Strategic Delegation and International Permit Markets: Why Linking May Fail*

Wolfgang Habla† and Ralph Winkler‡

† Department of Economics, University of Gothenburg
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

This version: April 2016

Abstract: We analyze a typical principal-agent relationship in the context of international climate policy, in which the principals of two countries first decide whether to merge their domestic emission permit markets to form an international market. In the second stage, they delegate the decision on domestic permit supply to an agent. We find that principals have an incentive to select agents who care less for environmental damages than they do themselves. Moreover, international permit markets amplify this incentive, rendering linking less attractive. This may explain why we do not observe international permit markets despite their seemingly favorable characteristics.

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

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

* This paper was previously circulated under the title "Strategic Delegation and Non-cooperative International Permit Markets". We are grateful to an anonymous reviewer whose comments on Habla and Winkler (2013) triggered the idea for this paper. We also thank Antoine Dechezleprêtre, Simon Dietz, Corina Haita, Andreas Lange, Antony Millner, Amrish Patel, Grisha Perino, Kerstin Roeder, Thomas Sterner, Luca Taschini, Alessandro Tavoni, participants in the EAERE conference in Toulouse (2013) and the workshop "Énergie et territoires" in Dijon (2015), as well as seminar participants at the Universities of Bern, Gothenburg, Graz, Hamburg, the London School of Economics, ETH Zurich and the Graduate Institute, Geneva, for valuable comments on an earlier draft. Habla acknowledges the generous financial support from the FORMAS research program COMMONS.

1 Introduction

Efforts to mitigate anthropogenic climate change are plagued by the public good property of greenhouse gas emissions reductions. Each country's efforts to control emissions will benefit all countries in a non-exclusive and non-rival manner. The absence of a supranational authority to enforce efficient provision leads to the observed under-provision of emissions reductions. As a potential remedy, international emission permit markets have been proposed (Flachsland et al. 2009; Jaffe et al. 2009; Green et al. 2014).

On the one hand, international permit markets promise efficiency gains, as marginal abatement costs are equalized across firms and countries, which is a necessary condition for efficiency (Montgomery 1972). On the other hand, the total number of permits in such a trading scheme is not necessarily efficient, because each country is free to decide on the number of permits it wants to issue within its own jurisdiction. In fact, some countries might be tempted to issue more permits than they would do in the absence of international trade in permits, because they might gain from selling permits to other countries. Helm (2003), among others, shows that the non-cooperative choice of allowances under an international permit market (which we will refer to as a "non-cooperative" international permit market) might increase total emissions by so much that an international permit market becomes unattractive for one or more countries.[1] Yet, Carbone et al. (2009) demonstrate that international permit markets exhibit substantial potential for greenhouse gas reductions under certain circumstances. In particular, linking the permit markets of countries with *high* carbon efficiency (i.e., high marginal benefits of greenhouse gas emissions) and *high* willingness to pay for emissions reductions (i.e., high marginal damages) and countries with *low* carbon efficiency and *low* willingness to pay leads to a Pareto improvement, in which efficiency gains due to equalizing marginal abatement costs are realized and total emissions decline. Despite these favorable characteristics, 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.[2]

In this paper, we offer an explanation for the observed reluctance in linking emission permit markets. We show that, even in these instances where an international permit market seems beneficial to countries in the aforementioned model frameworks, this may not be the

[1] Copeland and Taylor (2005) also find that, when taking international trade in goods into account, permit trading between two countries may harm at least one country by causing a deterioration in the terms of trade and/or raising the emission levels in unconstrained (with respect to emissions) countries.

[2] Australia, which had already announced a plan to establish a domestic permit market and link it with the EU's scheme, abandoned these plans after a change in government. Moreover, the EU-ETS does not strictly fit our definition of non-cooperative international permit market, because of the supranational authority that the EU exerts on the national governments with respect to domestic emission permit levels.

case anymore when we take the hierarchical structure of climate policy into account. By "hierarchical" we mean that political decisions in democratic societies are not made by a single – let alone benevolent – decision maker. In fact, representative democracies typically feature a chain of delegation from voters to those who govern, with at least four discrete steps (Strøm 2000): (i) from voters to elected representatives, (ii) from legislators to the executive branch (head of government), (iii) from the head of government to the heads of different executive departments, and (iv) from these heads to civil servants. In all these situations, one party (an agent) acts on behalf of another (the principal) because the principal either lacks the information or skills of the agent, or simply the time. Another reason for delegation is that the choice of an agent with certain preferences signals the intentions that the principal pursues and, thus, credibly commits the principal to a particular policy (e.g., Perino 2010). We focus on the latter purpose of delegation.

