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// MARIA ARVANITI AND WOLFGANG HABLA

The Political Economy of Negotiating International Carbon Markets

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Maria Arvaniti[§] and Wolfgang Habla[†]

[§] Centre of Economic Research, ETH Zurich
Zürichbergstrasse 18, 8092 Zürich, Switzerland; marvaniti@ethz.ch
[†] Department of Environmental and Resource Economics, Environmental Management,
ZEW – Leibniz Centre for European Economic Research
L7, 1, 68161 Mannheim, Germany; habla@zew.de

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Abstract: International carbon markets are frequently propagated as an efficient instrument for reducing CO_2 emissions. We argue that such markets, despite their desirable efficiency properties, might not be in the best interest of governments who are guided by strategic considerations in negotiations. We identify the circumstances under which governments benefit or are harmed by cooperation in the form of an international market. Our results challenge the conventional wisdom that an international market is most beneficial for participating countries when they have vastly diverging marginal abatement costs; rather, it may be more promising to negotiate agreements with non-tradable emissions caps.

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

The issue of increasing greenhouse gas (GHG) emissions and anthropogenic climate change has been a subject of fierce debate over the past few decades. The global scale of this environmental externality and the associated free-riding incentives, in conjunction with the lack of overarching political institutions on the global level, call for greater cooperation among national governments. International negotiations about coordinated emissions reductions, however, are far from being a success story, and the potential benefits from cooperation have undoubtedly not fully materialized.

Economic theory suggests that the provision of a transboundary public good, such as a stable climate on Earth, increases when decisions are taken cooperatively by governments because cooperation internalizes cross-border spillovers. International negotiations hold the promise of making every negotiating party better off as compared to non-cooperation, but they are also prone to manipulation by the participating countries, in an attempt to increase their bargaining power in the negotiations. One particularly effective instrument in achieving this is committing oneself to a policy—in case negotiations fail—that is less ambitious than it would have been in the absence of cooperation. As an example of such a commitment device, consider a government that appoints a delegate with a certain well-known political agenda.[1] If this agenda can credibly signal that the delegate's country has not much to gain from the negotiations, the other parties involved in the negotiations have to step up their contributions, which is beneficial for the considered country. In the case of climate change, this would imply sending a less "green" delegate to the negotiations. In the literature, this mechanism is referred to as "strategic delegation" or "strategic voting", depending on who selects the delegate, i.e., whether the principal on whose behalf the negotiations are conducted is the electorate (the median voter, to be more specific) or an institution such as the government.[2] As all countries face the same incentives for strategic delegation, they are likely to end up in a prisoners' dilemma, and it is unclear whether negotiations are still beneficial for every party when we take the strategic delegation incentives into account. If they are not beneficial, there are strong incentives to withdraw from the agreement at a later point, or to not enter the negotiations at all.

In this paper, we investigate how the combination of cooperation and strategic delegation affects the prospects of establishing a particular type of international environmental agree-

[1] Two of President Donald Trump's most controversial nominees for environment posts—one a coal industry lobbyist, the other a former Texas environmental official who dubbed carbon dioxide the "gas of life"—can be seen as signaling his views over the climate change issue and his commitment to a business friendly environmental policy.

[2] As Perino (2010) shows, delegation can also serve as a commitment device when governments face time-inconsistency.

ment (IEA), namely an international emissions permit market. Such markets have been proposed as one potential instrument for the efficient reduction of GHG emissions (Flachsland et al., 2009; Jaffe et al., 2009; Green et al., 2014). The obvious gain from such markets is the equalization of marginal abatement costs across firms and countries, which is a necessary condition for efficiency (Montgomery, 1972). This efficiency gain is higher the more marginal abatement costs diverge across countries in the absence of trading. At the same time, these markets necessarily involve a transfer payment from one country to the other (unless countries have the same marginal abatement costs before trading permits), and hence countries negotiating an international carbon market have an interest in either increasing or decreasing this transfer.

The contribution of this paper is threefold. First, we show that cooperation in combination with strategic delegation leads to lower aggregate emissions than a non-cooperative regime, i.e., the costs of strategic delegation do not offset the benefits of cooperation in terms of aggregate emissions. From an environmental perspective, this is good news.

Second, despite lower aggregate emissions and thus lower individual damages, we find that cooperation in the form of an international permit market may not be a Pareto improvement for the principals of the negotiating countries (governments or median voters); rather, it may be detrimental to one of the principals as compared to a non-cooperative regime. This is due to the strategic delegation incentives that the principals face and the corresponding transfers, which may be quite high. We identify three cases for which negotiations about an international carbon market are mutually beneficial for the principals of two countries, whereby: i) the principals' marginal damage costs from aggregate emissions diverge by a factor of at least three; ii) countries are relatively symmetric, i.e., they differ in terms of marginal abatement costs (for given abatement levels) *and* marginal damages as perceived by the principals by a factor of no more than 1.2; iii) and a high-damage, low-abatement cost country meets a low-damage, high-abatement cost country, which is an unlikely combination in the real world. Our results imply that, in contrast to conventional economic wisdom, strongly diverging marginal abatement costs across countries (for given abatement levels) are not sufficient for the principals to establish an international permit market through Coasean cooperation.

Third, negotiating an IEA without transfers, i.e., an agreement with non-tradable emissions permits or domestic taxes, is—for empirically relevant combinations of marginal benefits and marginal costs—a more promising way to establish mutually beneficial cooperation and achieve emissions reductions than negotiating an agreement with tradable caps. The reason for this result is that the possibility of getting a transfer under an international permit market is exploited by the principals, as they strategically appoint even less green agents than in the absence of transfers. A high transfer and high aggregate emissions make it eventually unattractive for one principal to cooperate via an international permit market. This is less likely to happen when transfers between countries are not possible.

