy for carbon efficiencies and using relative WTPs based on the rough estimates provided in Carbone et al. (2009). The results are illustrated in Table 1. In the case of self-representation, an international permit market comes into existence as the principals of both the EU and China have higher payoffs under international than under domestic permit markets. Furthermore, China is the seller of emission permits, which is in line with findings from Carbone et al. (2009). The EU, being the high-damage country block, benefits from both an overall decrease in total emissions and a decrease in marginal abatement costs.

In the case of strategic delegation, the delegation incentives are rather mild under domestic permit markets, as can be seen in Figure 2, which depicts the reaction functions from the delegation stage for the principals in both countries. As a consequence, total emissions under this regime rise only slightly compared with the case of self-representation due to a slightly higher permit issuance by country 2, and the two principals' payoffs are nearly the same as without strategic delegation. In the case of an international permit market, however, the

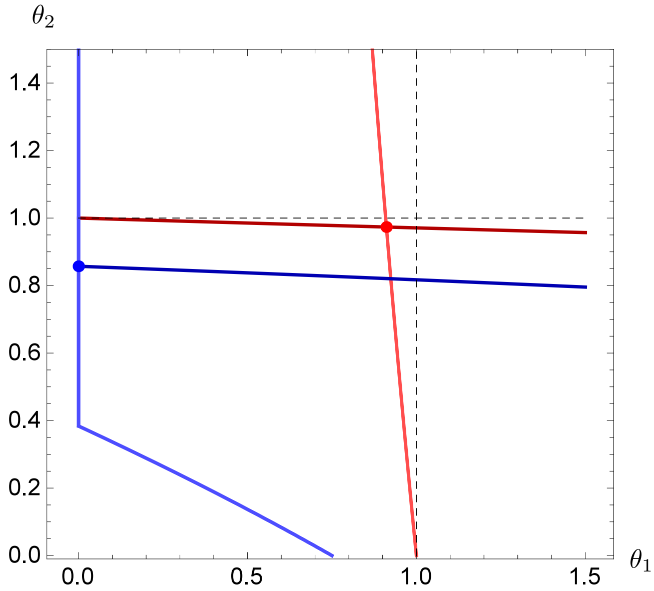

Figure 2: Reaction functions for the principals in country 1 (China, light) and country 2 (EU, dark) under the regimes $R = D$ (red) and $R = I$ (blue) at the delegation stage.

delegation incentives for the permit-selling country are much stronger than those for the permit-buying country, as stated in Corollary 4 and shown in Figure 2. The principal of country 1, i.e., China, even chooses a corner solution in equilibrium and delegates to an agent with environmental preferences at the lower bound of the distribution (zero). By doing so, the number of emission permits issued in China rises by approximately 5% compared with self-representation, whereas the EU increases the number of permits only slightly compared with self-representation. Overall emissions rise in both regimes under strategic delegation relative to self-representation and, unsurprisingly, by relatively more in the case of an international permit market. While the principal of country 1 still prefers an international permit market regime, the principal of the other country would incur excessive damages under this regime and is, thus, better off under domestic permit markets. In contrast to the case of self-representation, *no* international market will emerge.

Our sensitivity analyses, detailed in the Appendix, show that varying relative carbon efficiencies, holding relative WTPs fixed, yields qualitatively identical results. Increasing, ceteris paribus, China's WTP for environmental damages, however, makes an interior solution for the delegation choices under an international permits market more likely, i.e., delegation in this regime is less strong for China, and – for sufficiently close WTPs for the two countries – a permit market will not be formed even without strategic delegation.

This example highlights that while the formation of an international permit market may be beneficial for all principals if they represent themselves, this is less likely to be the case under strategic delegation. The reason is that the incentives to delegate to less green agents are usually much stronger under an international permit market relative to domestic permit markets. This commitment by the principals leads to higher aggregate emissions and makes the principal of the high-damage country (the EU) less inclined to consent to the formation of an international market.

6 Discussion

Our results rely on Assumptions 1 and 2 of almost quadratic benefit and environmental cost functions. At least with respect to climate change, the empirical literature finds that both abatement cost curves (which correspond to the benefits of not abating emissions) and damage cost curves can be well approximated by quadratic functions (e.g., Tol 2002; Klepper and Peterson 2006). In addition, Assumptions 1 and 2 are sufficient but not necessary conditions for our results to hold.

We analyze a particular environmental policy in our model: emission permit markets. However, our results do not hinge on the domestic policy being an emissions permit scheme, which we chose for analytical convenience. Our results would still hold if we considered domestic emission tax schemes instead. In addition, whether permits are grandfathered or auctioned is inconsequential in our model, as firm profits accrue to the individual agents in the respective countries. In the case of grandfathering, endowing firms with permits for free implies higher profits for the firms and, thus, higher income for the individual agents, whereas in the case of auctioning, the revenues from the auction would directly accrue to the individual agents, for example, in the form of a lump-sum transfer.

We model a highly stylized, four-stage principal-agent game. Nevertheless, we argue that both the timing of the game and the delegation procedure is compatible with different principal-agent relationships that arise in the hierarchical policy procedures of modern democracies. We wish to illustrate this claim with two examples. First, assume that the principal is the median voter and the agent is an elected government.[9] Then, the four-stage game translates into the following sequence of events. In stage one, the median voter decides on the regime choice. While this may be unusual in representative democracies, this is rather the rule in direct democracies such as Switzerland, where binary and one-shot decisions are

[9] For this interpretation, we require that $\theta_i^M = 1$ is indeed the median in the preference distribution with respect to environmental damages. This can always be achieved by an appropriate normalization. In addition, it is straightforward to show that the voters can be ordered according to the preference parameter θ_i^j, with $\partial\omega_i/\partial\theta_i^j < 0$. As a consequence, the median voter theorem applies.

often made by the electorate via referendum. In the second stage, the median voter elects a government that determines the number of allowances issued to the domestic firms in the third stage. Following this interpretation, we have a strategic voting game between the electorate and the elected government.