In the realm of climate policy, the most common form of delegation is that a country's government – the principal – decides upon the rough orientation of the policy (e.g., on whether a permit market or a tax will be implemented) and delegates the implementation of this policy to the minister of environment – the agent. The appointment of a minister with a particular political agenda that is publicly observable and well-known can be regarded as an (additional) instrument to signal the country's ambitions in the international policy arena.[3]

We model the principal-agent relationship outlined above 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 empowered to issue emission permits. Then, the selected agents in both countries non-cooperatively determine the number of emission permits issued to domestic firms. Finally, trading of permits – within or between countries, contingent on the regime chosen in the first stage – takes place.

We find that the principals of both countries, no matter whether they form an international permit market or otherwise carry out domestic climate policies, have an incentive to appoint agents that care less about environmental damages than they do themselves – a result that is well known in the strategic voting and strategic delegation literature and is due

[3] The EU's climate policy, for example, is represented by the Commissioner for Climate Action whose mission is to "formulate and implement climate policies and strategies" at the EU and the international level. This post was created in 2010, splitting it from the environmental portfolio of the Directorate-General for Environment, and thus it figures prominently in the EU's policy portfolio. The appointment of Miguel Arias Cañete as the Commissioner for Climate Action in November 2014 can be seen as a strong signal to the international community, since Cañete is a politician of the centre-right and, in addition, his family was involved in the oil industry. After accusations of possible conflicts of interest, he and his son resigned from the boards of oil companies Petrolífera Ducar and Petrologis Canarias in September 2014 (Financial Times 2014).

to the strategic substitutability of climate policies (e.g., Segendorff 1998; Siqueira 2003 and Buchholz et al. 2005). Our main contribution is to show that this incentive is more pronounced under international permit markets (compared to the situation under domestic policies). The reason is that, on an international market, it is beneficial for each country to issue more permits, because the marginal benefits from additional emissions, which are equal to the equilibrium permit price, decrease by less than under domestic permit markets. The principals in both countries can achieve higher issuance of permits by choosing agents with a lower valuation of environmental damages than the principals exhibit themselves. This effect, however, may render the formation of an international permit market less beneficial to at least one principal. Overall, we find that the conditions for the formation of an international permit market are less favorable than suggested by the standard permit market literature, which neglects the hierarchical structure of international climate policy. We illustrate this by a numerical example calibrated to the potential linking between the EU and China.

Our paper contributes to several strands of literature. It builds on and extends the literature on non-cooperative international permit markets, developed in Helm (2003), Carbone et al. (2009), Holtsmark and Sommervoll (2012) 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). These two bodies of literature exhibit strong similarities with one another 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 may occur if the selected agents cooperatively (or via a bargaining procedure) determine the division or provision of a good, or if they non-cooperatively make decisions about 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. However, this result 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. 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, we examine delegation not only under caps but also under international permit markets.[4]

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) 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. With respect to hierarchical policy structures within countries, our paper is related to Habla and Winkler (2013), in which we analyze the formation of international permit markets under legislative lobbying.

2 The model

We consider two countries, indexed by $i = 1, 2$ and $-i = \{1, 2\} \setminus i$.[5] In each country i, emissions e_i imply strictly increasing and concave country-specific benefits from the productive activities of a representative firm, while global emissions $E = e_1 + e_2$ cause strictly increasing and convex country-specific damages.

[4] 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 conservatives improves the conservatives' bargaining position, the progressives are more likely to be included in majority coalitions and hence increase the political power of the jurisdiction they represent. 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 that has cross-country spillovers. The choice of delegates is highly dependent on the distributive characteristics of the proposed agreement.

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

2.1 Non-cooperative international climate policy

Both countries establish perfectly competitive domestic emission permit markets[6] and determine, non-cooperatively, the number of permits ω_i issued to a representative domestic firm. As firms in all countries i require emission permits for an amount equal to the emissions e_i they produce, global emissions are given by the sum of emission permits issued, $E = \omega_1 + \omega_2$. Countries may agree to link their domestic markets and form 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:

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

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 Agency Structure

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 strictly convex country-specific damages, with $D_i(0) = D_i'(0) = 0$ and $D_i' > 0$, $D_i'' > 0$ 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 $\theta_i^{\max} > 1$.

[6] As we point out in the discussion, our results do not hinge on the domestic policy being a permit market.

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 individuals (principals and agents) are selfish in the sense that they maximize their respective utilities, 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.

We assume that preference parameters of all individuals are common knowledge. Thus, we abstract from all issues related to asymmetric information.[7]

2.3 Structure and timing of the game

We model the hierarchical structure of climate 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. Because 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 merged to form 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.

