Strategic Delegation and Centralised Climate Policy *

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Abstract: We analyze a typical principal-agent relationship within the context of international environmental agreements. First, the principals delegate the authority to negotiate an agreement to an agent each who acts on their behalf. Second, the appointed agents bargain over the total level of emissions (and possibly the allocation of permits). In the last stage, emission permits are traded. Solving by backwards induction and using the Nash-Bargaining Solution, we find that despite the strategic considerations in the choice of the delegates, emissions are lower in the cooperative scenario in comparison to non-cooperative domestic markets. We also explore under which circumstances a principal benefits from cooperation (and delegation) or is harmed by it.

Keywords: 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

In this paper, we ask whether and under which circumstances countries which are represented by their principal, have an incentive to form an international environmental agreement, specifically an international permit market. We assume that under such an agreement, agents selected by the respective principal in each country negotiate over the total level emissions and possibly over the allocation of permits. As the delegates that are sent to the negotiations are chosen independently by each country, we conjecture that the centralised solution may not necessarily fare better than decentralised solutions to the problem of global climate change. The reason is that, governments might have an incentive to send delegates to the negotiation table that have different preferences than their own. Therefore, even if global emissions are lower in the cooperative scenario, welfare might be lower in comparison to non-cooperative domestic markets as a result of the strategic considerations in the choice of the delegates. Here, it should be emphasised that centralised policies are not first-best from the principals' point of view - they are only first-best from their selected agents' point of view.

Formally, we model the hierarchical structure of climate policy in the following way. In the first stage, the principals simultaneously select an agent each from the continuum of available agents who will then, in the second stage, negotiate on the total number of emission allowances and their distribution. If they fail to agree, they will set up domestic permit markets.[1] In the final stage, emission permits are traded. We solve the game by backward induction. We first determine the equilibrium levels of emission permits in the bargaining default and under cooperation as functions of the preferences of the selected agents in both countries. Second, we determine the preferences of the agents whom the principals select. Finally, we compare whether principals benefit from cooperation (and delegation) or whether they are indeed better off if they chose policies in a purely non-cooperative fashion. We also examine whether negotiations over non-tradable emissions caps would result in higher or lower global emissions and individual welfare.

Our paper contributes to several strands of literature. In assuming that countries are represented by one welfare-maximizing decision maker (the government), 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 that serves as the principal and a selected executive or government agency that serves as an agent. In this regard, we heavily draw on the strategic delegation literature.

[1] This type of delegation corresponds to "strong delegation" (Segendorff, 1998) as compared to "weak delegation" where the principals decide themselves once negotiations have failed.

The first papers on strategic delegation can be found in the Industrial Organization literature analyzing the delegation of managerial decisions from shareholders to chief executive officers. Vickers (1985), Fershtman and Judd (1987) and Sklivas (1987) consider a managerial compensation scheme that is based not only on profits but also on sales respectively revenues. They show that in a duopoly or oligopoly with quantity-setting firms, the profits of the owner who designs such a contract exceed those of her rivals who just prescribe their managers to maximize profits, because the additional incentive device is common knowledge (or can be inferred in repeated games) and thus serves as a credible commitment to a particular strategy. This reasoning does not only apply to markets in which the performance of each firm depends on the choices of all firms (for an excellent survey in this context see Kopel and Pezzino, forthcoming). It is relevant for *all* environments of strategic interdependence in which one player's payoff depends on the decisions of other players. It comes as no surprise that the concept of strategic delegation subsequently found its way into the literature on negotiation and cooperation (Crawford and Varian 1979; Sobel 1981; Jones 1989; Burtraw 1992, 1993; Segendorff 1998) where it has been utilized in various contexts with inter-agent spillovers, such as environmental policy or the provision of public goods more generally. In contrast to the early IO papers, the principal in these papers does not misrepresent her own preferences by incentivizing the agent with an additional instrument. Instead, she is able to raise her payoff by delegating the task at hand to an agent with preferences different from her own. It is also worth mentioning that the literature on strategic delegation sometimes goes under the name "strategic voting" (Persson and Tabellini 1992). In the latter case, we can interpret the electorate or, to be precise, the median voter as the principal and the elected government as the agent.

Siqueira (2003), Buchholz et al. (2005), Roelfsema (2007) and Hattori (2010) analyze strategic voting in the context of environmental policy. While the first three contributions exclusively focus on environmental taxation, Hattori (2010) also examines the outcome of strategic voting under emissions caps. Siqueira (2003) and Buchholz et al. (2005) both find that voters' selection of agents is 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. [2] Our work is closely related to Habla and Winkler(2017) however they only consider non-cooperative policies. In contrast, we study the case where total emissions and country specific permits are decided on a centralised level, employing a Nash Bargaining solution. Therefore, we explore whether the prospect of cooperation makes linking to an international permits market more plausible. In the context of cooperative policies, Loeper (2017) analyzes the provision of public goods with cross-border externalities by representative democracies. They find once voters' incentives are taken into account, whether cooperation is beneficial depends neither on voters' preferences, nor on the magnitude of spillovers, nor on the size, bargaining power, or efficiency of each country. Instead, it depends only on the curvature of the demand for the public good: cooperation increases (decreases) public good provision when the demand function is more (less) convex than the unit elastic demand function. Hence, the desirability of international cooperation depends mostly on the type of public good considered. Instead, we find that whether a principal benefits or not from cooperation depends on the characteristics of the counties participating and in particular on the marginal abatement and marginal cost parameters. However, we do find that a allowing for transfers across countries can make cooperation detrimental, a finding similar to Loeper (2017).

Our paper adds to this literature in various ways. We model damages as linear and benefits from emissions as concave. In Buchholz et al., damages are convex while benefits are linear. Moreover, our analysis allows for asymmetric countries. In fact, an international permit market only makes sense when countries are not symmetric and can exploit efficiency gains from trading permits. Finally, the public good will never be provided by a single country when transfers are allowed.

The broader 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 that have been identified are different levels of ambition, competing domestic policy objectives, objections to financial transfers and the difficulty of regulatory coordination (Green et al. 2014). We contribute to this literature by suggesting that the

[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 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.

hierarchical structures underlying environmental policy may well 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) and Marchiori et al. (2017), in which the influence of legislative lobbying on the formation of international permit markets and international environmental agreements, respectively, is analysed.