Second, assume that the principal is the parliament of a representative democracy and the agent is, for example, the minister of environment. Now, the parliament determines the regime choice in the first stage. In the second stage, the parliament elects the executive, including the minister of environment, who then determines the number of emission allowances in the third stage. While it is rather unusual that the parliament, i.e., the legislative, elects the executive, this is, for example, the case in Germany.

The structure and timing of our principal-agent game is consistent with real-world hierarchical decision-making procedures, but there is a more general interpretation of the principal-agent relationship in our game setting. Because of the strategic interaction at the international level, the principals in both countries have an incentive to signal to the other principal that they will choose a less green policy to free-ride on the abatement efforts of the other country. However, such a signal is only credible if the principals can somehow commit to actually pursuing the signaled policy, as it is at odds with their own preferences. The strategic delegation framework in our model provides such a commitment device for the principal to signal a credible international policy to the principal of the other country. Yet, any other credible commitment device, such as investments in adaptation to climate change or in long-lived, emissions-intensive energy infrastructure would result in a similar race to the bottom whereby principals in both countries would issue more emission allowances than if they could not credibly commit to such a policy.[10] Thus, our results are qualitatively robust beyond the particular principal-agent relationship considered in our model framework.

Our explicit discussion of the hierarchical structure of international environmental policies may shed light on the puzzle of why we have yet to witness the formation of many non-cooperative international permit markets. The advantage of an international permit market, in which individual countries non-cooperatively determine permit issuance, over non-cooperative domestic environmental policies is the equalization of marginal benefits from emissions across all countries, which is a necessary condition for efficiency. However, from the principals' perspective, the efficiency gains from equalizing marginal benefits across countries come at the cost of a higher degree of strategic delegation, i.e., the incentive to delegate the emission permit choice to agents who have a lower valuation for the environment than they have themselves. As this incentive is likely to be stronger under an international

[10] Copeland (1990), Buchholz and Konrad (1994), Buchholz and Haslbeck (1997) and Beccherle and Tirole (2011) discuss technological choices and investments as commitment devices through which a country can improve its position in negotiations concerning an environmental agreement.

than under a domestic permit market regime, there is an additional trade-off favoring the domestic permit market regime that has been overlooked in the standard non-cooperative permit market setting.

Finally, we would like to discuss the relationship between this paper and Habla and Winkler (2013), in which we analyze the influence of legislative lobbying on the formation of a non-cooperative international permit market. In Habla and Winkler (2013), we find that lobbying may backfire in the sense that if one lobby's influence increases in one country, this may lead to a policy shift in the direction that is less favored by the lobby. For example, if the green lobby increases its influence in one country, this may result in higher total emissions and, thus, higher environmental damages in both countries. The reason for this effect is that, while an increase in the green lobby group's influence in one country reduces the equilibrium emissions in both the domestic and the international permit market regimes, it may also induce a regime shift from the regime with lower toward the regime with higher total emissions. As discussed in Habla and Winkler (2013), this result holds not only for legislative lobbying but for any changes in the preferences of the decision maker. In fact, it also applies to a change in the preference parameter θ_i^M of the principal in country i in the model framework of this paper, as we show in the Appendix.

7 Conclusion

We have analyzed the non-cooperative formation of an international permit market in a hierarchical policy framework, in which a principal in each country chooses an agent who is responsible for determining the domestic emissions allowance. We find that principals in both countries choose agents who have less green preferences than they have themselves. As emission allowance choices are strategic substitutes, delegation allows the principals to credibly commit to a less green policy and, thus, shift – ceteris paribus – part of the abatement burden to the other country. However, due to the additional terms of trade effect, this incentive is (usually) stronger under an international permit market regime than under domestic permit markets and is particularly strong for the permit seller. As a consequence, under strategic delegation, the formation of an international permit market is less likely to be a Pareto improvement for the principals than under conditions of self-representation.

While our results may explain the reluctance to establish non-cooperative international permit markets, despite their seemingly favorable characteristics, they also constitute the more general warning that treating countries as atomistic agents in the international policy arena may be an oversimplification. As a consequence, the analysis of the nexus between domestic and international (environmental) policy seems to be a promising avenue for future research.

Appendix

Proof of Proposition 1

(i) Existence: The maximization problem of country i's selected agent is strictly concave:

$$\mathrm{SOC}_i^D \equiv B_i''(\omega_i) - \theta_i D_i''(E) < 0 \ . \tag{A.1}$$

Thus, for each country $i = 1, 2$, the reaction function yields a unique best response for any given choice ω_{-i} of the other country. This guarantees the *existence* of a Nash equilibrium.

(ii) Uniqueness: Solving the best response functions (9) for e_i and summing up over both countries yields the following equation for the aggregate emissions E:[11]

$$E = B_i'^{-1}\left(\theta_i D_i'(E)\right) + B_{-i}'^{-1}\left(\theta_{-i} D_{-i}'(E)\right) \ . \tag{A.2}$$

As the left-hand side is strictly increasing and the right-hand side is decreasing in E, there exists a unique level of total emissions $E^D(\Theta)$ in the Nash equilibrium. Substituting back into the reaction functions yields the unique Nash equilibrium $\left(\omega_1^D(\Theta), \omega_2^D(\Theta)\right)$. □