[7] Although this may seem restrictive at first glance, it is not in the context of our model framework. One principal's incentive to strategically delegate to an agent stems exclusively from the other principal's ability to observe the principal's and agent's preferences. Moreover, the assumption is not unrealistic, as high-level political delegates have, in general, well-known political agendas.

Despite being highly stylized, this model 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 might be the median voter of the electorate while the agent represents the elected government. Alternatively, the principal might be the parliament 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 levels 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 under which conditions the principals in both countries consent to the formation of an international permit market and compare this to the case when there is no possibility for the principals to delegate strategically.

3 Permit market equilibrium and delegated 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 country-specific 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:

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

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, which we analyze next.

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:[8]

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

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:

$$B_i'(\omega_i) - \theta_i D_i'(E) = 0 \ , \quad (9)$$

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 NE in stage three under 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.

[8] Superscript "D" stands for "domestic", indicating the regime in which only domestic permit markets exist.

We denote the subgame perfect Nash equilibrium of the subgame beginning in stage three by $\Omega^D(\Theta) = (\omega_1^D(\Theta), \omega_2^D(\Theta))$ 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 (Stage three comparative statics under 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 $\Omega^D(\Theta)$:*

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

Corollary 1 states that domestic emission levels ω_i^D of country i and global emissions E^D are lower in equilibrium when the preference parameter θ_i is higher, i.e., when country i's selected agent cares more about 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. Yet, 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:[9]

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

subject to equations (5) and (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:

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

[9] Superscript "I" stands for "international", indicating the regime in which an international permit permit market is formed.

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 NE in stage three under 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) *and* (6) *and taking the permit level ω_{-i} of the other country as given.*

Denoting the Nash equilibrium by $\Omega^I(\Theta) = \big(\omega_1^I(\Theta), \omega_2^I(\Theta)\big)$ 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 (Stage three comparative statics under int'l 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, the principals can always find a delegate for preference parameters in the interval $\theta_i \in [0, \theta_i^{\max}]$. We shall see that the principals will select agents who have 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:

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

This 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 $\theta_i^M = 1$) 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 NE in stage two 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 that 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 (i.e.,* $d\omega_{-i}(\Theta)/d\theta_i = 0$*).*

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 less green ($\theta_i^D < 1$) than they are themselves.[10] 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 would not be possible because the permit choices in the third stage are dominant strategies. As a consequence, self-representation would 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 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 high from the principals' point of view.

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:

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

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

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):

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

Similarly 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 are given by the uniform permit price p.

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

Proposition 4 (NE in stage two under international permit markets)
Given an international permit market regime, there exists a 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 (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:

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

In contrast to Propositions 1–3, even Assumptions 1 and 2 do not guarantee a *unique* subgame perfect Nash equilibrium (as we show in the Appendix). 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 international permit markets)
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. *For any given θ_{-i}, principal i delegates to an agent with lower θ_i the less increasing are her marginal damages and the less decreasing are her marginal benefits.*

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 principals' incentives to strategically delegate increase the less marginal damages increase, because the less sensitive marginal damages are with respect to total emissions, the more the principals benefit from a higher issuance of permits. In addition, the more marginal benefits fall in country i, the lower is the incentive of the principal in country i to strategically delegate to an agent with lower θ_i. The reason is that more steeply falling marginal benefits imply a stronger reaction of the equilibrium permit price to a change in total emissions, i.e., the equilibrium permit price will fall by more if emissions increase marginally due to a lower θ_i of the selected agent. But since the equilibrium permit price is part of the marginal benefits of strategic delegation, see equation (20), a lower permit price is equivalent to lower marginal benefits of strategic delegation. Hence, the incentive to choose an agent with lower θ_i becomes weaker.

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, under rather weak conditions, these incentives are 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. This implies that, without strategic delegation, i.e., $\theta_i = \theta_i^M = 1$, 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.

Now consider the Nash equilibrium Θ^D for this situation. Obviously it would also be symmetric, but, because $\theta_i^D < 1$, 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 $\theta_i D'_i(E^I(\Theta))$ 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 in order to become the seller of emission permits and thus realize the resulting revenues. Ultimately, this race to the bottom leads again to a symmetric equilibrium, in which neither country is a buyer or a seller, and overall emissions are higher, i.e., $E^I > E^D$.