2 The model

We consider two countries, indexed by $i = 1, 2$ and $-i = \{1, 2\} \setminus i$.[3] In each country i, emissions e_i imply strictly increasing and concave country-specific benefits from the productive activities of a representative firm, $B(e_i)$, while global emissions $E = e_1 + e_2$ cause strictly increasing country-specific damages, $D_i(E)$. Specifically, we assume the following functional forms for benefits and damages:

$$B_i(e_i) = \frac{1}{\phi_i} e_i(\epsilon_i - \frac{1}{2} e_i) \ , \quad B_i'(e_i) = \frac{\epsilon_i - e_i}{\phi_i} \ , \quad B_i''(e_i) = -\frac{1}{\phi_i} \ , \tag{1}$$

$$D_i(E) = \delta_i E \ , \quad D_i'(E) = \delta_i \ , \quad D_i''(E) = 0 \ , \tag{2}$$

where $\epsilon_i, \delta_i, \phi_i > 0$, and $\epsilon_i \geq e_i$ denotes business-as-usual emissions in the absence of any climate policy. We will employ the following substitutions: $\epsilon \equiv \epsilon_i + \epsilon_{-i}$ and $\phi \equiv \phi_i + \phi_{-i}$. We only resort to these functional forms where necessary and keep to the more general notation elsewhere.

The above assumptions allow, by and large, for analytical tractability and highlight the mechanism underlying our results. Moreover, they are not unrealistic. Klepper and Peterson (2006) show that abatement cost curves (which, in our model, correspond to the benefits of unabated emissions) can well be approximated by quadratic functions. The linear damage specification is in line with the results of complex integrated assessment or general equilibrium climate-economy models (see, e.g., Nordhaus and Boyer 2000, Golosov et al. 2014) in which climate damage is approximately linear in the greenhouse gas concentration in the atmosphere. This is because, typically, temperature is assumed to increase logarithmically with concentrations, whereas damage is assumed to be exponential or polynomial in temperature. The recent empirical literature (Burke et al., 2015, Hsiang et al., 2017) also finds that damages are convex respectively quadratic in *temperature*. Finally, a convex damage function would be an additional source of strategic interaction among principals (and agents), which would obfuscate our results.

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

2.1 International climate policy

We assume that both countries have agreed to negotiate an international climate agreement, specifically, an international permit market. To this end, they each appoint an agent of their choice, and these agents bargain over the total number of emission permits and their distribution across countries. Their outside option in the negotiations are national permit markets (which are equivalent to introducing domestic emissions taxes). The number of permits issued to the representative domestic firm in country i amounts to ω_i. 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, $E = \omega_i + \omega_{-i}$.

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:

$$\pi_i(e_i) = B_i(e_i) + p(\omega_i - e_i) \ , \qquad i = 1, 2 \ , \tag{3}$$

where p is the price of permits on an international market. If negotiations fail (which they never will), domestic permit markets are established and $\omega_i = e_i$ holds in equilibrium, implying that the second term in the above equation vanishes.

2.2 Agency Structure

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

$$V_i = \pi_i(e_i) - \theta_i^P D_i(E) \ . \tag{4}$$

Without loss of generality, we normalize θ_i^P to unity. In addition, there is a continuum of agents of mass one in each country i, whose utility is given by:

$$W_i = \pi_i(e_i) - \theta_i D_i(E) \ , \tag{5}$$

where θ_i is a preference parameter that is continuously distributed on the bounded interval $[\theta_i^{\min}, \theta_i^{\max}]$. To ensure that, in both countries, the principal's preferences are represented in the continuum of agents, we impose $\theta_i^{\max} > 1$, and we also assume that $\theta_i^{\min}$ can be negative such that damages are actually perceived as benefits by an agent of that type.

In each country, all agents and the principal thus have equal stakes in the profits of the domestic firm but differ with respect to how much they suffer (or even benefit) from 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 an agent in country i makes decisions to maximize *his* utility W_i.

We assume that preference parameters of all individuals are common knowledge. Thus, we abstract from all issues related to asymmetric information.[4]

2.3 Structure and timing of the game

We model the hierarchical structure of climate policy in the following way. In the first stage, the principals simultaneously select an agent each from the continuum of available agents who will then, in the second stage, negotiate on the total number of emission allowances and their distribution. If they fail to agree, they will set up domestic permit markets.[5] In the final stage, emission permits are traded. The complete structure and timing of the game are summarized as follows:

1. Delegation stage:
   Principals in both countries simultaneously select an agent.
2. Policy-making stage:
   Selected agents in both countries choose the total number of permits and the number of emission permits issued to the domestic firms through Nash bargaining. If negotiations fail (which they never will), the agents act non-cooperatively in determining permit issuance in their countries, on their domestic permit markets.
3. Permit trading stage:
   Depending on the established regime, emission permits are traded on perfectly competitive domestic markets *or* an international permit market.

Despite being highly stylised, this model captures essential characteristics of the hierarchical structure of domestic and international environmental policy as it 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

[4] 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, high-level political delegates have, in general, well-known political agendas, and therefore, this assumption seems to be a good description of reality.

[5] This type of delegation corresponds to "strong delegation" (Segendorff, 1998) as compared to "weak delegation" where the principals decide themselves once negotiations have failed.

government. Alternatively, the principal might be the parliament that delegates a decision to an agent, for example, to the minister of the environment.

We solve the game by backward induction. We first determine the equilibrium levels of emission permits in the bargaining default and under cooperation as functions of the preferences of the selected agents in both countries. Second, we determine the preferences of the agents whom the principals select. Finally, we compare whether principals benefit from cooperation (and delegation) or whether they are indeed better off if they chose policies in a purely non-cooperative fashion. We also examine whether negotiations over non-tradable emissions caps would result in higher or lower global emissions and individual welfare.

3 Permit market equilibrium

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:

$$p_i(\omega_i) = B_i'(e_i) = \frac{\epsilon_i - \omega_i}{\phi_i} \ , \quad i = 1, 2 \ . \tag{6}$$

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

$$p(E) = B_i'(e_i(E)) = B_{-i}'(e_{-i}(E)) = \frac{\epsilon_i - e_i(E)}{\phi_i} \ . \tag{7}$$

In addition, the market clearing condition:

$$\omega_i + \omega_{-i} = B_i'^{-1}(p(E)) + B_{-i}'^{-1}(p(E)) = e_i(E) + e_{-i}(E) = E \ , \tag{8}$$

implicitly determines the permit price $p(E)$ in the market equilibrium as a function of the total number of issued emission allowances E.

$$p(E) = \frac{\epsilon - E}{\phi} \ . \tag{9}$$

Existence and uniqueness follow directly from the assumed properties of the benefit functions B_i. Equation (7) and $e_i(E) = B_i'^{-1}(p(E))$ imply:

$$p'(E) = p' = \frac{B_i'' B_{-i}''}{B_i'' + B_{-i}''} = -\frac{1}{\phi} < 0 \ , \quad e_i'(E) = e_i' = \frac{B_{-i}''}{B_i'' + B_{-i}''} = \frac{\phi_i}{\phi} \in (0, 1) \ . \tag{10}$$

Naturally, the permit price goes down as global supply of permits increases, and this increase is absorbed by all countries (to different extents).

4 Delegated permit choice under the bargaining default

Before we can characterize the bargaining solution, we need to examine the permit choices that the selected agents will make if the negotiations break down, in which case domestic permit markets will be established.