Proof of Corollary 1

Introducing the abbreviation

$$\Gamma_i^D \equiv B_i''(\omega_i)\mathrm{SOC}_{-i}^D - \theta_i D_i''(E) B_{-i}''(\omega_{-i}) > 0 \ , \tag{A.3}$$

and applying the implicit function theorem to the first-order conditions (9) for both countries, we derive:

$$\frac{d\omega_i^D(\Theta)}{d\theta_i} = \frac{D_i'(E)\mathrm{SOC}_{-i}^D}{\Gamma_i^D} < 0 \ , \tag{A.4a}$$

$$\frac{d\omega_{-i}^D(\Theta)}{d\theta_i} = \frac{D_i'(E)\theta_{-i} D_{-i}''(E)}{\Gamma_i^D} \geq 0 \ , \tag{A.4b}$$

$$\frac{dE^D(\Theta)}{d\theta_i} = \frac{D_i'(E) B_{-i}''(\omega_{-i})}{\Gamma_i^D} < 0 \ . \tag{A.4c}$$

□

Proof of Proposition 2

(i) Existence: By virtue of Assumption 1 and as $e_i'(E) \in (0, 1)$, the maximization problem

[11] As all marginal benefit functions B_i' are strictly and monotonically decreasing, the inverse functions $B_i'^{-1}$ exist and are also strictly and monotonically decreasing.

of country i's delegate is strictly concave:

$$\text{SOC}_i^I = p'(E)[2 - e_i'(E)] + p''(E)[\omega_i - e_i(E)] - \theta_i D_i''(E) < 0 \ . \tag{A.5}$$

Thus, for each country $i = 1, 2$, the reaction function yields a unique best response for any given choice ω_{-i} of the other country, which guarantees the *existence* of a Nash equilibrium.

(ii) Uniqueness: Summing up the reaction function (12) over both countries yields the following condition, which holds in the Nash equilibrium:

$$2p(E) = \theta_i D_i'(E) + \theta_{-i} D_{-i}'(E) \ . \tag{A.6}$$

The left-hand side is strictly decreasing in E, while the right-hand side is increasing in E. Thus, there exists a unique level of total emission allowances $E^I(\Theta)$ in the Nash equilibrium. Inserting $E^I(\Theta)$ back into the reaction functions (12) yields the unique equilibrium allowance choices $(\omega_i^I(\Theta), \omega_{-i}^I(\Theta))$. □

Proof of Corollary 2

Introducing the abbreviation

$$\Gamma^I = p'(E)[\text{SOC}_i^I + \text{SOC}_{-i}^I - p'(E)] > 0 \ , \tag{A.7}$$

and applying the implicit function theorem to the first-order conditions (12) for both countries, we derive:

$$\frac{d\omega_i^I(\Theta)}{d\theta_i} = \frac{D_i'(E)\text{SOC}_{-i}^I}{\Gamma^I} < 0 \ , \tag{A.8a}$$

$$\frac{d\omega_{-i}^I(\Theta)}{d\theta_i} = -\frac{D_i'(E)\left[\text{SOC}_{-i}^I - p'(E)\right]}{\Gamma^I} > 0 \ , \tag{A.8b}$$

$$\frac{dE^I(\Theta)}{d\theta_i} = \frac{D_i'(E)p'(E)}{\Gamma^I} < 0 \ . \tag{A.8c}$$

□

Proof of Proposition 3

(i) Existence: By virtue of Assumptions 1 and 2, the maximization problem of country i's principal is strictly concave:

$$\begin{aligned}\text{SOC}_i^{P|D} &\equiv B_i''(\omega_i)\left(\frac{d\omega_i}{d\theta_i}\right)^2 + B_i'(\omega_i)\frac{d^2\omega_i}{d\theta_i^2} - \theta_i^M\left[D_i''(E)\left(\frac{dE}{d\theta_i}\right)^2 + D_i'(E)\frac{d^2E}{d\theta_i^2}\right] \\ &= \frac{(D_i'(E))^2\,\text{SOC}_{-i}^D}{\left(\Gamma_i^D\right)^2}\left[B_i''(\omega_i)\text{SOC}_{-i}^D - \theta_i D_i''(E)B_{-i}''(\omega_{-i})\right] < 0 \ .\end{aligned} \tag{A.9}$$

Thus, for each country $i = 1, 2$, the reaction function yields a unique best response for any given choice θ_{-i} of the other country. This guarantees the *existence* of a Nash equilibrium.

(ii) Uniqueness: Solving (16) for the best response function, we derive

$$\theta_i^D(\theta_{-i}) \equiv \theta_i^M \frac{B''_{-i}(\omega_{-i})}{B''_{-i}(\omega_{-i}) - \theta_{-i} D''_{-i}(E)} \ . \tag{A.10}$$

By virtue of Assumptions 1 and 2, $B''_{-i}(\omega_i)$ and $D''_{-i}(E)$ are (almost) constant. Then, the reaction functions can be shown to intersect (at most) once in the feasible range $\Theta \in [0, \theta_i^M] \times [0, \theta_{-i}^M]$ by inserting the reaction functions into each other and solving for the equilibrium delegation choices. □

Proof of Corollary 3

The first property follows directly from equation (A.10) since $B''_{-i}(\omega_{-i}) \neq 0$. For deriving the second property, solve equation (16) for the best response function as follows:

$$\theta_i^D(\theta_{-i}) = \theta_i^M + \frac{B'_i(\omega_i)}{D'_i(E)} \frac{d\omega_{-i}^D/d\theta_i}{dE^D/d\theta_i} \ . \tag{A.11}$$

Therefore, $\theta_i^D(\theta_{-i}) = \theta_i^M$ if and only if $d\omega_{-i}^D/d\theta_i = 0$, see equation (A.8a). □

Proof of Proposition 4

(i) Existence: By virtue of Assumptions 1 and 2, the maximization problem of country i's principal is strictly concave:

$$\text{SOC}_i^{P|I} \equiv \left(\frac{D'_i(E)p'(E)}{\Gamma^I}\right)^2 \left[p'(E)(3 - e'_{-i}(E)) - \theta_{-i} D''_{-i}(E) - \theta_i^M D''_i(E)\right] < 0 \ . \tag{A.12}$$

Thus, for each country $i = 1, 2$, the reaction function yields a unique best response for any given choice θ_{-i} of the other country. This guarantees the *existence* of a Nash equilibrium.