We model the hierarchical structure of delegation and cooperation as follows. In the first stage of the game, the principals of two countries play a Nash game by simultaneously selecting an agent each from the continuum of available agents in their economies. We find that they 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 to the strategic substitutability of policies (Segendorff, 1998; Siqueira, 2003; Buchholz et al., 2005; Graziosi, 2009; Habla and Winkler, 2018). In particular, the principal that suffers less from higher aggregate emissions has very strong incentives to misrepresent her preferences by selecting a delegate who puts little or even no weight on climate damages. By doing so, the principal credibly commits to a less ambitious climate policy, passing the burden of abatement to the other principal. In the second stage, the appointed agents negotiate on the total number of emission allowances and their distribution. If they fail to agree, they set up domestic policies (either domestic permit markets or a domestic tax). We model the negotiations using the Nash Bargaining Solution. The negotiated policies are jointly efficient from the appointed agents' point-of-view. In the final stage, emission permits are traded, either on domestic markets or on an international market, depending on whether the negotiations were successful.

Our main results hinge on the assumption that the principals leave the decision power with the appointed agents in case negotiations fail. This type of delegation is referred to in the literature as "strong delegation" (Segendorff, 1998) and stands in contrast to "weak delegation", where the principals rescind the agents' decision power and decide themselves, rather, when negotiations have failed. Under weak delegation, negotiations are by definition always a Pareto improvement, as the principals can only gain through the negotiations relative to the outside option, which is determined by themselves.

Our analysis deviates from previous papers in the strategic delegation and strategic voting literature in a number of ways. First, while it is conceivable that for traditional public goods the costs of provision are linear and the benefits are concave, the opposite is true in the case of the climate as a public good: the costs of providing this good are convex and the benefits from this good are linear. This change in the curvature of cost and benefit functions induces an important difference. With linear costs, the country that is more efficient at providing the public good will produce all of it and is compensated for its efforts by the other country in the Nash Bargaining Solution. In the case of climate change, however, it is arguably never optimal that one country provides all of the public good, i.e., abates all emissions it has.

Instead, it is optimal that all countries do some abatement. Second, we show that for a linear benefit and a convex cost function, asymmetries between countries in terms of marginal costs and marginal benefits do matter for the success of an agreement (and not only the curvature of the demand function for the public good, as found by Loeper, 2017). Third, we assume a quadratic abatement cost function, which guarantees that even for symmetric countries, there exists an equilibrium in which both agents have a positive valuation for the environment. This result is in sharp contrast with Buchholz et al. (2005) who assume a linear abatement cost function and find that in a symmetric equilibrium, both principals choose an agent who put zero weight on environmental damages when transboundary environmental spillovers from emissions across countries are perfect, as is the case in our model. Consequently, aggregate emissions soar to plus infinity in both the cooperative and the non-cooperative outcome. A quadratic abatement cost function limits total emissions to finite business-as-usual emissions. All of these aspects show that the analysis of international agreements in the context of climate policy may substantially differ from and lead to other conclusions than analyses of more traditional transboundary public goods problems.

2 Literature

Our paper contributes to several strands of literature. In assuming that countries are not 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 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 pioneered by Vickers (1985), Fershtman and Judd (1987), and Sklivas (1987). “Strategic” in this context 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.

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, i.e., 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, since 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, 2018). Rather, 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, more generally, the provision of public goods. 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 by the name of "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.[3]

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. In 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.[4] Lange and

[3] While we frame our model in terms of strategic delegation, it is straightforward to show that the results are the same in a voting context. The median voter theorem holds in our setting, as indirect utilities of the agents are strictly concave.

[4] Strategic delegation in the provision of public goods other than the environment 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

Schwirplies (2017) analyze the strategic delegation incentives in international climate negotiations when agents are concerned about the distribution of the abatement burden. Our work is also closely related to Habla and Winkler (2018), who consider non-cooperative policies. In contrast, we study the case in which total emissions and country-specific permits are decided on a centralized level, employing a Nash Bargaining Solution. We thus explore whether cooperation makes linking to an international permit market more attractive. In the context of cooperative policies, Loeper (2017) analyzes the provision of public goods with cross-border externalities by representative democracies. Loeper finds that 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 and 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. In contrast to this, we find that whether a principal benefits from cooperation or not depends on the characteristics of the countries participating and in particular on the marginal benefit and marginal cost parameters. In line with Loeper (2017), we find that allowing for transfers across countries can make cooperation detrimental.

We further contribute to the literature that asks whether and under which circumstances the linking of emissions trading schemes is in the best interest of each individual country. Babiker et al. (2004) show in a partial equilibrium model and a calibrated computable general equilibrium (CGE) model that linking leads to higher social costs if the permit price interacts with distortionary domestic taxes. Marschinski et al. (2012) analyze linkage in a general equilibrium model and identify a terms-of-trade effect, which may lead to a deterioration of welfare under an international permit market. Anger (2008) shows in a two-sector general equilibrium model that linkage may not be beneficial if only one sector is linked and the national allocation of allowances towards the two sectors is endogenous. Doda and Taschini (2017) argue that fixed set up costs associated with linking may outweigh the efficiency gains from trade. Using a CGE model, Gavard et al. (2016) show that the limited trading of emissions permits between developed and developing countries or regions can be beneficial for all regions. Doda et al. (2019) quantify the efficiency gains from linking which accrue to an individual jurisdiction participating in an arbitrary linkage group. They also identify two independent sources of efficiency gains, namely effort- and risk-sharing gains. We add political economy aspects to this literature by modeling the hierarchical structure of linkage decisions and allowance choices and show that such considerations may well be a reason for the rejection of otherwise beneficial policies. With respect to hierarchical

choice of delegates is highly dependent on the distributive characteristics of the proposed agreement.

policy structures within countries, our paper is related to Habla and Winkler (2013) and Marchiori et al. (2017), who analyze the influence of legislative lobbying on the formation of international permit markets and international environmental agreements, respectively.