The appointed agent of country i sets the level of emission permits ω_i to maximize:[6]

$$W_i^D = B_i(\omega_i) - \theta_i D_i(E) \ , \tag{11}$$

subject to equation (6) and given the permit choice ω_{-i} of the other country's agent. The reaction function of the selected agent i is then implicitly given by:

$$B_i'(\omega_i) - \theta_i D_i'(E) = 0 \ , \tag{12}$$

implying that the delegate 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 two in the bargaining default)
For any given vector $\Theta = (\theta_i, \theta_{-i})$ of preferences of the selected agents in the bargaining default, there exists a unique Nash equilibrium, in which both selected agents simultaneously set the levels of emission permits ω_i to maximize (11) *subject to equation* (6) *and taking the permit level ω_{-i} of the other country as given.*

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

Permit choices are dominant strategies due to the assumed linearity of the damage function. We denote the total emissions level in this Nash equilibrium by $E^D(\Theta)$ and the Nash equilibrium permit choices in the bargaining default of stage two by $\Omega^D(\Theta) = \big(\omega_i^D(\theta_i), \omega_{-i}^D(\theta_{-i})\big)$. Given our assumption about the functional forms we find:

$$\omega_i^D(\theta_i) = e_i^D(\theta_i) = \epsilon_i - \theta_i\delta_i\phi_i \ , \quad E^D(\Theta) = \epsilon - \theta_i\delta_i\phi_i - \theta_{-i}\delta_{-i}\phi_{-i} \ , \tag{13}$$

$$W_i^D(\Theta) = \frac{\epsilon_i^2}{2\phi_i} - \theta_i\delta_i\epsilon + \theta_i\delta_i(\frac{1}{2}\theta_i\delta_i\phi_i + \theta_{-i}\delta_{-i}\phi_{-i}) \ . \tag{14}$$

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

It is easy to see that the appointment of a marginally less green agent (θ_i marginally lower) increases permit issuance and thus emissions in country i but does not affect permit issuance in the other country. As a result, total emissions go up.

For the further analysis, we differentiate both agents' welfare with respect to θ_i:

$$\frac{dW_i^D(\Theta)}{d\theta_i} = -\delta_i(\epsilon - \theta_i\delta_i\phi_i - \theta_{-i}\delta_{-i}\phi_{-i}) < 0 \ , \tag{15}$$

$$\frac{dW_{-i}^D(\Theta)}{d\theta_i} = \theta_{-i}\delta_{-i}\delta_i\phi_i > 0 \ . \tag{16}$$

The appointment of a marginally less green agent in country i increases the welfare of agent i, simply because he suffers less from climate damages (despite of increased global emissions), and decreases the other agent's welfare due to higher global emissions. The principal in country i can improve her agent's bargaining position and worsen the other agent's bargaining position by choosing an agent with less green preferences, i.e., an agent with a lower θ_i.

5 Delegated permit choice in the negotiations

In the following, we analyze the outcome when the agents cooperate, i.e., when they sign an international agreement. We capture the international agreement through the Nash Bargaining Solution (NBS) with equal bargaining weights.[7] The delegated agents are assumed to bargain over the total level of emissions E and over the country-specific permit endowments. We denote the share of total permits allocated to countries i and $-i$ with λ and $(1-\lambda)$, respectively. Effectively, we analyze the case of an international agreement with transfers here, since one country will always be the buyer of permits while the other country will be the seller (unless they are perfectly symmetric). In Section 8, we examine the outcome when no transfers between countries are possible, i.e., no international market is established.

The NBS is given by the levels of E and λ that solve

$$\max_{E,\lambda} \quad \left[W_i^C - W_i^D(\Omega^D(\Theta))\right] \times \left[W_{-i}^C - W_{-i}^D(\Omega^D(\Theta))\right] \ , \tag{17}$$

where superscript C stands for "cooperation" and (W_i^D, W_{-i}^D) denotes agents' welfare in the threat point. Furthermore, let an agent's welfare gain in the cooperative scenario compared

[7] We focus on equal bargaining weights for two reasons. First, it is hard to determine in reality whose countries' weight in the negotiations is higher. Second, we want to focus on how other asymmetries between countries, i.e., differences with respect to marginal damages and marginal emission benefits, impact on emissions and welfare levels. If countries have unequal bargaining weights, this will change the results in a straightforward way.

to the default be $\Delta W_i \equiv W_i^C - W_i^D$.

The FOCs for the optimal E and λ yield (we show that the maximization problem is strictly concave in the Appendix) (MAYBE WRITE AS FUNCTIONS OF THETA?)

$$\Big[p'(E)(\lambda E - e_i(E)) + p(E)\lambda - \theta_i D_i'\Big]\Delta W_{-i} =$$
$$- \Big[p'(E)\Big((1-\lambda)E - e_{-i}(E)\Big) + p(E)(1-\lambda) - \theta_{-i}D_{-i}'\Big]\Delta W_i \ , \tag{18}$$
$$\Delta W_i = \Delta W_{-i} \ . \tag{19}$$

Substituting (18) into (19), we get the optimal level of λ:

$$\lambda = \frac{1}{2p(E)E}\Big(B_{-i}(e_{-i}(E)) - B_i(e_i(E)) + 2p(E)e_i(E) + \theta_i D_i(E) - \theta_{-i}D_{-i}(E) + W_i^D - W_{-i}^D\Big) \ , \tag{20}$$

and an implicit expression for the optimal level of aggregate emissions:

$$p(E) - \theta_i D_i' - \theta_{-i}D_{-i}' = 0 \ . \tag{21}$$

The optimal level of emissions, E^C, that the NBS dictates, is also the socially optimal level of emissions from the agents' point of view: it maximizes the aggregate sum of their welfare. Equation (21) equates the marginal benefit of emissions, which is the same for the two countries and equal to the permit price, with the sum of marginal damages from emissions, as perceived by the agents. On the other hand, equation (19) reveals that the country-specific permits are allocated so that the gains from bargaining (relative to the non-cooperative solution as chosen by the appointed agents) are split equally between the two countries. In other words, the NBS in our framework is rather simple: countries decide on the optimal level of emissions from an aggregate point of view and then split the bargaining gains equally by appropriately allocating the initial permit endowment across the two countries.

Moreover, we can see from equation (20) how the threat point affects the bargaining outcome: the higher is the welfare of country i's agent and the lower is the welfare of the other country's agent at the threat point, the more permits it is allocated in the NBS. In other words, the better-off an agent is in case the negotiations fail, the more he benefits if the negotiations are successful in terms of an increased transfer from the other country or a decreased transfer to the other country. Hence, there are strategic incentives for the principals to alter their agents' threat point and thereby improve their bargaining position but also to alter the threat point of the other country's agent. As we have seen in Section 4, the welfare of country i's agent is higher and the welfare of country $-i$'s agent is lower the lower is the agent's preference parameter θ_i. While this effect benefits country i's principal, it also raises aggregate emissions as determined by equation (21). Furthermore, a country's share of permits increases with the (agent's) damages under the negotiated treaty and decreases with the benefits from emissions. The principal thus faces several trade-offs when selecting an agent, which we will look at in the next section.