(ii) Multiplicity of equilibria: Solving equations (19) for the best response functions of each principal, we can write (omitting the terms containing $p''(E) \approx 0$ and suppressing the arguments of the benefit functions):

$$\theta_i^I(\theta_{-i}) = \theta_i^M + \frac{p(E)}{D_i'(E)} \frac{\theta_{-i} D_{-i}''(E) - p'(E)[1 - e_{-i}'(E)]}{p'(E)} \ , \tag{A.13a}$$

$$= \frac{2 + \frac{D_{-i}'(E)}{D_i'(E)} \theta_{-i} \left[\theta_{-i} D_{-i}''(E) \frac{B_i''(.) + B_{-i}''(.)}{B_i''(.) B_{-i}''(.)} - \frac{B_{-i}''(.)}{B_i''(.) + B_{-i}''(.)} \right]}{2 - \left[\theta_{-i} D_{-i}''(E) \frac{B_i''(.) + B_{-i}''(.)}{B_i''(.) B_{-i}''(.)} - \frac{B_{-i}''(.)}{B_i''(.) + B_{-i}''(.)} \right]} \ , \tag{A.13b}$$

$$\theta_{-i}^I(\theta_i) = \frac{2 + \frac{D_i'(E)}{D_{-i}'(E)} \theta_i \left[\theta_i D_i''(E) \frac{B_i''(.) + B_{-i}''(.)}{B_i''(.) B_{-i}''(.)} - \frac{B_i''(.)}{B_i''(.) + B_{-i}''(.)} \right]}{2 - \left[\theta_i D_i''(E) \frac{B_i''(.) + B_{-i}''(.)}{B_i''(.) B_{-i}''(.)} - \frac{B_i''(.)}{B_i''(.) + B_{-i}''(.)} \right]} \ , \tag{A.13c}$$

where we made use of equations (5), (7) and (13).

As all terms in (A.13b) and (A.13c) besides the delegation choice variables are – by virtue of Assumptions 1 and 2 – almost constant, we define:

$$\alpha \equiv \frac{D_{-i}'(E)}{D_i'(E)} > 0 \ , \quad \beta \equiv \frac{B_{-i}''(.)}{B_i''(.) + B_{-i}''(.)} > 0 \quad \gamma_i \equiv -\frac{D_i''(E)}{B_i''(.)} > 0 \ .$$

Applying these definitions to equations (A.13b) and (A.13c), we can express the reaction functions as follows:

$$\theta_i^I(\theta_{-i}) = \frac{2(1-\beta) - \alpha \theta_{-i} \left[\gamma_{-i} \theta_{-i} + \beta(1-\beta) \right]}{2(1-\beta) + \left[\gamma_{-i} \theta_{-i} + \beta(1-\beta) \right]} \ , \tag{A.14a}$$

$$\theta_{-i}^I(\theta_i) = \frac{2\alpha\beta - \theta_i \left[\gamma_i \theta_i + \beta(1-\beta) \right]}{\alpha \left[2\beta + \gamma_i \theta_i + \beta(1-\beta) \right]} \ . \tag{A.14b}$$

Using these equations, it is straightforward to show:

$$\frac{d\theta_i^I(\theta_{-i})}{d\theta_{-i}} < 0 \ , \qquad \frac{d\theta_{-i}^I(\theta_i)}{d\theta_i} < 0 \ , \tag{A.15}$$

$$\frac{d^2\theta_i^I(\theta_{-i})}{d\theta_{-i}^2} \gtreqless 0 \ , \qquad \frac{d^2\theta_{-i}^I(\theta_i)}{d\theta_i^2} \gtreqless 0 \ . \tag{A.16}$$

Both reaction functions are thus downward-sloping but either can be concave or convex which implies that multiple equilibria may arise. Before characterizing the possible equilibria, we calculate:[12]

$$\theta_i(0) = \frac{2}{2+\beta} < 1 \ , \quad \theta_i^0 = \frac{1}{2\gamma_i}\left[\sqrt{\beta^2(1-\beta)^2 + 8\alpha\beta\gamma_i} - \beta(1-\beta)\right] \ , \tag{A.17}$$

$$\theta_{-i}(0) = \frac{2}{3-\beta} < 1 \ , \quad \theta_{-i}^0 = \frac{1}{2\alpha\gamma_{-i}}\left[\sqrt{\alpha^2\beta^2(1-\beta)^2 + 8\alpha(1-\beta)\gamma_{-i}} - \alpha\beta(1-\beta)\right] \ , \tag{A.18}$$

where $\theta_{-i}(\theta_i^0) = 0$ and $\theta_i(\theta_{-i}^0) = 0$. If both reaction functions are strictly concave, we can have the following four cases, as illustrated by the four diagrams of Figure 3 (the same reasoning applies to strictly convex functions or a combination of both):

i) Unique interior Nash equilibrium if and only if:

$$\theta_i(0) < \theta_i^0 \quad \wedge \quad \theta_{-i}(0) < \theta_{-i}^0 \ . \tag{A.19}$$

ii) Two corner Nash equilibria and at most two interior Nash equilibria (or a continuum of Nash equilibria if the two reactions functions overlap) if and only if:

$$\theta_i(0) \geq \theta_i^0 \quad \wedge \quad \theta_{-i}(0) \geq \theta_{-i}^0 \ . \tag{A.20}$$

iii) One corner Nash equilibrium and at most two interior Nash equilibria if and only if:

$$\theta_i(0) < \theta_i^0 \quad \wedge \quad \theta_{-i}(0) > \theta_{-i}^0 \ . \tag{A.21}$$

iv) One corner Nash equilibrium and at most two interior Nash equilibria if and only if:

$$\theta_i(0) > \theta_i^0 \quad \wedge \quad \theta_{-i}(0) < \theta_{-i}^0 \ . \tag{A.22}$$

Equation (21) follows immediately from conditions (A.19).