3 The model

We consider two (possibly heterogeneous) countries, indexed by $i \in \{1, 2\}$ and $-i \in \{1, 2\}$, $i \neq -i$.[5] In each country i, emissions e_i imply strictly increasing and concave country-specific benefits from the productive activities of a representative firm, $B_i(e_i)$, 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:

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

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

where $\epsilon_i, \delta_i, \phi_i > 0$. The benefit function can be interpreted as a production function, with emissions as the only input. It needs to be strictly increasing. Therefore, we restrict it to the domain $e_i \in [0, \epsilon_i]$.[6] The parameter $\epsilon_i \geq e_i$ denotes emissions in the absence of any climate policy (business-as-usual emissions), and ϕ_i is a measure of carbon efficiency, i.e., of how emissions translate into output (a higher ϕ_i implies lower carbon efficiency). This parameter is inversely related to marginal abatement cost (and its curvature), i.e., a higher ϕ_i is equivalent to lower marginal abatement cost for *given* abatement (and a lower gradient of the marginal abatement cost curve).[7] In addition, 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 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 be well approximated by quadratic functions. The linear damage specification is in line with the assumptions of complex integrated assessment and general equilibrium climate-economy models (see, e.g. Nordhaus and Boyer (2000),Golosov et al. (2014), Gerlagh and Liski (2018)) in which climate damage is approximately linear in the greenhouse

[5] The model can be extended to $n > 2$ countries, although it would lose analytical tractability.

[6] If we assumed a strictly increasing concave benefit function everywhere on $\mathbb{R}_{++}$, such as a logarithmic or isoelastic function, a country could desire an infinite amount of emissions in some cases, which clearly is unrealistic.

[7] To see this, define abatement costs $\text{AC} = B_i(\epsilon_i) - B_i(e_i) = (\epsilon_i - e_i)^2/(2\phi_i) = a_i^2/(2\phi_i) \equiv \text{AC}(a_i)$, where $a_i = \epsilon_i - e_i$ is the amount of abatement.

gas concentration in the atmosphere. As Holtsmark and Weitzman (2020) point out, this assumption is reasonable, as it is in fact the stock of accumulated emissions that causes the damage and the relatively small flow of emissions within, say, a five- to ten-year period has an effectively linear impact on the overall stock of atmospheric greenhouse gas emissions. While linearity is a simplifying assumption, it allows for tractability of our model and for some sharp insights to arise. A convex damage function would merely add an additional source of strategic interaction, which would obfuscate our results. In our model, strategic interdependency solely arises from the international permit market.

3.1 International climate policy

We assume that the two countries negotiate an international climate agreement. More specifically, they negotiate the parameters of an international permit market, i.e., the total number of emission permits and their distribution across the two countries. The countries' outside options (or threat points) in the negotiations are national permit markets which are not linked. In our setting, these are equivalent to domestic emissions taxes.

The number of permits issued to the representative domestic firm in country i amounts to ω_i.[8] As firms in both countries 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 (in the case of successful negotiations), a firm can generate additional profits by selling permits to the firm in the other country, or reduce the compliance cost via buying permits from abroad. Thus, the profits of the representative firm in country i read:

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

where p is the price of permits on an international market. If negotiations fail, domestic permit markets are established, and $\omega_i = e_i$ holds in equilibrium, implying that the second term in the above equation vanishes. For the later analysis, we define $T_i = p \times (\omega_i - e_i)$ to be the (sign-unconstrained) financial transfer through the permit market.

[8] The method of allocating permits has no bearing on our results. Grandfathering the permits and auctioning them are equivalent in our setting.

3.2 Agency structure and timing of the game

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 to the principal, there is a continuum of agents of mass one in each country, whose utilities are 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 $[0, \theta_i^{\max}]$. To ensure that, in both countries, the principal's preferences are represented in the continuum of agents' preferences, we impose $\theta_i^{\max} > 1$. In each country, all agents and the principal thus have equal stakes in the profits of the domestic firm but differ with respect to how much they suffer from environmental damage. This may be either because damages are heterogeneously distributed, or because the monetary valuation of homogenous physical environmental damage differs.[9] We assume that all individuals (principals *and* agents) 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. As will become clear in the next section, this assumption implies that the principals behave strategically, while the agents do not.

Importantly, the preference parameters of all individuals are assumed to be common knowledge. Thus, we abstract from all issues related to asymmetric information.[10]

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. The appointed agents then negotiate, in the second stage, about the total number of emission allowances and their allocation. If they fail to agree, they set up domestic permit markets. In the final stage, emission permits are traded. The complete structure and timing

[9] In the case of climate change, it does not seem unrealistic that some individuals benefit from global warming, while the majority are actually harmed, implying $\theta_i^{\min} < 0$. For instance, some individuals might perceive warmer temperatures as beneficial, while others actually suffer because they see many ecosystems and landscapes deteriorate and would prefer a more stable climate. Varying preferences with respect to global warming can also be rooted in economic gains or losses in sectors that are sensitive to a change in temperature, such as agriculture. While this remains a possibility, we focus on the case with $\theta_i^{\min} = 0$, which is the standard assumption in the literature.

[10] This may seem restrictive at first glance, but 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 foreign agent's preferences. Moreover, high-level political delegates generally have well-known political agendas; therefore, this assumption seems to be a good description of reality.