Given our assumptions about the functional forms, we can characterize the level of emissions, permits, the permit market price and welfare in the Nash equilibrium as follows:

$$\omega_i^C(\Theta) = \epsilon_i - \frac{1}{4(\theta_i\delta_i + \theta_{-i}\delta_{-i})}\Big((\theta_i\delta_i)^2(4\phi_i + 3\phi_{-i}) + (\theta_{-i}\delta_{-i})^2\phi_i + 8\theta_i\delta_i\theta_{-i}\delta_{-i}\phi_i\Big) \ , \tag{22a}$$

$$e_i^C(\Theta) = \epsilon_i - \phi_i(\theta_i\delta_i + \theta_{-i}\delta_{-i}) \ , \quad E^C(\Theta) = \epsilon - \phi(\theta_i\delta_i + \theta_{-i}\delta_{-i}) \ , \tag{22b}$$

$$p^C(\Theta) = \theta_i\delta_i + \theta_{-i}\delta_{-i} \ . \tag{22c}$$

Finally, it remains to specify which country is the permit seller and which the permit buyer under the international agreement, and how large the transfer is from one country to the other. Using equations (22), we find:

$$\omega_i^C(\Theta) - e_i^C(\Theta) = \frac{3}{4(\theta_i\delta_i + \theta_{-i}\delta{-i})}\Big((\theta_{-i}\delta_{-i})^2\phi_i - (\theta_i\delta_i)^2\phi_{-i}\Big) \ , \tag{23a}$$

$$p^C(\Theta)\Big[\omega_i^C(\Theta) - e_i^C(\Theta)\Big] = \frac{3}{4}\Big((\theta_{-i}\delta_{-i})^2\phi_i - (\theta_i\delta_i)^2\phi_{-i}\Big) \ . \tag{23b}$$

A country is thus more likely to sell permits and receive a transfer amounting to equation (23b) if its marginal benefits fall by little, i.e., if its marginal abatement costs are low, and if its agent's marginal damages are low. The following corollary summarizes the impacts of a marginal change in θ_i on the levels of permits and emissions, the permit price and the transfer in equilibrium.

Corollary 1 (Stage two comparative statics)
The following conditions hold for the levels of emission allowances ω_i^C, ω_{-i}^C, emissions e_i^C, e_{-i}^C, total emissions E^C, the equilibrium permit market price and the transfer in the NBS $\Omega^C(\Theta) = (\omega_1^C(\Theta), \omega_2^C(\Theta))$:

$$\frac{d\omega_i^C(\Theta)}{d\theta_i} < 0 \ , \quad \frac{d\omega_{-i}^C(\Theta)}{d\theta_i} \gtreqless 0 \ , \tag{24a}$$

$$\frac{de_i^C(\Theta)}{d\theta_i} < 0 \ , \quad \frac{de_{-i}^C(\Theta)}{d\theta_i} < 0 \ , \quad \frac{dE^C(\Theta)}{d\theta_i} < 0 \ , \tag{24b}$$

$$\frac{d\Big[\omega_i^C(\Theta) - e_i^C(\Theta)\Big]}{d\theta_i} < 0 \ , \quad \frac{dp^C(\Theta)}{d\theta_i} > 0 \ , \quad \frac{dp^C(\Theta)\Big[\omega_i^C(\Theta) - e_i^C(\Theta)\Big]}{d\theta_i} < 0 \ . \tag{24c}$$

As expected, total emissions as well as country-specific emissions increase when the selected agent in a country becomes less green, i.e., when θ_i becomes smaller. The number of emission permits in country i increases by even more than emissions so that the country is more likely to be the permit seller (and thus less likely to be the permit buyer). While the price for permits falls, the direct effect outweighs the indirect effect, and country i thus receives a higher transfer or needs to pay a lower transfer to country $-i$.

6 Strategic delegation

We now turn to the selection of agents by the principals in the first 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 $\theta_i \in [\theta_i^{\min}, \theta_i^{\max}]$.

The principal in country i selects an agent with preference parameter θ_i to maximize

$$V_i^C(\Theta) = B_i(e_i^C(\Theta)) + p(E^C(\Theta)) \left[\omega_i^C(\Theta) - e_i(E^C(\Theta))\right] - D_i(E^C(\Theta)) \ , \tag{25}$$

given the Nash bargaining outcome $\Omega^C(\Theta)$ in the second stage and the preference parameter θ_{-i} of the selected agent in the other country. The first-order condition yields:

$$p(E^C(\Theta))\frac{d\omega_i^C(\Theta)}{d\theta_i} + p'\frac{dE^C(\Theta)}{d\theta_i}\left[\omega_i^C(\Theta) - e_i^C(E^C(\Theta))\right] - D_i'\frac{dE^C(\Theta)}{d\theta_i} = 0 \ . \tag{26}$$

Taking into account equation (21) in the second stage, the first-order condition becomes

$$(1-\theta_i)D_i'\frac{dE^C(\Theta)}{d\theta_i} = \theta_{-i}D_{-i}'\frac{d\omega_i^C(\Theta)}{d\theta_i} - \theta_i D_i'\frac{d\omega_{-i}^C(\Theta)}{d\theta_i} + p'\frac{dE^C(\Theta)}{d\theta_i}\left[\omega_i^C(\Theta) - e_i^C(E^C(\Theta))\right] \ , \tag{27}$$

and implicitly determines the reaction function of country i, $\theta_i^C(\theta_{-i})$:

$$\theta_i^C(\theta_{-i}) = \frac{2\phi}{2\phi + \phi_{-i}} - \frac{2\delta_{-i}\phi_i}{\delta_i(2\phi + \phi_{-i})}\theta_{-i} \ . \tag{28}$$

The reaction function is downward-sloping, which implies that the choices of agents' preference parameters are strategic substitutes. It follows directly from this equation that $\theta_i^C < 1$, i.e., principal i will choose an agent with lower environmental preferences than her own for any given θ_{-i}, and thus also in equilibrium.