□

[12] For expositional convenience we drop the superscript I.

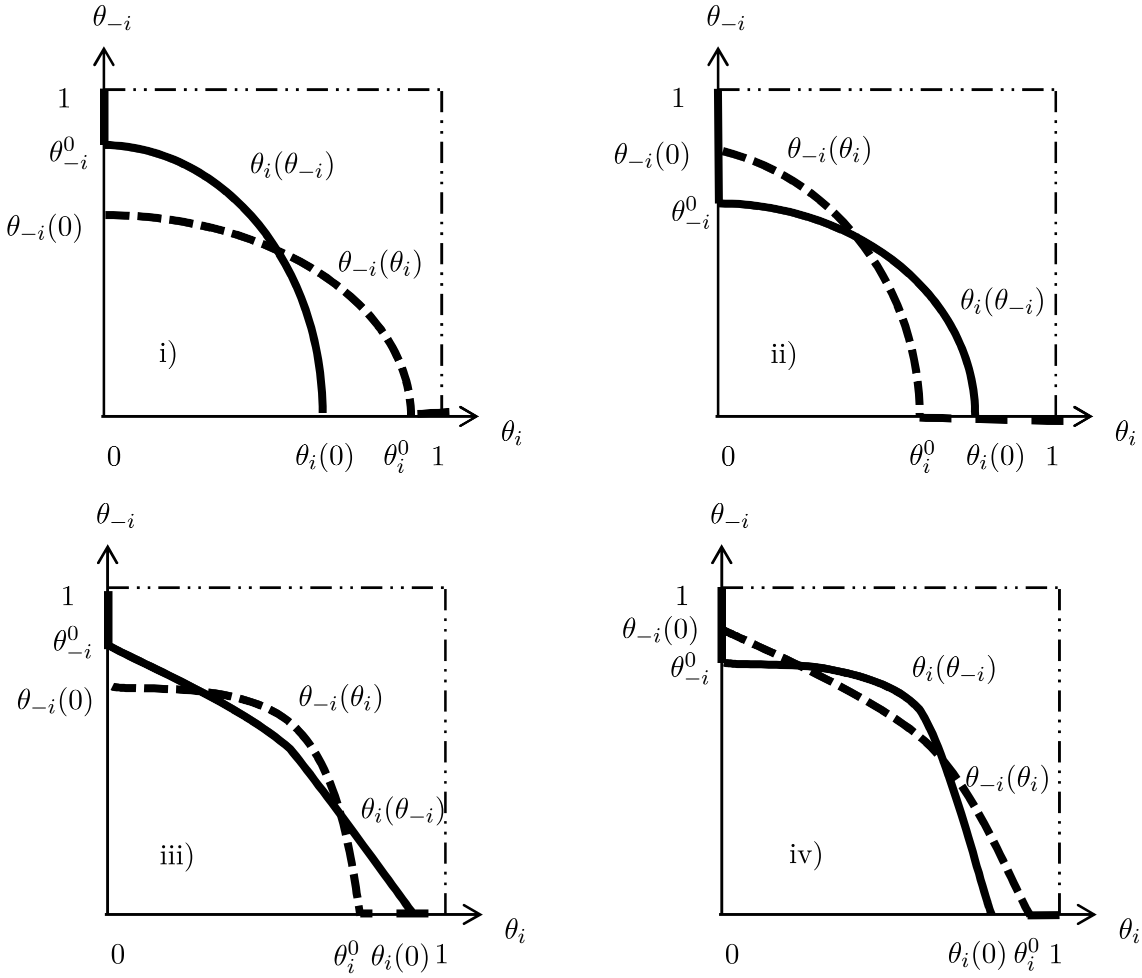

Figure 3: Possible Nash equilibria of the delegation stage with concave reaction functions.

Proof of Corollary 4

The second term in equation (A.13a) is negative which is why we have $\theta_i^I < 1$, and it may also be smaller than -1 in which case we get a corner solution.

To show statement (iii) we re-write the first-order conditions to yield:

$$\theta_i = 1 + \left[1 - \frac{p'(E)[\omega_i - e_i(E)]}{D_i'(E)}\right] \frac{\partial \omega_{-i}/\partial \theta_i}{\partial \omega_i/\partial \theta_i} \ . \tag{A.23}$$

We further assume that country i is the seller of permits, i.e. $\omega_i - e_i(E) > 0$. Define

$$\Delta = -p'(E)[\omega_i - e_i(E)] = \frac{1}{2}\left[\theta_{-i} D_{-i}'(E) - \theta_i D_i'(E)\right] > 0 \ . \tag{A.24}$$

Thus, we have to show that

$$\left[1 + \frac{\Delta}{D_i'(E)}\right] \frac{\partial \omega_{-i}/\partial \theta_i}{\partial \omega_i/\partial \theta_i} < \left[1 + \frac{\Delta}{D_{-i}'(E)}\right] \frac{\partial \omega_i/\partial \theta_{-i}}{\partial \omega_{-i}/\partial \theta_{-i}} \ . \tag{A.25}$$

Inserting and re-arranging yields:

$$\begin{aligned} &SOC_i^I SOC_{-i}^I \left[\frac{\Delta}{D_i'(E)} + \frac{\Delta}{D_{-i}'(E)}\right] - p'(E)\left[SOC_i^I \frac{\Delta}{D_i'(E)} + SOC_{-i}^I \frac{\Delta}{D_{-i}'(E)}\right] \\ &\quad - p'(E)\left[SOC_i^I - SOC_{-i}^I\right] > 0 \ . \end{aligned} \tag{A.26}$$

The first two terms are always positive and the third one is positive if $SOC_i^I - SOC_{-i}^I > 0$. As

$$SOC_i^I - SOC_{-i}^I = 2\frac{\Delta}{E} - p'(E)[e_i'(E) - e_{-i}'(E)] \ , \tag{A.27}$$

a sufficient condition for $SOC_i^I - SOC_{-i}^I > 0$ to hold is that $e_i' > e_{-i}'$, which, in turn, holds if $|B_i''(\cdot)| < |B_{-i}''(\cdot)|$.