Now assume that the curvatures of the benefit functions are not identical but sufficiently similar. Then, $\theta_i^I(\theta_{-i}) < \theta_i^D(\theta_{-i})$ for all i by Proposition 5. Yet, even though the reaction functions of both principals shift inward under $R = I$ relative to $R = D$ in this case, this does *not* imply that both principals 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.[11] In this example, both countries exhibit identical damage functions, but, for any given level of domestic emissions $\bar{e}$, the marginal benefits from

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

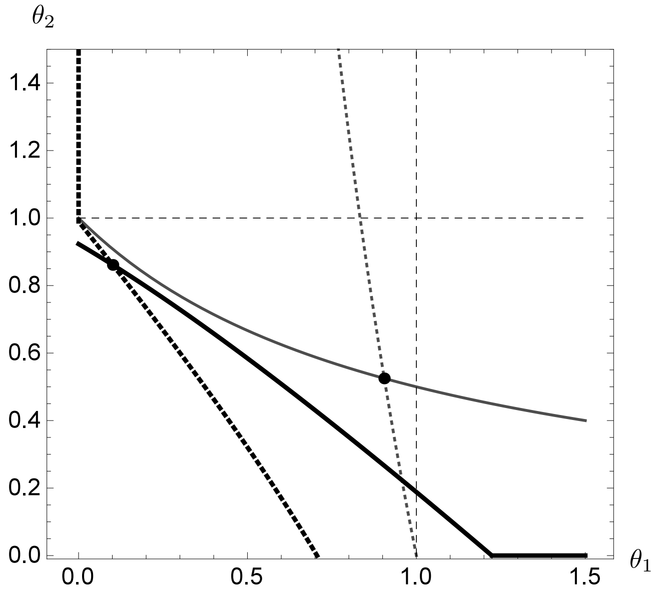

Figure 1: Reaction functions at the delegation stage of the principals in country 1 (dotted) and country 2 (solid line) under the regimes $R = D$ (grey and thin) and $R = I$ (black and fat).

emissions are higher and decrease to a greater extent in country 2 (i.e., $B_2'(\bar{e}) > B_1'(\bar{e})$ and $|B_2''(\bar{e})| > |B_1''(\bar{e})|$). Thus, country 2 has higher carbon efficiency and therefore higher marginal 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 marginal 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 principal in 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 if it 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 compared to domestic permit markets:[12]

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

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

[12] 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.

permit markets. In addition, it is possible that global emissions are lower under an international emission permit market regime but that 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 emissions and damages from global emissions across the two countries.

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. We contrast this with the situation without strategic delegation (i.e., where the principals in both countries directly decide on the issuance of emission permits), in which case an international permit market would be Pareto superior to domestic permit markets.

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 the international market would have been in the interest of both principals in the case of self-representation.*

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 marginal 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

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
Without strategic delegation									
$R = D$	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									
$R = D$	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.

self-representation, an international permit market comes into existence, as the principals of both the EU and China have higher payoffs under international markets 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 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, yield qualitatively identical results. However, increasing

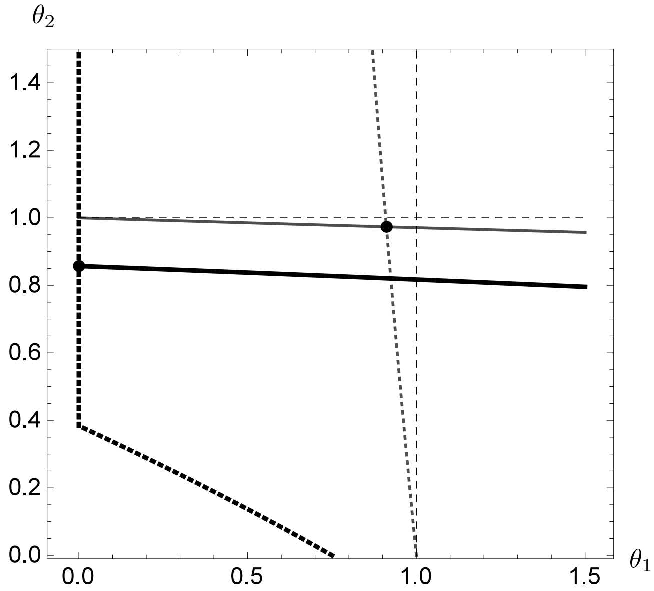

Figure 2: Reaction functions of the principals in country 1 (China, dotted) and country 2 (EU, solid line) under the regimes $R = D$ (grey and thin) and $R = I$ (black and fat) at the delegation stage.

China's WTP for environmental damages, ceteris paribus, makes an interior solution for the delegation choices under an international permits market more likely. In other words, 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 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 than under a domestic permit market regime, there is an additional trade-off favoring the domestic permit market regime, which has been overlooked in the standard non-cooperative permit market setting.