In equilibrium, it holds:

$$\theta_i^C = \frac{2\phi(2\phi + \phi_i(1 - 2\frac{\delta_{-i}}{\delta_i}))}{(2\phi + \phi_i)(2\phi + \phi_{-i}) - 4\phi_i\phi_{-i}} = \frac{2}{3}\phi\frac{2\phi + \phi_i(1 - 2\frac{\delta_{-i}}{\delta_i})}{2\phi_i^2 + 2\phi_{-i}^2 + 3\phi_i\phi_{-i}} \; . \tag{29}$$

It is easy to show that $\theta_i^C > 0$ if $\delta_i/\delta_{-i} > 2/3$; and if δ_i is sufficiently small compared to δ_{-i}, then θ_i^C becomes negative:

$$\theta_i^C \gtreqless 0 \Leftrightarrow \frac{\delta_i}{\delta_{-i}} \gtreqless \frac{2}{3 + 2\frac{\phi_{-i}}{\phi_i}} \; . \tag{30}$$

Proposition 2 (Unique Nash equilibrium at stage one)
There exists a unique Nash equilibrium at stage one in which the principals in both countries simultaneously choose agents with environmental preferences lower than their own, i.e., $\theta_i^C < 1$.

This is not surprising given that θ_i and θ_{-i} are strategic substitutes. Our findings are in line with, e.g., Loeper (2017) who also finds that principals appoint agents who value the public good less than they do themselves. In contrast to Buchholz et al. (2005) who examine only the symmetric equilibrium, a unique Nash equilibrium exists, even in the case of purely symmetric countries.

For the further analysis, it is of particular interest how the equilibrium preference parameter θ_i^C changes with marginal changes in the exogenous parameters:

$$\frac{d\theta_i^C}{d\delta_i} = \frac{4\delta_{-i}\phi_i\phi}{3\delta_i^2(2\phi_i^2 + 2\phi_{-i}^2 + 3\phi_i\phi_{-i})} > 0 \; , \tag{31a}$$

$$\frac{d\theta_i^C}{d\phi_i} = -\frac{2\phi_{-i}\left[\phi_i^2(\delta_i + 2\delta_{-i}) + 4\phi_{-i}^2(\delta_{-i} - \delta_i) - 4\phi_i\phi_{-i}(\delta_i - 2\delta_{-i})\right]}{3\delta_i(2\phi_i^2 + 2\phi_{-i}^2 + 3\phi_i\phi_{-i})^2} \gtreqless 0 \; , \tag{31b}$$

$$\frac{d\theta_i^C}{d\delta_{-i}} = -\frac{4\phi_i\phi}{3\delta_i^2(2\phi_i^2 + 2\phi_{-i}^2 + 3\phi_i\phi_{-i})} < 0 \; , \tag{31c}$$

$$\frac{d\theta_i^C}{d\delta_{-i}} = \frac{2\phi_i\left[\phi_i^2(\delta_i + 2\delta_{-i}) + 4\phi_{-i}^2(\delta_{-i} - \delta_i) - 4\phi_i\phi_{-i}(\delta_i - 2\delta_{-i})\right]}{3\delta_i(2\phi_i^2 + 2\phi_{-i}^2 + 3\phi_i\phi_{-i})^2} \gtreqless 0 \; . \tag{31d}$$

When a country's marginal damages are marginally higher, then this country's principal will choose, in equilibrium, a delegate with greener environmental preferences. The same holds true if the other country's marginal damages are marginally lower. While the effect of an increased ϕ_i is ambiguous, we know for certain that when ϕ_i increases, i.e., i's marginal abatement costs are marginally lower, principal i will choose a delegate with less green preferences if her country is also the low-damage country, i.e., if $\delta_i \leq \delta_{-i}$. The reverse holds true when the other country's marginal abatement costs are marginally lower.

Finally, it remains to say that if principals were to negotiate the international agreement themselves, they would fully internalize all environmental externalities such that equation (21) would read:

$$p(E) - D_i' - D_{-i}' = 0 \ . \tag{32}$$

Clearly, global emissions would be lower under this scenario than under the regime with delegation. In other words, delegation erodes part of the gains from cooperation in terms of reducing emissions, and we will examine in the next section whether and when principals are indeed better off under cooperation and delegation, or whether they should better not participate in the international agreement and set policies non-cooperatively themselves.

7 When is cooperation beneficial – and for whom?

In a next step, we ask whether cooperation is beneficial in terms of global emissions and individual welfare. To this end, we define the benchmark against which the outcome under cooperation is assessed as the outcome of the Nash game if the principals set up domestic permit markets and decide on permit issuance themselves, without any cooperation. As we show in the Appendix, this outcome is equivalent to a regime in which the principals delegate to agents who choose policies non-cooperatively and establish domestic permit markets. The reason for this is that principals do not have an incentive to misrepresent their own preferences by selecting an agent with different preferences than their own because permit choices made by the agents in a non-cooperative framework are strategically neutral due to the linearity of the damage function (see also Habla and Winkler, 2017, for more on this issue).

7.1 Comparison of equilibrium emissions

First, we examine whether global emissions are higher in equilibrium under cooperation and delegation than if principals were to choose policies in a purely non-cooperative fashion, forming domestic permit markets. We can establish the following proposition.

Proposition 3 (Cooperation lowers aggregate emissions)
Cooperation in the presence of delegation yields strictly lower aggregate equilibrium emissions than policies set by the principals in a non-cooperative fashion, i.e., $E^C(\Theta^C) < E^D(\Theta^P)$*, where* $\Theta^P = (1,1)$ *are the principals' set of preference parameters.*

While we found earlier that the gains from cooperation in terms of lower aggregate emissions are partly eroded by the strategic delegation incentives of the principals, they are not fully eroded relative to the non-cooperative outcome when the principals choose policies non-cooperatively. For the environment, this is good news. This finding stands in stark contrast to the results of Buchholz et al. (2005) in which damages would soar to plus infinity in both the cooperative and the non-cooperative outcome when transboundary environmental spillovers from emissions across countries become perfect. However, their result is an artefact of the specification of costs and benefits. Buchholz et al. assume that the benefits of emissions are linear while the costs of emissions are convex, which results in a corner solution in either regime.

7.2 Comparison of equilibrium welfare

Despite the fact that global emissions are strictly lower under cooperation and delegation than when the principals choose policies themselves, it is not clear that also both principals are better off under this regime, due to the assumed asymmetries in marginal emission benefits and environmental damage costs. For example, it could be that the principal of the country which has very high marginal marginal abatement costs compared to the other country, is better off when climate policy is less ambitious even when she does not suffer much from environmental damage. While the gains from cooperation are shared equally between the appointed agents at stage two, this does not hold for the principals at stage one.

More formally, a principal benefits from cooperation (under delegation) if

$$\Delta V_i = V_i^C(\Theta^C) - V_i^D(\Theta^P) > 0 \ , \tag{33}$$

where $\Theta^P = (1,1)$ are the principals' preferences. Furthermore, an international permit market under cooperation and delegation is a Pareto improvement if it holds:

$$\Delta V_i > 0 \quad \wedge \quad \Delta V_{-i} > 0 \ . \tag{34}$$

In order to get an impression of when cooperation is still beneficial in the presence of delegation, we run some numerical simulations, in which we vary the exogenous parameters $\delta_i, \delta_{-i}, \phi_i, \phi_{-i}$. Note that the efficiency gains from trading are highest when we match a country with high marginal abatement costs (low ϕ_i) with a country that exhibits low marginal abatement costs (high ϕ_{-i}). Details on the numerical simulations can be found in the Appendix.