□

Proof of Proposition 5

We can re-write the reaction functions (A.10) and (A.13b) (again omitting the terms containing $p''(E) \approx 0$ and suppressing the arguments of the benefit functions) to yield:

$$\theta_i^D(\theta_{-i}) = \theta_i^M + \frac{D''_{-i}(E)\theta_{-i}}{B''_{-i}(\omega_{-i}) - D''_{-i}(E)\theta_{-i}} \ , \tag{A.28a}$$

$$\theta_i^I(\theta_{-i}) = \theta_i^M + \frac{\left[1 + \frac{D'_{-i}(E)}{D'_i(E)}\theta_{-i}\right]\left[\theta_{-i}\frac{D''_{-i}(E)}{B''_{-i}(.)}\frac{B''_i(.)+B''_{-i}(.)}{B''_i(.)} - \frac{B''_{-i}(.)}{B''_i(.)+B''_{-i}(.)}\right]}{2 - \theta_{-i}\frac{D''_{-i}(E)}{B''_{-i}(.)}\frac{B''_i(.)+B''_{-i}(.)}{B''_i(.)} + \frac{B''_{-i}(.)}{B''_i(.)+B''_{-i}(.)}} \ , \tag{A.28b}$$

where we made use of equations (5), (7), (9) and (13).

Applying the definitions introduced in the proof of Proposition 4 to equations (A.13b) and (A.28a), we obtain:

$$\theta_i^D(\theta_{-i}) = 1 - \frac{\gamma_{-i}\theta_{-i}}{1 + \gamma_{-i}\theta_{-i}} \ , \tag{A.29a}$$

$$\theta_i^I(\theta_{-i}) = 1 - \frac{(1 + \alpha\theta_{-i})\left[\gamma_{-i}\theta_{-i} + \beta(1-\beta)\right]}{2(1-\beta) + \left[\gamma_{-i}\theta_{-i} + \beta(1-\beta)\right]} \ . \tag{A.29b}$$

Then, delegation choices of country i under domestic permit markets are – for any given θ_{-i} of the other country – strictly higher than under an international permit market, $\theta_i^D(\theta_{-i}) > \theta_i^I(\theta_{-i})$, if and only if the following condition holds:

$$\begin{aligned} \text{LHS}(\theta_{-i}) \equiv &(1 + \alpha\gamma_{-i})\left[\gamma_{-i}\theta_{-i} + \beta(1-\beta)\right] \\ &> \gamma_{-i}\theta_{-i}\left[(2 - \alpha\beta\theta_{-i})(1-\beta) - \alpha\gamma_{-i}\theta_{-i}^2\right] \equiv \text{RHS}(\theta_{-i}) \ . \end{aligned} \tag{A.30}$$

It is straightforward to show that

$$\frac{d\text{LHS}(\theta_{-i})}{d\theta_{-i}} > 0 \ , \qquad \frac{d\text{RHS}(\theta_{-i})}{d\theta_{-i}} \gtreqless 0 \ , \tag{A.31}$$

$$\frac{d^2\text{LHS}(\theta_{-i})}{d\theta_{-i}^2} > 0 \ , \qquad \frac{d^2\text{RHS}(\theta_{-i})}{d\theta_{-i}^2} < 0 \ . \tag{A.32}$$

LHS is a convex, RHS a concave function in θ_{-i}. As $\text{LHS}(0) = \beta(1-\beta) > 0 = \text{RHS}(0)$, LHS and RHS will not intersect in the interval $\theta_{-i} \in [0,1]$ and thus $\theta_i^D(\theta_{-i}) > \theta_i^I(\theta_{-i})$ if:

$$\frac{d\text{LHS}(0)}{d\theta_{-i}} > \frac{d\text{RHS}(0)}{d\theta_{-i}} - \beta(1-\beta) \ . \tag{A.33}$$

Replacing the defined variables by the original terms yields equation (22). □

Details of the numerical illustrations

For all numerical illustrations, we apply the following quadratic benefit and damage functions:

$$B_i(e_i) = \frac{1}{\phi_i} e_i \left(1 - \frac{1}{2} e_i\right) \ , \quad B_i'(e_i) = \frac{1 - e_i}{\phi_i} \ , \quad B_i''(e_i) = -\frac{1}{\phi_i} \ , \tag{A.34a}$$

$$D_i(E) = \frac{\epsilon_i}{2} E^2 \ , \quad D_i'(E) = \epsilon_i E \ , \quad D_i''(E) = \epsilon_i \ . \tag{A.34b}$$

In **Section 4** we employ the following exogenously given parameters:

$$\phi_1 = 1 \ , \qquad \phi_2 = 0.2 \ , \qquad \epsilon_1 = 1 \ , \qquad \epsilon_2 = 1 \ . \tag{A.35}$$

This yields the following equilibrium delegation choices:

$$\theta_1^D = 0.90 \ , \qquad \theta_2^D = 0.52 \ , \qquad \theta_1^I = 0.10 \ , \qquad \theta_2^I = 0.86 \ , \tag{A.36}$$

as illustrated in Figure 1.