Our results rely on Assumptions 1 and 2 of almost quadratic benefit and environmental cost functions. 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.

Despite our highly stylized, four-stage principal-agent model, we argue that both the timing of the game and the delegation procedure are 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.[13] Then, the four-stage game translates into the following sequence of events. In stage one, the median voter decides on the regime. While this may be unusual in representative democracies, it is rather the rule in direct democracies such as Switzerland, where binary and one-shot decisions are often made by the electorate via referendum. In the second stage, the median voter elects a government

[13] 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.

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 in the first stage. In the second stage, it elects the executive, for example, 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 legislature, 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 in order 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, because 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 would be the case if they could not credibly commit to such a policy.[14] Thus, our results are qualitatively robust beyond the particular principal-agent relationship considered in our model framework.

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. Because 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

[14] 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.

effect, this incentive is (usually) stronger under an international permit market regime than under domestic permit markets. 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 single welfare-maximizing 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:[15]

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

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:

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

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

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

□

Proof of Proposition 2
(i) Existence: By virtue of Assumption 1 and because $e_i'(E) \in (0, 1)$, the maximization

[15] 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.

problem 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 $\left(\omega_i^I(\Theta), \omega_{-i}^I(\Theta)\right)$. □

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:

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

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 $B''_{-i}(\omega_{-i}) \neq 0$. To derive 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 $d\omega_{-i}^D/d\theta_i = 0$. □

Proof of Proposition 4

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

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

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:

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

$$\frac{d^2\theta^I_i(\theta_{-i})}{d\theta^2_{-i}} \gtreqless 0 \;, \qquad \frac{d^2\theta^I_{-i}(\theta_i)}{d\theta^2_i} \gtreqless 0 \;. \tag{A.16}$$

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:[16]

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

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

where $\theta_{-i}(\theta^0_i) = 0$ and $\theta_i(\theta^0_{-i}) = 0$. 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):

[16] For expositional convenience, we drop the superscript "I".

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).