Superscript	Description
C	Cooperative regime featuring an international permit market (with delegation)
C, NT	Cooperative regime featuring unlinked domestic permit markets (with delegation)
NC	Non-cooperative regime featuring unlinked domestic permit markets (no delegation)
D	(Unlinked) domestic permit markets (under the authority of the selected agents)

Table 1: The different regimes analyzed in the paper

of the game are summarized as follows:[11]

1. Delegation stage (agent appointment game):
   Principals in both countries simultaneously select an agent each.

2. Policy-making stage:
   The selected agents choose the total number of permits and the allocation of permits across the two countries through (utilitarian) Nash bargaining. If negotiations fail (which they never will in our setting), the agents act non-cooperatively in determining the number of permits issued in their countries, for 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.

We solve the game by backward induction. First, we determine the equilibrium on the permit market. Second, we characterize 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. Third, we determine the equilibrium preferences of the agents that the principals select.

As we will make a number of comparisons in this paper, e.g., between the outcome of the regime *with* negotiations and the outcome of the regime *without* negotiations, we introduce the following notation: Superscript D stands for domestic permit markets, superscript C for cooperation featuring an international permit market, superscript C, NT for cooperation featuring domestic permit markets ("Non-Tradable" permits), and superscript NC for the regime with no international cooperation ("Non-Cooperation"). For an overview of the various regimes, see also Table 1.

In Section 8, we compare whether principals benefit from "delegated cooperation" or whether they would be better off if they chose policies in a purely non-cooperative fashion (com-

[11] There may also be a ratification stage 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.

parison between regimes C and NC). This comparison can also be interpreted as an initial stage to the game outlined above. Finally, in Section 9, we examine whether negotiations over non-tradable emissions caps would result in higher or lower global emissions and individual welfare than negotiations over an international permit market (comparison between regimes C, NT and C). The former regime is equivalent to an international climate agreement in the absence of transfers between countries.

Despite being highly stylized, the model captures essential characteristics of the hierarchical structure of international environmental policy and international negotiations. It is compatible with various delegation mechanisms that are present in modern democratic societies. For example, the principal might be the median voter among the electorate, while the agent represents the elected government. Alternatively, the principal might be the parliament or government that delegates a decision to an agent (e.g., to the minister of the environment). We prefer the latter interpretation, because it seems to be more realistic for an issue such as negotiations about an international carbon market.[12]

4 Permit market equilibrium

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

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

In the case of an international permit market, there is only one permit 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

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

[12] While our model is cast in the latter interpretation, it is straightforward to show that our results also hold in a median voter model in which the agents constitute the voters and the principal is the politician elected under majority rule. For this, we require the preferences of the voters to be single-peaked, which is the case in our setting.

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 of the market equilibrium 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 the global supply of permits increases, and this increase is absorbed by the representative firms in both countries to different extents. In particular, if country i's marginal abatement cost is smaller than country $-i$'s (for given abatement), i.e., $\phi_i > \phi_{-i}$, country i increases its emissions more relative to $-i$ when an additional permit is issued (or decreases its emissions relatively more when one permit is retired).

5 Delegated permit choice in 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 are established.

The appointed agent of country i – with preference parameter θ_i – sets the level of emission permits ω_i to maximize:

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

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:

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

The selected agent in country i thus trades off the marginal benefits of issuing more permits against the corresponding environmental damage costs (as valued by him) in his own country. There exists a unique Nash equilibrium (NE), as the following proposition states.

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, there exists a unique

Nash equilibrium in permit choices in the bargaining default, $\Omega^D(\Theta) = (\omega_i^D(\theta_i), \omega_{-i}^D(\theta_{-i}))$. *Given our assumption about the functional forms, we find:*

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

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

Proof. See the Appendix.

According to the first equation of (13), the agents' permit choices are dominant strategies due to the assumed linearity of the damage function. Note that as long as agent i perceives global warming as harmful, i.e., $\theta_i > 0$, he will choose an emissions level ω_i which is lower than business-as-usual emissions ϵ_i; otherwise, he will choose $\omega_i = \epsilon_i$.

The appointment of a marginally less green agent (θ_i marginally lower) increases permit issuance and thus emissions in country i (for $\theta_i > 0$) but does not affect permit issuance in the other country. As a result, total emissions go up, at least if θ_i was not already equal to zero before the marginal change.

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

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

If the principal of country i appoints a marginally less green agent, the welfare of agent i increases, simply because the identity of the agent has changed and he thus suffers less from climate damages (despite of increased global emissions) and additionally incurs lower abatement costs due to higher domestic emissions. Simultaneously, this appointment weakly decreases the other agent's welfare due to higher global emissions. The principal in country i can thus improve her agent's bargaining position and weakly worsen the other agent's bargaining position by choosing an agent with less green preferences, i.e., an agent with a lower θ_i.

6 Delegated permit choice in the negotiations

In the following, we analyze the outcome when the agents cooperate, i.e., when they sign an agreement regarding the establishment of an international carbon market. We capture the international agreement through the Nash Bargaining Solution (NBS) with equal bargaining weights.[13]

In the absence of strategic considerations, it would be optimal from a cost-efficiency point of view that the country whose marginal abatement costs rise by less (or, equivalently, the country with the lower marginal abatement costs for given abatement) does more of the total abatement.[14] This is in stark contrast to a traditional public good setting in which the costs of public good provision are assumed to be linear and it is thus always optimal that the country with the cheaper public good technology provides the whole amount of the public good, as determined in the agreement. In our setting, provision costs (abatement costs) are convex.

The delegated agents bargain about the total level of emissions E and the country-specific permit endowments ω_i and ω_{-i}. 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 the countries are perfectly symmetric).

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

$$\max_{E,\lambda} \quad \Big[W_i^C(\Theta) - W_i^D(\Omega^D(\Theta))\Big] \times \Big[W_{-i}^C(\Theta) - W_{-i}^D(\Omega^D(\Theta))\Big] \ . \tag{16}$$

Furthermore, let agent i's welfare gain in the cooperative scenario compared to the default be $\Delta W_i(\Theta) \equiv W_i^C(\Theta) - W_i^D(\Omega^D(\Theta))$.