For the numerical exercise in **Section 5** we parameterize functions (A.34) using relative energy productivities from the OECD Green Growth Indicators database[13] for the year 2011 and relative WTPs for abatement of carbon emissions from Carbone et al. (2009). As there is no explicit data on energy productivities for the EU as a whole, we take the productivity of all OECD countries together as a proxy. According to this database, China exhibits approximately half the energy productivity of the OECD. Following Carbone et al. (2009), Western Europe has a six times higher WTP to avoid climate damages than China. As a consequence, we set the exogenous parameters to:

$$\phi_1 = 1 \ , \qquad \phi_2 = 0.5 \ , \qquad \epsilon_1 = 0.03 \ , \qquad \epsilon_2 = 0.2 \ . \tag{A.37}$$

Sensitivity analyses: We first keep the WTPs constant but vary the energy productivities, and then do the opposite. Consider an increase in the energy productivity in China such that $\phi_1 = 2/3$. The results are depicted in Table 2. Again, China is the permit seller, and an international permits market forms only in the case of self-representation. The corner Nash equilibrium from before prevails, as can be seen in Figure 4.

Increasing China's WTP from $\epsilon_1 = 0.03$ to $\epsilon_1 = 0.15$ yields a unique interior Nash equilibrium (see Figure 5). Again, a permit market forms under self-representation but is rejected under strategic delegation, this time by both countries. The results are summarized in Table 3.

[13] DOI:10.1787/9789264202030-en

Without strategic delegation

Regime	θ_1^R	θ_2^R	ω_1^R	ω_2^R	e_1^R	e_2^R	E^R	V_1^R	V_2^R
$R = D$	1	1	0.96	0.82			1.79	0.65	0.330
$R = I$	1	1	1.04	0.72	0.86	0.90	1.76	0.68	0.332

With strategic delegation

Regime	θ_1^R	θ_2^R	ω_1^R	ω_2^R	e_1^R	e_2^R	E^R	V_1^R	V_2^R
$R = D$	0.91	0.98	0.97	0.82			1.79	0.65	0.33
$R = I$	0	0.82	1.08	0.75	0.90	0.92	1.82	0.67	0.30

Table 2: Overview of the outcomes in the subgame perfect Nash equilibria without and with strategic delegation for $\phi_1 = 2/3$.

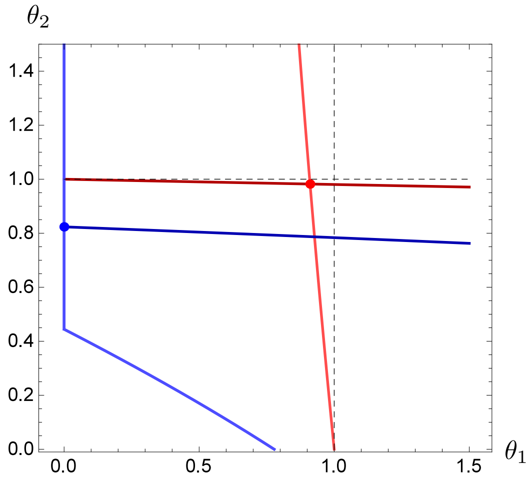

Figure 4: Reaction functions for the principals in country 1 (China, light) and country 2 (EU, dark) under the regimes $R = D$ (red) and $R = I$ (blue) on the delegation stage (for $\phi_1 = 2/3$).

Effect of marginal change in environmental awareness

To analyze the effect of a marginal change in environmental awareness θ_i^M of the principal, we differentiate equation (23) for both countries with respect to θ_i^M (suppressing some of

Without strategic delegation

Regime	θ_1^R	θ_2^R	ω_1^R	ω_2^R	e_1^R	e_2^R	E^R	V_1^R	V_2^R
$R = D$	1	1	0.80	0.84			1.64	0.16	0.436
$R = I$	1	1	0.84	0.77	0.74	0.87	1.61	0.18	0.438

With strategic delegation

Regime	θ_1^R	θ_2^R	ω_1^R	ω_2^R	e_1^R	e_2^R	E^R	V_1^R	V_2^R
$R = D$	0.92	0.90	0.82	0.85			1.67	0.1499	0.42
$R = I$	0.26	0.82	1.00	0.75	0.83	0.92	1.75	0.1492	0.35

Table 3: Overview of the outcomes in the subgame perfect Nash equilibria without and with strategic delegation for $\epsilon_1 = 0.15$.

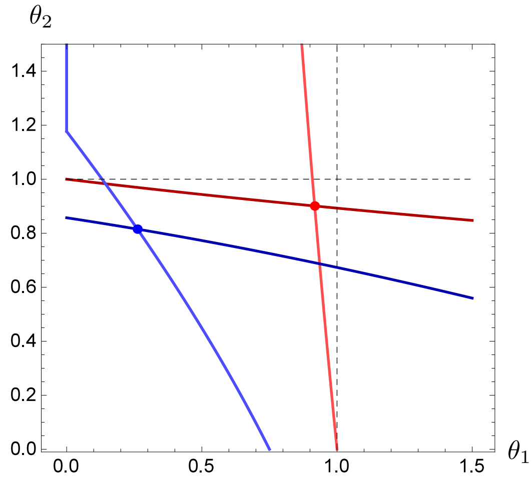

Figure 5: Reaction functions for the principals in country 1 (China, light) and country 2 (EU, dark) under the regimes $R = D$ (red) and $R = I$ (blue) on the delegation stage (for $\epsilon_1 = 0.15$).