□

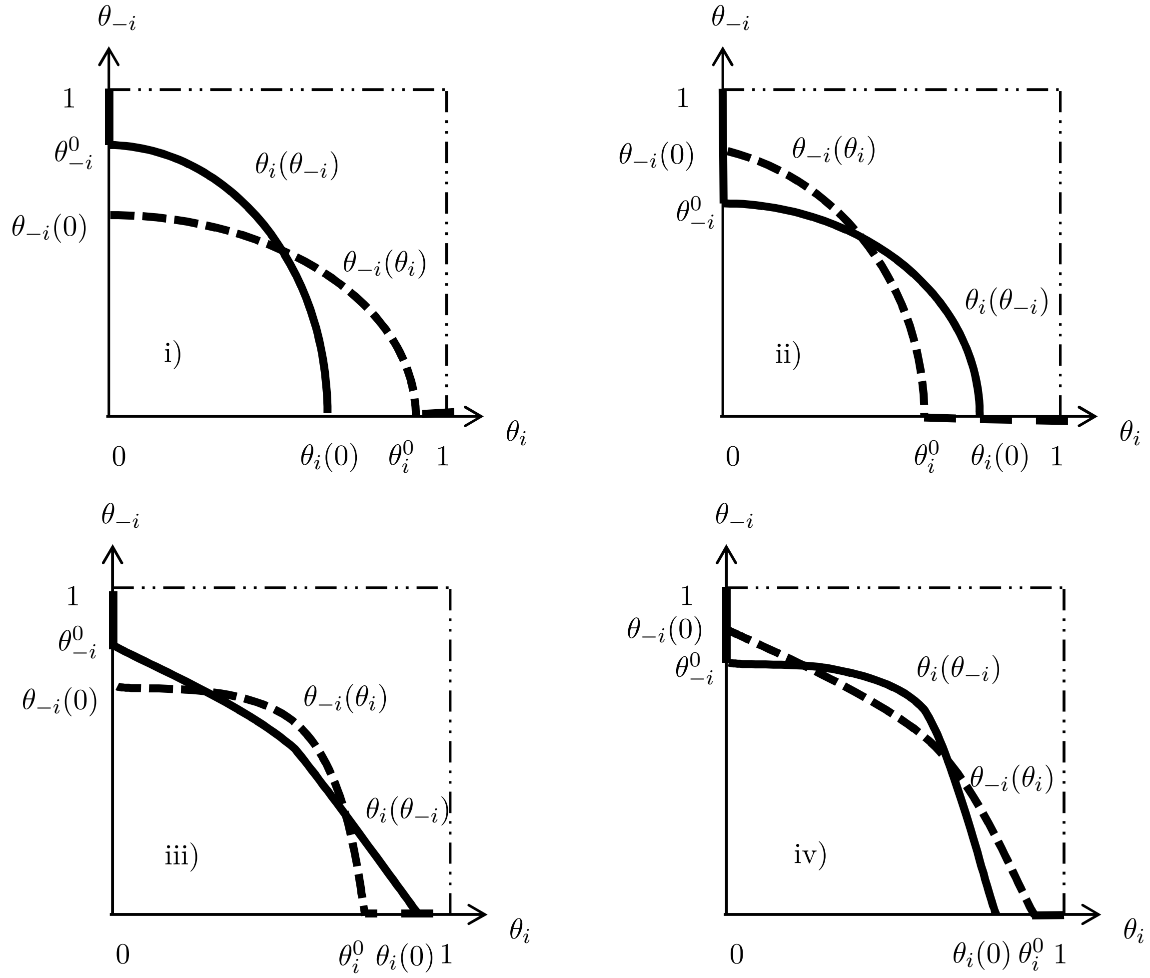

Figure 3: Possible Nash equilibria of the delegation stage with concave reaction functions.

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 property (iii), we re-write the reaction function (A.13b) using equations (5), (7) and (13). In addition, we exploit Assumption 2 to derive $D'_{-i}(E)/D'_i(E) \approx D''_{-i}(E)/D''_i(E)$:

$$\theta_i^I(\theta_{-i}) = \theta_i^M + \frac{\left[1 + \frac{D''_{-i}(E)}{D''_i(E)}\theta_{-i}\right]\left[\theta_{-i}\frac{D''_{-i}(E)}{B''_{-i}(.)}\frac{B''_i(.)+B''_{-i}(.)}{B''_i(.)} - \frac{B''_{-i}(.)}{B''_i(.)+B''_{-i}(.)}\right]}{2 - \theta_{-i}\frac{D''_{-i}(E)}{B''_{-i}(.)}\frac{B''_i(.)+B''_{-i}(.)}{B''_i(.)} + \frac{B''_{-i}(.)}{B''_i(.)+B''_{-i}(.)}} \ , \tag{A.23}$$

Since D''_i and B''_i are (almost) constant by virtue of Assumptions 1 and 2, the derivatives of $\theta_i^I(\theta_{-i})$ with respect to D''_i and B''_i are well defined, and we obtain:

$$\frac{d\theta_i^I(\theta_{-i})}{dD''_i} > 0 \ , \qquad \frac{d\theta_i^I(\theta_{-i})}{dB''_i} < 0 \ . \tag{A.24}$$

□

Proof of Proposition 5

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

$$\theta_i^D(\theta_{-i}) = \theta_i^M + \frac{D''_{-i}(E)\theta_{-i}}{B''_{-i}(\omega_{-i}) - D''_{-i}(E)\theta_{-i}} \ , \tag{A.25}$$

where we made use of (9).

Applying the definitions introduced in the proof of Proposition 4 to equations (A.13b) and (A.25), we obtain:

$$\theta_i^D(\theta_{-i}) = 1 - \frac{\gamma_{-i}\theta_{-i}}{1+\gamma_{-i}\theta_{-i}} \ , \tag{A.26a}$$

$$\theta_i^I(\theta_{-i}) = 1 - \frac{(1+\alpha\theta_{-i})\left[\gamma_{-i}\theta_{-i} + \beta(1-\beta)\right]}{2(1-\beta) + \left[\gamma_{-i}\theta_{-i} + \beta(1-\beta)\right]} \ . \tag{A.26b}$$

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:

$$\begin{aligned}\text{LHS}(\theta_{-i}) \equiv &(1+\alpha\gamma_{-i})\left[\gamma_{-i}\theta_{-i} + \beta(1-\beta)\right] \\ &> \gamma_{-i}\theta_{-i}\left[(2-\alpha\beta\theta_{-i})(1-\beta) - \alpha\gamma_{-i}\theta_{-i}^2\right] \equiv \text{RHS}(\theta_{-i}) \ .\end{aligned} \tag{A.27}$$

It is straightforward to show that

$$\frac{d\text{LHS}(\theta_{-i})}{d\theta_{-i}} > 0 \ , \qquad \frac{d\text{RHS}(\theta_{-i})}{d\theta_{-i}} \gtreqless 0 \ , \tag{A.28}$$

$$\frac{d^2\text{LHS}(\theta_{-i})}{d\theta_{-i}^2} > 0 \ , \qquad \frac{d^2\text{RHS}(\theta_{-i})}{d\theta_{-i}^2} < 0 \ . \tag{A.29}$$