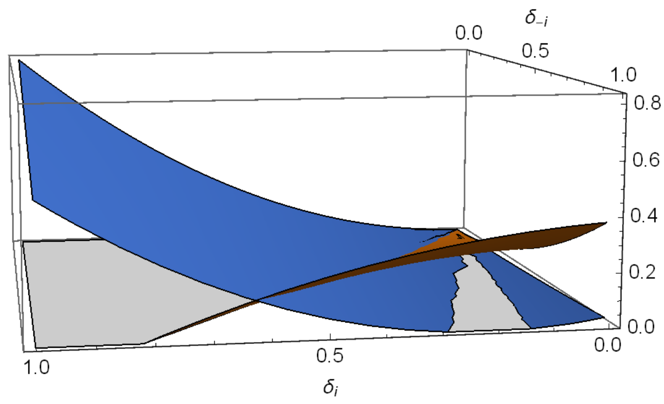

Figure 1: $\Delta V_i > 0$ (orange) and $\Delta V_{-i} > 0$ (blue)

First, we assume that country i has a higher carbon efficiency, i.e., higher marginal abatement costs (a lower ϕ_i). In Figure 1, principal i's and principal $-i$'s difference in payoffs is depicted for varying marginal damages δ_i and δ_{-i}, but only in the positive domain where it is beneficial for both principals to send delegates to the negotiations.

It is obvious from the figure that the lower the principal's marginal damages in either country, the more beneficial it is for that principal to cooperate through agents. The intuition behind this goes as follows. For example, the higher δ_i, the higher will be the appointed agent's preference parameter θ_i in equilibrium, i.e., the greener is the agent. However, as greener agents imply a more ambitious abatement target in the NBS, this becomes relatively expensive at some point. In particular, since country i has higher marginal abatement costs, cooperation through agents is relatively detrimental for principal i at higher levels of marginal damages δ_i. On the other hand, the country with the lower marginal abatement costs (here country $-i$) benefits on a larger domain from cooperation than country i. Cooperation is mutually beneficial when both principals have a positive payoff difference ΔV_i. This is the case when the principals exhibit low to intermediate marginal damages.

Second, we assume that both principals suffer from the same marginal environmental damages and that their countries only differ with respect to marginal abatement costs. Figure 2 illustrates this case.

As we have seen earlier (equation (31b)), lower marginal abatement costs, i.e., a higher ϕ_i, induce a principal to choose a delegate who is less green because this increases the likelihood of getting a transfer from the other country or lowers the transfer to the other country. As it turns out, it is more beneficial for principal i to have lower marginal abatement costs for given marginal abatement costs in the other country. When marginal abatement costs are higher, i.e., ϕ_i is lower, we know from equation (38b) that principal i will choose a delegate

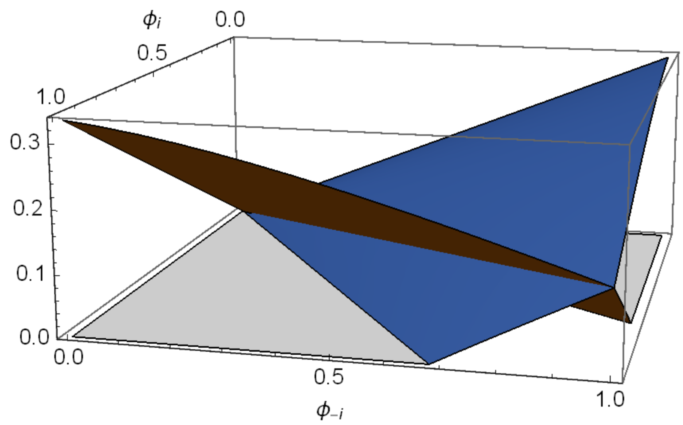

Figure 2: $\Delta V_i > 0$ (orange) and $\Delta V_{-i} > 0$ (blue)

who is greener (not than herself but greener than if marginal abatement costs were lower), and, again, at some point the more ambitious climate policy comes at such high cost that i does not benefit from cooperation in the presence of delegation anymore. Taken together, cooperation is mutually beneficial in this equal marginal damage scenario when marginal abatement costs are not too high and do not diverge too much.

Finally, we examine a scenario in which $-i$ is the high-damage, high-marginal abatement costs country or country block. We then vary ϵ_i and ϕ_i. In theory, if we match $-i$ with a low-damage, low-marginal abatement costs country or country block i, this constellation should be the most mutually beneficial one. It has been identified in the literature as the most promising one for the formation of a non-cooperative permit market, for which each country issues its own permits. One reason for this is that the gains from trading are highest when marginal abatement costs differ by a lot. Think, for example, of country block $-i$ as the EU and country block i as China. Figure 3 illustrates this scenario.

While such a scenario is indeed beneficial for principal i for almost all (δ_i, ϕ_i)-combinations, principal $-i$ only benefits from cooperation in the presence of delegation when country i has relatively high marginal abatement costs (and relatively high marginal damages). In other words, only if the two countries are very similar do both principals benefit from cooperation under delegation. Otherwise, the potential gains from cooperation are eroded on the side of the high-damage, high carbon efficiency country, particularly when i's marginal damages and marginal abatement costs are low, since principal i will then appoint an agent with relatively low (and possibly negative) θ_i. That increases emissions in equilibrium and thus harms the high-damage country most.

We have analyzed in this section under which circumstances a principal benefits from co-

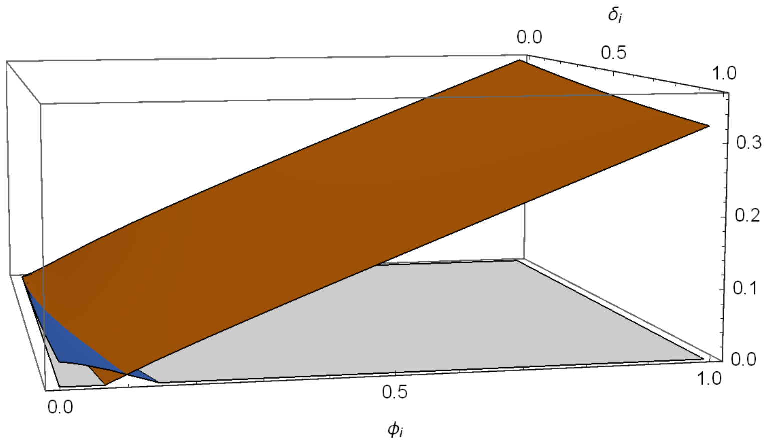

Figure 3: $\Delta V_i > 0$ (orange) and $\Delta V_{-i} > 0$ (blue)

operation (and delegation) or is harmed by it. This analysis can also be understood as an initial first stage in which principals decide whether to act non-cooperatively or let agents negotiate an international agreement.[8]

8 An international agreement without transfers

In this section, we explore the case when transfers are not feasible as part of an international agreement (maybe for political or other reasons). As the establishment of an international market implicitly leads to transfers between countries, we analyze here what non-tradable caps agents would negotiate in the absence of an international market. Put differently, only domestic permit markets are established, but the individual emission targets are subject to negotiations.