The first-order conditions for the optimal E and λ yield (for notational convenience, we suppress all dependencies on Θ in the following):

$$\begin{aligned} &\Big[p'\Big(\lambda E - e_i(E)\Big) + p(E)\lambda - \theta_i D_i'\Big]\Delta W_{-i} = \\ &\qquad - \Big[p'\Big((1-\lambda)E - e_{-i}(E)\Big) + p(E)(1-\lambda) - \theta_{-i} D_{-i}'\Big]\Delta W_i \ , \end{aligned} \tag{17}$$

$$\Delta W_i = \Delta W_{-i} \ . \tag{18}$$

Substituting (17) into (18), we get the (jointly) optimal levels of λ and E.

[13] We assume equal bargaining weights for three reasons. First, it is hard to determine in reality the weight of which country is higher in the negotiations. Second, we focus on the effects that other asymmetries between countries, i.e., differences with respect to marginal damages and marginal emission benefits, have on emissions and welfare levels. Third, if countries have unequal bargaining weights, this will change the results in a straightforward way.

[14] At the same time, as it will then incur higher abatement costs than in the absence of cooperation, it will have to be compensated for its additional abatement effort.

Proposition 2 (Unique optimum in the NBS)
There is a unique optimum in the Nash Bargaining Solution for any given vector $\Theta = (\theta_i, \theta_{-i})$ *of agents' preferences, characterized by:*

$$p(E) - \theta_i D_i' - \theta_{-i} D_{-i}' = 0 \ , \tag{19}$$

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

Given the assumed functional forms and equations (7) *and* (9)*, emissions/allowance levels and the permit market price in the NBS as functions of* Θ *are given by:*

$$e_i^C(\Theta) = \epsilon_i - \phi_i(\theta_i\delta_i + \theta_{-i}\delta_{-i}) \ , \quad E^C(\Theta) = \epsilon - \phi(\theta_i\delta_i + \theta_{-i}\delta_{-i}) \ , \tag{21}$$

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

$$p^C(\Theta) = \theta_i\delta_i + \theta_{-i}\delta_{-i} \ , \quad T_i^C(\Theta) = \frac{3}{4}\Big((\theta_{-i}\delta_{-i})^2\phi_i - (\theta_i\delta_i)^2\phi_{-i}\Big) \ . \tag{23}$$

Proof. Existence and uniqueness follow from the fact that aggregate welfare of the agents is strictly concave in aggregate emissions E.

The optimal level of emissions, E^C, which the NBS dictates, is jointly optimal from the appointed agents' points of view. It maximizes their aggregate welfare: equation (19) 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. Equation (18) reveals that the permits are allocated in such a way that the gains from bargaining (relative to the non-cooperative solution as chosen by the appointed agents) are split equally between the two agents. In other words, the NBS in our framework is straightforward: countries decide on the level of emissions that is optimal from the perspective of the negotiating agents, and then split the bargaining gains equally by appropriately allocating the initial permit endowment across the two countries.

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 country i 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 points, thereby improving their agents' bargaining positions, but there are also incentives to alter the threat point of the other country's agent (if this is possible, i.e., when $\theta_{-i} > 0$). As we have seen in Section 5, the welfare of country i's agent is higher and the welfare of country $-i$'s agent is (weakly) 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 (19). Furthermore, a country's allocated 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 analyze in the next section.

From the first equation of (23), it is clear that $\theta_i\delta_i + \theta_{-i}\delta_{-i}$ must be strictly larger than zero for the permit market to be functional (and emissions to be below their business-as-usual levels ϵ_i, see equation 21). Otherwise, the price of permits would be zero, and there would be no trading of permits between the two countries. Considering the second equation of (23), a country is more "likely" (not in a stochastic sense) to sell permits and receive a financial transfer if its marginal benefits fall by little, i.e., if its marginal abatement costs are low, and if the marginal damage incurred by the agent in power is low, either because of a low θ_i or a low δ_i, or both. This provides an incentive for each principal to downplay her agent's valuation of environmental damages θ_i.

The following corollary summarizes the impacts of a marginal change in θ_i.

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 and E^C, the equilibrium permit price p^C and the transfer T_i^C in the NBS as characterized by $\Omega^C(\Theta) = (\omega_1^C(\Theta), \omega_2^C(\Theta))$:

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

$$\frac{d\omega_i^C(\Theta)}{d\theta_i} < 0 \ , \quad \frac{d\omega_{-i}^C(\Theta)}{d\theta_i} \gtreqless 0 \ , \quad \frac{d\left[\omega_i^C(\Theta) - e_i^C(\Theta)\right]}{d\theta_i} < 0 \ , \quad \frac{dT_i^C(\Theta)}{d\theta_i} \leq 0 \ . \tag{24b}$$

Proof. See the Appendix.

As expected, total emissions as well as country-specific emissions increase when the selected agent in a country is less green, i.e., when θ_i is smaller. At the same time, the permit price unambiguously falls. The number of emission permits allocated to country i increases by even more than emissions do, so that country i is now more likely to be the permit seller (and less likely to be the permit buyer). Moreover, country i receives a (weakly) higher transfer or needs to pay a (weakly) lower transfer to country $-i$ when θ_i is smaller, suggesting again that it might be beneficial for principal i to appoint an agent with lower environmental preferences than she has herself.