LHS is a convex function and RHS a concave function in θ_{-i}. Because LHS(0) $= \beta(1-\beta) > 0 =$ 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:

$$\frac{d\text{LHS}(0)}{d\theta_{-i}} > \frac{d\text{RHS}(0)}{d\theta_{-i}} - \beta(1-\beta) \ . \tag{A.30}$$

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:

$$B_i(e_i) = \frac{1}{\phi_i} e_i \left(1 - \frac{1}{2} e_i\right) \ , \quad B_i'(e_i) = \frac{1-e_i}{\phi_i} \ , \quad B_i''(e_i) = -\frac{1}{\phi_i} \ , \tag{A.31a}$$

$$D_i(E) = \frac{\epsilon_i}{2} E^2 \ , \quad D_i'(E) = \epsilon_i E \ , \quad D_i''(E) = \epsilon_i \ . \tag{A.31b}$$

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

$$\phi_1 = 1 \ , \qquad \phi_2 = 0.2 \ , \qquad \epsilon_1 = 1 \ , \qquad \epsilon_2 = 1 \ . \tag{A.32}$$

This yields the following equilibrium delegation choices:

$$\theta_1^D = 0.90 \ , \qquad \theta_2^D = 0.52 \ , \qquad \theta_1^I = 0.10 \ , \qquad \theta_2^I = 0.86 \ , \tag{A.33}$$

as illustrated in Figure 1.

For the numerical exercise in **Section 5** we parameterize functions (A.31) using relative energy productivities from the OECD Green Growth Indicators database[17] 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),

[17] DOI:10.1787/9789264202030-en

Western Europe has an approximately six times higher WTP to avoid climate damages than does China. As a consequence, we set the exogenous parameters to:

$$\phi_1 = 1 \ , \qquad \phi_2 = 0.5 \ , \qquad \epsilon_1 = 0.03 \ , \qquad \epsilon_2 = 0.2 \ . \tag{A.34}$$

Sensitivity analyses: We first keep the WTPs constant but vary the energy productivities, and then do the opposite. Consider first 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.

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 $\phi_1 = 2/3$.

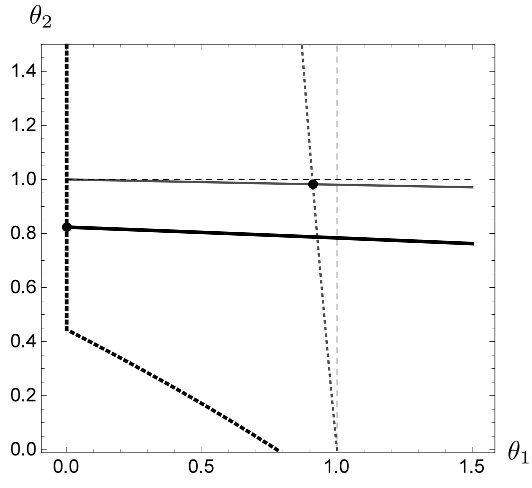

Figure 4: Reaction functions of the principals in country 1 (China, dotted) and country 2 (EU, solid line) under the regimes $R = D$ (grey and thin) and $R = I$ (black and fat) on the delegation stage (for $\phi_1 = 2/3$).

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 numerical results are summarized in Table 3.

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	0.76	0.84			1.60	0.09	0.46240
$R = I$	1	1	0.78	0.80	0.72	0.86	1.58	0.10	0.46241

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	0.88	0.78	0.86			1.63	0.08	0.45
$R = I$	0.37	0.78	0.95	0.78	0.82	0.91	1.73	0.06	0.37

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

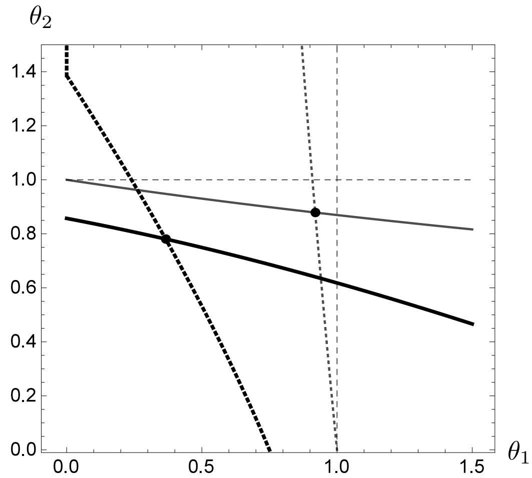

Figure 5: Reaction functions of the principals in country 1 (China, dotted) and country 2 (EU, solid line) under the regimes $R = D$ (grey and thin) and $R = I$ (black and fat) on the delegation stage (for $\epsilon_1 = 0.15$).