The NBS is given by the levels of ω_i and ω_{-i} (which correspond to e_i and e_{-i}) that solve the following program:

$$\max_{\omega_i, \omega_{-i}} \quad \left[W_i^{C,NT} - W_i^D(\Omega^D(\Theta))\right] \times \left[W_{-i}^{C,NT} - W_{-i}^D(\Omega^D(\Theta))\right] \ , \tag{35}$$

where NT stands for the regime without transfers and (W_i^D, W_{-i}^D) are the welfare levels under the same threat point as before.

[8] Alternatively, it is conceivable that there is a ratification stage at the end of the game in which the government, the national parliament or another institution have a say over whether the outcome of the negotiations is accepted or not. As shown by Graziosi (2009), adding such a stage would limit the extent of strategic delegation.

The FOCs for the optimal ω_i and ω_{-i} yield

$$\Big[B_i'(\omega_i) - \theta_i D_i'\Big]\Delta W_{-i} - \theta_{-i} D_{-i}' \Delta W_i = 0 \ , \tag{36}$$

$$\Big[B_{-i}'(\omega_{-i}) - \theta_{-i} D_{-i}'\Big]\Delta W_i - \theta_i D_i' \Delta W_{-i} = 0 \ . \tag{37}$$

It is evident from these equations that unlike for the international permit market, $\Delta W_i \neq \Delta W_{-i}$ because there is no mechanism or instrument through which gains from cooperation could be shared (equally).

Using our functional form assumptions, we arrive at the following results:

$$\omega_i^{C,NT}(\Theta) = \epsilon_i - \theta_i\delta_i\phi_i \left[1 + \Big(\frac{\theta_{-i}\delta_{-i}\phi_{-i}}{\theta_i\delta_i\phi_i}\Big)^{\frac{1}{3}}\right] \ , \tag{38a}$$

$$E^{C,NT}(\Theta) = \epsilon - \theta_i\delta_i\phi_i \left[1 + \Big(\frac{\theta_{-i}\delta_{-i}\phi_{-i}}{\theta_i\delta_i\phi_i}\Big)^{\frac{1}{3}}\right] - \theta_{-i}\delta_{-i}\phi_{-i} \left[1 + \Big(\frac{\theta_i\delta_i\phi_i}{\theta_{-i}\delta_{-i}\phi_{-i}}\Big)^{\frac{1}{3}}\right] \ . \tag{38b}$$

We are now ready to establish the following corollary.

Corollary 2 (Stage two comparative statics in the absence of transfers)
The following conditions hold for the levels of emission allowances $\omega_i^{C,NT}$, $\omega_{-i}^{C,NT}$ and total emissions $E^{C,NT}$ in the NBS without transfers, $\Omega^{C,NT}(\Theta) = \big(\omega_1^{C,NT}(\Theta), \omega_2^{C,NT}(\Theta)\big)$:

$$\frac{d\omega_i^{C,NT}(\Theta)}{d\theta_i} = -\delta_i\phi_i \left[1 + \frac{2}{3}\Big(\frac{\theta_{-i}\delta_{-i}\phi_{-i}}{\theta_i\delta_i\phi_i}\Big)^{\frac{1}{3}}\right] < 0 \ , \tag{39a}$$

$$\frac{d\omega_{-i}^{C,NT}(\Theta)}{d\theta_i} = -\frac{1}{3}\delta_i\phi_i\Big(\frac{\theta_{-i}\delta_{-i}\phi_{-i}}{\theta_i\delta_i\phi_i}\Big)^{\frac{2}{3}} < 0 \ , \tag{39b}$$

$$\frac{dE^{C,NT}(\Theta)}{d\theta_i} = -\delta_i\phi_i \left[1 + \frac{2}{3}\Big(\frac{\theta_{-i}\delta_{-i}\phi_{-i}}{\theta_i\delta_i\phi_i}\Big)^{\frac{1}{3}} + \frac{1}{3}\Big(\frac{\theta_{-i}\delta_{-i}\phi_{-i}}{\theta_i\delta_i\phi_i}\Big)^{\frac{2}{3}}\right] < 0 \ . \tag{39c}$$

As in the case with transfers, if principal i chooses a marginally less green agent for the negotiations, the number of permits allocated to that country and allocated to the other country increase, resulting in an increase in aggregate emissions.

As before, the principal in country i selects an agent with preference parameter θ_i to maximize

$$V_i^{C,NT}(\Theta) = B_i(\omega_i^{C,NT}(\Theta)) - D_i(E^{C,NT}(\Theta)) \ , \tag{40}$$

given the Nash bargaining outcome $\Omega^{C,NT}(\Theta)$ in the second stage and the preference parameter θ_{-i} of the selected agent in the other country. Compared to the case with transfers, the second term in equation (25) is missing.

The first-order condition yields:

$$B_i'(\omega_i^{C,NT}(\Theta))\frac{d\omega_i^{C,NT}(\Theta)}{d\theta_i} - D_i'\frac{dE^{C,NT}(\Theta)}{d\theta_i} = 0 \; . \tag{41}$$

Unfortunately, there is no algebraic solution to this system of two equations.

Before proceeding with some numerical illustrations, we compare the regime with transfers and the regime without transfers for perfectly symmetric countries. Although an international permit market only unfolds its advantages when countries are heterogeneous with respect to marginal abatement costs or marginal emission benefits, it is useful to compare both regimes in order to shed light on the effects of transfers on the delegation outcome.

For perfectly symmetric countries, we can characterize the Nash equilibrium in the absence of transfers on the delegation stage as follows:

$$\theta_i^{C,NT} = \frac{3}{5} \; . \tag{42}$$

By contrast, in the regime with transfers, we find from equation (29):

$$\theta_i^{C} = \frac{4}{7} < \frac{3}{5} \; . \tag{43}$$

Clearly, the strategic delegation incentives are stronger for perfectly symmetric countries when transfers between countries are possible. Transfers thus make things worse because they lead to higher global emissions and lower welfare of the principals compared to an IEA without transfers.

When countries are asymmetric with respect to marginal emission benefits and marginal damages, we have to rely on numerical illustrations. Assume first that countries are symmetric with respect to their marginal benefits but sufficiently asymmetric with respect to their marginal damage costs. Then the principal of the high-damage country delegates more strongly, i.e., chooses a delegate with lower preference parameter θ_i, in the regime where no transfers are possible, whereas the opposite holds true for the principal of the low-damage country. The reason for this is that the principal of the high-damage country counteracts the extreme delegation made by the other principal in the regime with transfers, while there is less need to do so when transfers are not part of the agreement. When the asymmetries are not severe, both principals delegate more strongly in the regime with transfers.