the arguments):[14]

$$\frac{d\Delta V_i}{d\theta_i^M} = \left\{ D_i(E^D(\Theta^D)) - D_i(E^I(\Theta^I)) \right\} - \frac{d\theta_{-i}^D}{d\theta_i^M} \left[B_i'(\omega_i^D(.)) \frac{d\omega_i^D}{d\theta_{-i}^D} - D_i'(E^D(.)) \frac{dE^D}{d\theta_{-i}^D} \right]$$
$$+ \frac{d\theta_{-i}^I}{d\theta_i^M} \left[p(E^I(.)) \frac{d\omega_i^I}{d\theta_{-i}^I} + p'(E^I(.)) \left[\omega_i^I(.) - e_i^I(E^I(.)) \right] \frac{dE^I}{d\theta_{-i}^I} - D_i'(E^I(.)) \frac{dE^I}{d\theta_{-i}^I} \right] , \tag{A.38}$$

[14] In the strategic voting interpretation of our model, we would have to assume that the environmental awareness of all agents changes alike as otherwise the identity of the median voter would change.

$$\frac{d\Delta V_{-i}}{d\theta_i^M} = -\frac{d\theta_i^D}{d\theta_i^M}\left[B'_{-i}(\omega_{-i}^D(.))\frac{d\omega_{-i}^D}{d\theta_i^D} - D'_{-i}(E^D(\Theta^D))\frac{dE^D}{d\theta_i^D}\right] + \frac{d\theta_i^I}{d\theta_i^M}\left[p(E^I(.))\frac{d\omega_{-i}^I}{d\theta_i^I} + p'(E^I(.))\left[\omega_{-i}^I(.) - e_{-i}^I(E^I(.))\right]\frac{dE^I}{d\theta_i^I} - D'_{-i}(E^I(.))\frac{dE^I}{d\theta_i^I}\right] . \tag{A.39}$$

In country i, there is a direct effect on ΔV_i of a marginal increase in environmental awareness (the term in curly brackets in (A.38)). This effect goes in the direction of the regime with lower total emissions. However, there are also indirect effects through a change in the equilibrium environmental awareness θ_{-i} of the appointed agent in the other country in the second stage which induces a change in the equilibrium permit choices of both countries and thus aggregate emissions under both regimes in the third stage. Therefore, the payoffs of country i's principal change under both regimes. For the principal in country $-i$, there are similar indirect changes in the payoffs under both regimes induced by a change in the equilibrium environmental awareness θ_i of the selected agent in country i and the associated changes in equilibrium permit choices in both countries.

To show that an increase (decrease) in environmental awareness may lead to a regime change and thus bring about higher (lower) global emissions, we focus on the case of quadratic benefit functions, as in (A.34), but linear environmental damages:

$$D_i(E) = \epsilon_i E \ , \quad D'_i(E) = \epsilon_i \ , \quad D''_i(E) = 0 \ . \tag{A.40}$$

It can be easily shown that the signs of the terms in square brackets in equations (A.38) and (A.39) are positive. Therefore, we need to evaluate the signs of $d\theta_i^R/d\theta_i^M$ and $d\theta_{-i}^R/d\theta_i^M$ for $R \in \{D, I\}$.

Using equations (A.28a) and (A.28b) for both countries, we find:

$$\theta_i^D = \theta_i^M \ , \quad \theta_{-i}^D = \theta_{-i}^M \ , \tag{A.41}$$

$$\theta_i^I = \frac{\theta_i^M\left[2(\epsilon_i)^2(\phi_i + \phi_{-i}) + \epsilon_i\epsilon_{-i}\phi_{-i}\right] - \theta_{-i}^M(\epsilon_{-i})^2\phi_i}{2(\epsilon_i)^2(\phi_i + \phi_{-i}) + \epsilon_i\epsilon_{-i}\phi_{-i} + (\epsilon_i)^2\phi_i} < \theta_i^M \ , \tag{A.42}$$

$$\theta_{-i}^I = \frac{\theta_{-i}^M\left[2(\epsilon_{-i})^2(\phi_i + \phi_{-i}) + \epsilon_{-i}\epsilon_i\phi_i\right] - \theta_i^M(\epsilon_i)^2\phi_{-i}}{2(\epsilon_{-i})^2(\phi_i + \phi_{-i}) + \epsilon_{-i}\epsilon_i\phi_i + (\epsilon_{-i})^2\phi_i} < \theta_{-i}^M \ . \tag{A.43}$$

Thus,

$$\frac{d\theta_i^D}{d\theta_i^M} > 0 \ , \quad \frac{d\theta_{-i}^D}{d\theta_i^M} = 0 \ , \quad \frac{d\theta_i^I}{d\theta_i^M} > 0 \ , \quad \frac{d\theta_{-i}^I}{d\theta_i^M} < 0 \ , \tag{A.44}$$

confirming our results that, for linear damages, delegation choices are dominant strategies in the domestic permit markets regime but strategic substitutes in the international permit market regime.

Consider the situation of an established international permit market with $E^I < E^D$, i.e., $\Delta V_i > 0$ and $\Delta V_{-i} > 0$. Now assume, for example, that θ_i^M increases. Then, in equation (A.38), the term in curly brackets is positive, the first term in square brackets drops out, and the term in the second line is negative. There is thus a direct effect which goes in the direction of the regime with lower emissions (the status quo regime) but an indirect effect which goes in the opposite direction. If the indirect effect outweighs the direct effect, the principal now favors the status quo regime less than before and may even change her support from regime I to regime D. In this case, regime I breaks down and the new regime exhibits higher global emissions. Moreover, in equation (A.39), the term in the first line is negative and the term in the second line is positive. So even if the changes in payoffs for the principal in country i do not suffice to induce a shift to the environmentally less friendly regime, this may happen because the principal in the other country ceases her support for regime I. The greening of preferences in one country may thus worsen the environmental outcome.

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