7 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 $\theta_i \in \left[0, \theta_i^{\max}\right]$. In particular, the principal in country i selects an agent with preference parameter θ_i to maximize

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

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. Taking equation (7) into account, the first-order condition yields:

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

The first term in the above equation gives principal i's marginal benefit of delegating to an agent with marginally lower environmental preferences than she has herself. This benefit is equal to the market price of the additional permits that she receives in the negotiations multiplied with the equilibrium permit price. The second term is either positive or negative (or zero for symmetric countries), as a higher permit supply decreases the equilibrium price of permits, which is beneficial for the permit-buying country and harmful to the permit-selling country. Finally, the third term illustrates the marginal costs of strategic delegation: total emissions rise, causing additional damage to principal i.

Taking into account equation (19), the above first-order condition becomes

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

and implicitly determines the reaction function of the principal of country i, $\theta_i^C(\theta_{-i})$. With the assumed functional forms, we obtain for the principal of country $i = 1, 2$:

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

The reaction function is downward-sloping, which implies that the choices of agents' preference parameters are strategic substitutes. There is a unique Nash equilibrium, as the following proposition states.

Proposition 3 (Unique Nash equilibrium at stage one)
There exists a unique Nash equilibrium at stage one in which the principals of both coun-

tries simultaneously choose agents, taking the other principal's choice as given. The Nash equilibrium $\Theta^C = (\theta_1^C, \theta_2^C)$ *has the following properties:*

1. ***Unique interior NE:***
   If the principals have sufficiently similar marginal damages, i.e., $2\phi_i/(3\phi_i + 2\phi_{-i}) < \delta_i/\delta_{-i} < (3\phi_{-i} + 2\phi_i)/(2\phi_{-i})$*, the appointed agents of both countries have a positive valuation of environmental damages equal to*

$$\theta_i^C = \frac{2}{3}\phi \frac{2\phi + \phi_i(1 - 2\frac{\delta_{-i}}{\delta_i})}{2\phi_i^2 + 2\phi_{-i}^2 + 3\phi_i\phi_{-i}} > 0 \quad \forall i = 1, 2 \ . \tag{29}$$

2. ***Unique corner NE:***
   If the principals exhibit substantially different marginal damages, i.e., $\delta_i/\delta_{-i} \leq 2\phi_i/(3\phi_i + 2\phi_{-i})$ *or* $\delta_i/\delta_{-i} \geq (2\phi_i + 3\phi_{-i})/(2\phi_{-i})$*, the principal with the higher marginal damage (say principal i) appoints an agent with positive valuation of damages and the other one an agent with a valuation of zero:*

$$\theta_i^C = \frac{2\phi}{2\phi + \phi_{-i}} > 0 \quad \textit{and} \quad \theta_{-i}^C = 0 \ . \tag{30}$$

3. ***In any equilibrium****, the appointed agent always has lower environmental preferences than the principal:*

$$\theta_i^C < 1 \quad \forall i = 1, 2 \ . \tag{31}$$

Proof. See the Appendix.

Plugging the equilibrium preference parameters into the equations in Proposition 2 yields equilibrium emission and allowance levels as well as the equilibrium permit price.

The first part of this proposition states that for principals who do not differ a lot in their marginal damages, the unique Nash equilibrium is interior, with both appointed agents having a positive valuation of environmental damages. The second part of the proposition states that if principal i's marginal damage is sufficiently low compared to the other principal's marginal damage, i.e., $\delta_i/\delta_{-i} \leq 2\phi_i/(3\phi_i + 2\phi_{-i})$, then she will appoint someone who has a valuation of environmental damages equal to zero. Finally, a principal will always delegate to an agent with lower environmental preferences than hers. This finding is in line with, e.g., Loeper (2017) or Buchholz et al. (2005) who also show that principals appoint agents who value the public good less than they do themselves. In contrast to the latter study, however, we show that a unique Nash equilibrium exists even in the case of symmetric countries and global pollution, and that both appointed agents have a positive valuation of environmental damages in this equilibrium.

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

Corollary 2 (Stage one comparative statics)
The following conditions hold for the equilibrium preference parameter θ_i^C:

i) in an interior NE:

$$\frac{d\theta_i^C}{d\delta_i} \geq 0 \ , \quad \frac{d\theta_i^C}{d\phi_i} \gtreqless 0 \ , \quad \frac{d\theta_i^C}{d\delta_{-i}} \leq 0 \ , \quad \frac{d\theta_i^C}{d\phi_{-i}} \gtreqless 0 \ . \tag{32}$$

ii) in a corner NE (in which principal i exhibits the higher marginal damage, i.e., $\delta_i > \delta_{-i}$):

$$\frac{d\theta_i^C}{d\delta_i} = 0 \ , \quad \frac{d\theta_i^C}{d\phi_i} > 0 \ , \quad \frac{d\theta_i^C}{d\delta_{-i}} = 0 \ , \quad \frac{d\theta_i^C}{d\phi_{-i}} < 0 \ , \tag{33a}$$

$$\frac{d\theta_{-i}^C}{d\delta_i} = 0 \ , \quad \frac{d\theta_{-i}^C}{d\phi_i} = 0 \ , \quad \frac{d\theta_{-i}^C}{d\delta_{-i}} = 0 \ , \quad \frac{d\theta_{-i}^C}{d\phi_{-i}} = 0 \ . \tag{33b}$$

Proof. See the Appendix.

From these equations, it follows that when a country's marginal damages (as perceived by the principal) are marginally higher, then this country's principal will, if in an interior equilibrium, choose a delegate with greener environmental preferences. The same holds true if the other principal's marginal damages are marginally lower. For the case of corner equilibria, an increase in a country's own marginal damages can have a zero or positive effect on the preference parameter of the appointed agent: if $\theta_i^C > 0$, then it has an effect of zero. If, on the other hand, $\theta_i^C = 0$, then it could have a positive effect: since in this case $\delta_i < \delta_{-i}$, by increasing δ_i, one could possibly move to the case of an interior equilibrium with a positive θ_i. A similar argument holds if the other principal's marginal damages are marginally lower.