References

Beccherle, J. and J. Tirole (2011). Regional initiatives and the cost of delaying binding climate change agreements. *Journal of Public Economics 95*, 1339–1348.

Buchholz, W. and C. Haslbeck (1997). Strategic manipulation of property rights in Coasean bargaining. *Journal of Institutional and Theoretical Economics 153*, 630–640.

Buchholz, W., A. Haupt, and W. Peters (2005). International environmental agreements and strategic voting. *Scandinavian Journal of Economics 107*, 175–195.

Buchholz, W. and K. A. Konrad (1994). Global environmental problems and the strategic choice of technology. *Journal of Economics 60*, 299–321.

Burtraw, D. (1992). Strategic delegation in bargaining. *Economics Letters 38*, 181–185.

Carbone, J. C., C. Helm, and T. F. Rutherford (2009). The case for international emission trade in the absence of cooperative climate policy. *Journal of Environmental Economics and Management 58*, 266–280.

Christiansen, N. (2013). Strategic delegation in a legislative bargaining model with pork and public goods. *Journal of Public Economics 97*, 217–229.

Copeland, B. R. (1990). Strategic enhancement and destruction of fisheries and the environment in the presence of international externalities. *Journal of Environmental Economics and Management 19*, 212–226.

Copeland, B. R. and M. S. Taylor (2005). Free trade and global warming: A trade theory view of the Kyoto protocol. *Journal of Environmental Economics and Management 49*(2), 205–234.

Financial Times (2014, September). European energy nominee sells oil holdings to appease MEPs. http://www.ft.com/intl/cms/s/0/33201298-3d9d-11e4-8797-00144feabdc0.html. Online; accessed: 2016-21-03.

Flachsland, C., R. Marschinski, and O. Edenhofer (2009). To link or not to link: Benefits and disadvantages of linking cap-and-trade systems. *Climate Policy 9*, 358–372.

Green, J. F., T. Sterner, and G. Wagner (2014). A balance of bottom-up and top-down in linking climate policies. *Nature Climate Change 4*, 1064–1067.

Habla, W. and R. Winkler (2013). Political influence on non-cooperative international climate policy. *Journal of Environmental Economics and Management 66*, 219–234.

Harstad, B. (2010). Strategic delegation and voting rules. *Journal of Public Economics 94*, 102–113.

Hattori, K. (2010). Strategic voting for noncooperative environmental policies in open economies. *Environmental and Resource Economics 46*, 459–474.

Helm, C. (2003). International emissions trading with endogenous allowance choices. *Journal of Public Economics 87*, 2737–2747.

Helm, C. and S. Pichler (2015). Climate policy with technology transfers and permit trading. *Environmental and Resource Economics 60*, 37–54.

Holtsmark, B. and D. E. Sommervoll (2012). International emissions trading: Good or bad? *Economics Letters 117*(1), 362 – 364.

Jaffe, J., M. Ranson, and R. N. Stavins (2009). Linking tradable permit systems: A key element of emerging international climate policy architecture. *Ecology Law Quarterly 36*, 789–808.

Jones, S. R. G. (1989). Have your lawyer call my lawyer: Bilateral delegation in bargaining situations.

Journal of Economic Behavior & Organization 11, 159–174.

Kempf, H. and S. Rossignol (2013). National politics and international agreements. *Journal of Public Economics 100*, 93–105.

Klepper, G. and S. Peterson (2006). Marginal abatement cost curves in general equilibrium: The influence of world energy prices. *Resource and Energy Economics 28*, 1–23.

Montgomery, W. D. (1972). Markets in licenses and efficient pollution control programs. *Journal of Economic Theory 5*(3), 395–418.

Perino, G. (2010). How delegation improves commitment. *Economics Letters 106*, 137–139.

Persson, T. and G. Tabellini (1992). The politics of 1992: Fiscal policy and European integration. *The Review of Economic Studies 59*, 689–701.

Roelfsema, H. (2007). Strategic delegation of environmental policy making. *Journal of Environmental Economics and Management 53*, 270–275.

Segendorff, B. (1998). Delegation and threat in bargaining. *Games and Economic Behavior 23*, 266–283.

Siqueira, K. (2003). International externalities, strategic interaction, and domestic politics. *Journal of Environmental Economics and Management 45*, 674–691.

Strøm, K. (2000). Delegation and accountability in parliamentary democracies. *European Journal of Political Research 37*, 261–290.

Tol, R. S. J. (2002). New estimates of the damage costs of climate change, part II: Dynamic estimates. *Environmental and Resource Economics 21*, 135–60.