Similarly, when countries are symmetric with respect to marginal damages but sufficiently asymmetric with respect to marginal benefits, the principal in the country with the higher ϕ_i

delegates more strongly in the presence of a transfer, and the reverse holds for the principal with the lower ϕ_i. The intuition is that the country with the lower marginal abatement cost can obtain a larger transfer (or has to pay a lower transfer) when delegating to someone who is less green. To sum up, whenever asymmetries are sufficiently large, the strategic delegation incentives of the two principals under one regime are diametrically opposed.

9 Conclusion

This paper attempts to gain a better understanding of the complex relationship between national politics (in the form of voting or delegation) and the formation of international policies. It shows that principals will choose delegates that have lower preferences for the environment than they have themselves, both in the non-cooperative and the cooperative outcome. In addition, we conjecture that centralization of policies, particularly the formation of an international permit market for which the total number of permits is decided upon through Nash bargaining by selected agents, does not necessarily need to lower global emissions. In this regard, we caution against centralizing policies at all costs. Instead, the mechanisms behind centralization play a crucial role in whether the implemented policies will be beneficial or harmful to the environment.

Appendix

Proof of Proposition 1

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

$$\mathrm{SOC}_i^D \equiv B_i'' < 0 \ . \tag{A.1}$$

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 (12) for e_i and summing up over both countries yields the following equation for the aggregate emissions E:[9]

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

As the left-hand side is strictly increasing and the right-hand side is CONSTANT 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 $\left(\omega_1^D(\Theta), \omega_2^D(\Theta)\right)$. □

[9] 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.

Concavity of Nash Bargaining Solution

Proof of Corollary ??

In more detail, the equations read:

$$\frac{d\omega_i^C(\Theta)}{d\theta_i} = -\frac{\delta_i\left[((\theta_i\delta_i)^2 + 2\theta_i\delta_i\theta_{-i}\delta_{-i})(4\phi_i + 3\phi_{-i}) + 7(\theta_{-i}\delta{-i})^2\phi_i\right]}{4(\theta_i\delta_i + \theta_{-i}\delta_{-i})^2} < 0 \ , \tag{A.3a}$$

$$\frac{d\omega_{-i}^C(\Theta)}{d\theta_i} = -\frac{\delta_i\left[(\theta_i\delta_i + \theta_{-i}\delta{-i})^2\phi_{-i} + 3(\theta_{-i}\delta_{-i})^2(\phi_{-i} - \phi_i\right]}{4(\theta_i\delta_i + \theta_{-i}\delta_{-i})^2} \gtreqless 0 \ , \tag{A.3b}$$

$$\frac{de_i^C(\Theta)}{d\theta_i} = -\delta_i\phi_i < 0 \ , \tag{A.3c}$$

$$\frac{de_{-i}^C(\Theta)}{d\theta_i} = -\delta_i\phi_{-i} < 0 \ , \tag{A.3d}$$

$$\frac{dE^C(\Theta)}{d\theta_i} = -\delta_i\phi < 0 \ , \tag{A.3e}$$

$$\frac{d(\omega_i^C(\Theta) - e_i^C(\Theta))}{d\theta_i} = \frac{3\delta_i\left[-(\theta_i\delta_i)^2\phi_{-i} - 2\theta_i\delta_i\theta_{-i}\delta_{-i}\phi_{-i} - (\theta_{-i}\delta_{-i})^2\phi_i\right]}{4(\theta_i\delta_i + \theta_{-i}\delta_{-i})^2} < 0 \ , \tag{A.3f}$$

$$\frac{dp(E^C(\Theta))}{d\theta_i} = \delta_i > 0 \ , \tag{A.3g}$$

$$\frac{dW_i^C(\Theta)}{d\theta_i} = -\delta_i\left[\epsilon - \frac{1}{2}\theta_i\delta_i(2\phi_i + \phi_{-i}) - \theta_{-i}\delta_{-i}\phi_{-i}\right] \gtreqless 0 \ , \tag{A.3h}$$

$$\frac{dW_{-i}^C(\Theta)}{d\theta_i} = \delta_i\left[\frac{1}{2}\theta_i\delta_i\phi_{-i} + \theta_{-i}\delta_{-i}\phi_i\right] > 0 \ . \tag{A.3i}$$

□

Proof of Proposition ??

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

$$\mathrm{SOC}_i^{NS} = p'[2 - e_i'] < 0 \ . \tag{A.4}$$

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 (**??**) over both countries yields the following condition, which holds in the Nash equilibrium:

$$2p(E) = \theta_i D_i' + \theta_{-i} D_{-i}' \ . \tag{A.5}$$

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

Delegation under non-cooperation among agents

If agents do not bargain but decide non-cooperatively about permit issuance on domestic permit markets, the principal in country i will select an agent with preference parameter θ_i to maximize

$$V_i^D = B_i(\omega_i^D(\Theta)) - D_i(E^D(\Theta)) \ , \tag{A.6}$$

given the Nash equilibrium $\Omega^D(\Theta)$ of the subgame starting in the second stage as described by equations (12) and Proposition 1, and given the preference parameter θ_{-i} of the selected agent in the other country. The first-order condition gives us

$$B_i'(\omega_i^D(\Theta))\frac{d\omega_i^D(\Theta)}{d\theta_i} - D_i'(E^D(\Theta))\frac{dE^D(\Theta)}{d\theta_i} = 0 \ , \tag{A.7}$$

which implicitly determines the reaction function of the principal in country i, $\theta_i^D(\theta_{-i})$. Taking into account the equilibrium outcome in the second stage and in particular equation (12), the first-order condition becomes

$$(1-\theta_i)D_i'(E^D(\Theta))\frac{dE^D(\Theta)}{d\theta_i} = 0 \ , \tag{A.8}$$

which implies that there is no incentive for strategic delegation: principals choose agents with the same preferences as theirs.

Proposition 4 (Unique Nash equilibrium at stage one under domestic markets) *When agents choose permit issuance on domestic permit markets in a non-cooperative way, there exists a unique Nash equilibrium at stage one in which the principals in both countries simultaneously choose agents with the same preferences as theirs, i.e.,* $\theta_i^D = \theta_{-i}^D = 1$*: self-representation is the equilibrium strategy.*

Substituting for $\theta_i^D = \theta_{-i}^D = 1$ in equations (13), we find:

$$\omega_i^D(\theta_i) = \epsilon_i - \phi_i\delta_i \qquad \text{and} \qquad E^D = \epsilon - \phi_1\delta_1 - \phi_2\delta_2 \ . \tag{A.9}$$

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