While the effect of an increased ϕ_i is ambiguous in an interior equilibrium, we know for certain that when ϕ_i is marginally higher, i.e., i's marginal abatement costs are marginally lower, principal i will choose a delegate with less green preferences than the other delegate 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. In a corner equilibrium, a marginal increase in ϕ_i or a marginal decrease in ϕ_{-i} increases θ_i^C and has no effect on θ_{-i}^C unless we move to the case of an interior equilibrium.

Finally, it remains to say that if the principals were to negotiate the international agreement themselves, they would fully internalize all environmental externalities such that the first equation of (23) would read:

$$p = \delta_i + \delta_{-i} \ . \tag{34}$$

Clearly, the permit price would be higher and thus global emissions would be lower in this case than under the regime with delegation. In other words, delegation erodes (at least) part of the gains from cooperation, and we will examine in the next section whether and when principals are indeed better off under cooperation, or whether they are better off not participating in the international agreement, instead setting policies non-cooperatively themselves.

8 When is cooperation beneficial – and for whom?

In this section, 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 to be the outcome of a Nash game where the principals establish domestic permit markets, deciding on permit issuance themselves, i.e., in the absence of cooperation. In other words, we compare the outcomes of the regimes C and NC. This comparison can be interpreted as an initial stage of the game, in which the principals of both countries decide whether they want to enter negotiations about a common permit market.

We show in the Appendix that the equilibrium in the regime NC is equivalent to the equilibrium when the principals delegate to agents who choose policies non-cooperatively, establishing domestic permit markets (as in the threat point described in Section 5). Thus, for instance, $E^{NC} = E^D(\Theta^P)$, where $\Theta^P = (\theta_i^P, \theta_{-i}^P) = (1, 1)$ is the set of the principals' preference parameters (analogously for all other variables). The reason for this equivalence is that in a non-cooperative framework without an international permit market, the 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 are strategically neutral due to the linearity of the damage function (see Habla and Winkler, 2018, for more on this issue).

8.1 Comparison of equilibrium emissions

First, we examine whether global emissions are higher in equilibrium under cooperation and delegation (regime C) than in the case when principals choose policies in a purely non-cooperative fashion, forming domestic permit markets (regime NC). We can establish the following proposition.

Proposition 4 (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., $E^C(\Theta^C) < E^{NC} = E^D(\Theta^P)$.

Proof. See the Appendix.

For the environment, this proposition is good news, because it implies that the principals indeed achieve emissions reductions through cooperation, even though cooperation comes at the cost of strategic delegation. This proposition stands in stark contrast to the results of the study by Buchholz et al. (2005), in which damages soar to plus infinity in both the cooperative and the non-cooperative outcome in the case of global pollutants, as we assume in this paper. 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 (infinitely high emissions) in either regime. As argued earlier, we assume exactly the opposite for the benefit and cost functions.

8.2 Comparison of equilibrium welfare

Despite the fact that global emissions are strictly lower under cooperation than when the principals choose policies non-cooperatively themselves, it is not clear that both principals are also better off under this regime, due to the assumed asymmetries in marginal emission benefits and marginal environmental damage costs. For example, it could be that the principal of the country that has very high 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, no similar condition holds for the principals' welfare at stage one. In the absence of strategic considerations associated with delegation, cooperation would always be beneficial for the negotiating parties.

Formally, a principal benefits from cooperation (under delegation) if

$$\Delta V_i = V_i^C(\Theta^C) - V_i^{NC} = V_i^C(\Theta^C) - V_i^D(\Theta^P)$$

$$= B_i(e_i^C(\Theta^C)) + T_i^C(\Theta^C) - D_i(E^C(\Theta^C)) - \Big[B_i(e_i^{NC}) - D_i(E^{NC})\Big] > 0 \ . \qquad (35)$$

We define $\Delta B_i = B_i(e_i^C(\Theta^C)) - B_i(e_i^{NC})$ and $\Delta D_i = \Big[D_i(E^C(\Theta^C)) - D_i(E^{NC})\Big]$ for later use. Furthermore, an international permit market under cooperation is a Pareto improvement if it holds:

$$\Delta V_i > 0 \quad \wedge \quad \Delta V_{-i} > 0 \ . \qquad (36)$$

It is straightforward to show that a principal's payoff difference ΔV_i does not depend on her business-as-usual emissions ϵ_i (or ϵ_{-i}). Instead, only $\delta_i, \delta_{-i}, \phi_i$ and ϕ_{-i} enter condition (35).

In order to gain some intuition for when cooperation is beneficial in the presence of delegation, we first distinguish two knife-edge cases for which we obtain analytical results before we proceed with the general case. These two cases are: i) the principals suffer from (almost) identical damages, i.e., $\delta_i \approx \delta_{-i}$; ii) the curvature of their benefit functions is (almost) identical, i.e., $\phi_i \approx \phi_{-i}$, which is equivalent to (almost) identical marginal abatement costs for the same abatement efforts in both countries in the absence of trading.[15]

Identical damages. In the first case, the ratio δ_i/δ_{-i} is (almost) unity. By Proposition 3, we thus have a unique interior Nash equilibrium on the first stage. Plugging the equilibrium preference parameters of the agents into the equation governing the permit price and the respective equations for emissions and allowance choices under both regimes C and NC, the payoff difference for principal i between these two regimes is given by:

$$\Delta V_i = \frac{\tilde{\delta}^2 \left[4(\phi_i^2 + \phi_{-i}^2) + 5\phi_i\phi_{-i}\right] \left[2(\phi_i^3 - \phi_{-i}^3) + 3\phi_i^2\phi_{-i}\right]}{6\left[2(\phi_i^2 + \phi_{-i}^2) + 3\phi_i\phi_{-i}\right]^2} \ , \qquad (37)$$

where $\delta_i = \delta_{-i} \equiv \tilde{\delta}$.

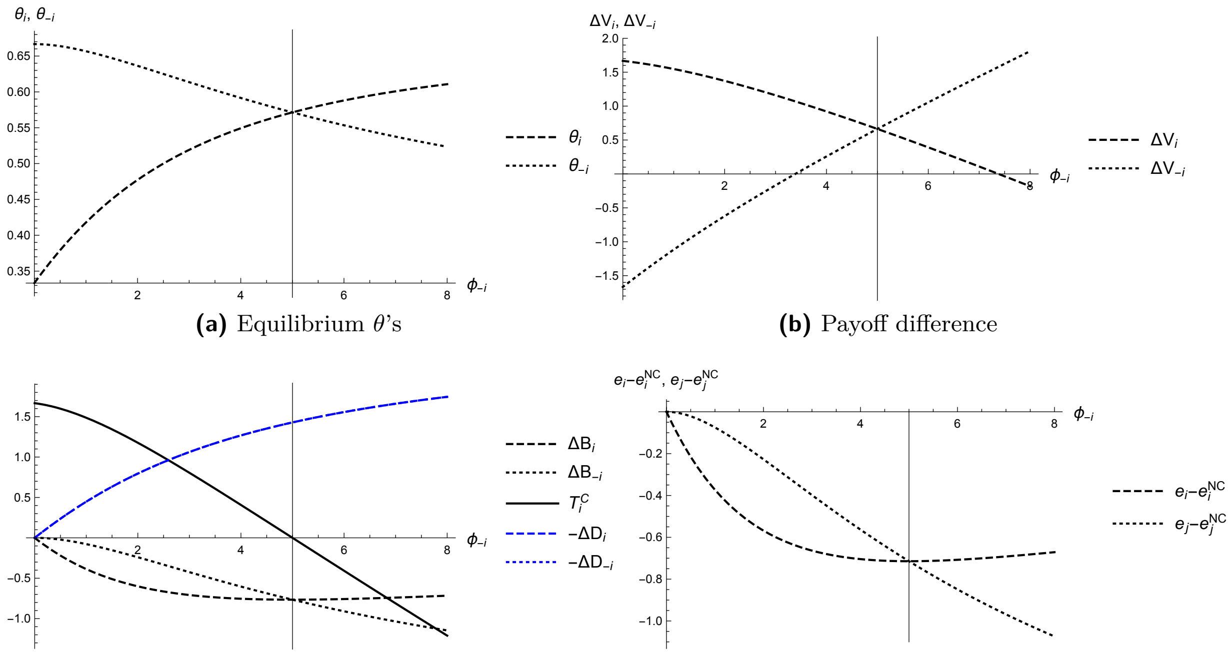
The above payoff difference can be positive or negative, depending on, among others, whether country i's ϕ_i is larger or smaller than ϕ_{-i}:

$$\text{for} \quad \phi_i \geq \phi_{-i}: \quad \Delta V_i > 0 \quad \wedge \quad \Delta V_{-i} \lesseqgtr 0 \ , \qquad (38a)$$

$$\text{for} \quad \phi_i < \phi_{-i}: \quad \Delta V_i \lesseqgtr 0 \quad \wedge \quad \Delta V_{-i} > 0 \ . \qquad (38b)$$

[15] Note that marginal abatement costs are, of course, equalized across countries under an international permit market, and they are also determined by actual abatement levels, which are different across countries. Nevertheless, we can cast the following analysis in terms of the parameters ϕ_i and ϕ_{-i}, which are, as argued earlier, a measure of marginal abatement costs in case the two countries do the same amount of abatement.

Figure 1: Comparison of regimes C and NC with identical damages for both principals (assuming $\phi_i = 5$, as indicated by the vertical lines)



(a) Equilibrium θ's

(b) Payoff difference

(c) Components of payoff difference

(d) Emissions reductions

That is, for both parameter combinations, the principal of one country always benefits from cooperation, while the other one may or may not be better off under this regime compared to the regime in which policies are chosen in a purely non-cooperative way. It is straightforward to show that both principals will only be better off under cooperation when ϕ_i and ϕ_{-i} are sufficiently similar. For $\phi_i > \phi_{-i}$, it additionally must hold $\phi_i^3 - \phi_{-i}^3 < 3/2\phi_i\phi_{-i}^2$, while for $\phi_i < \phi_{-i}$, it must hold $\phi_{-i}^3 - \phi_i^3 < 3/2\phi_i^2\phi_{-i}$ (see equation 37) . In other words, only if both principals exhibit not only (almost) identical damages but have benefit functions that are also sufficiently similar in terms of their curvature (sufficiently similar marginal abatement costs), do both principals gain from cooperation. This is surprising, given that the efficiency gains from trading permits are higher the more marginal abatement costs differ across countries (before trading or for the same levels of abatement).

The intuition behind this result can best be illustrated using Figure 1, which is based on a numerical example (the details of which can be found in the Appendix). The principal of the country with the higher ϕ_i, i.e., with the lower marginal abatement costs relative to those in the other country, chooses an agent who is less environmentally friendly than the agent in the other country (see equation 29), as can be seen in Figure 1(a). This result is counter-intuitive, as one would expect that the principal of the country with the lower marginal abatement costs should have a higher interest in pursuing more ambitious climate policy, because it is cheaper for her to do so. The explanation for this unexpected result is that this principal has a strong incentive to downplay θ_i in order to increase the bargaining position of her agent and thus obtain a financial transfer from the other country (by receiving more permits than the country needs for covering its own emissions). In other words, this principal wants to be compensated for its cheap abatement possibilities.

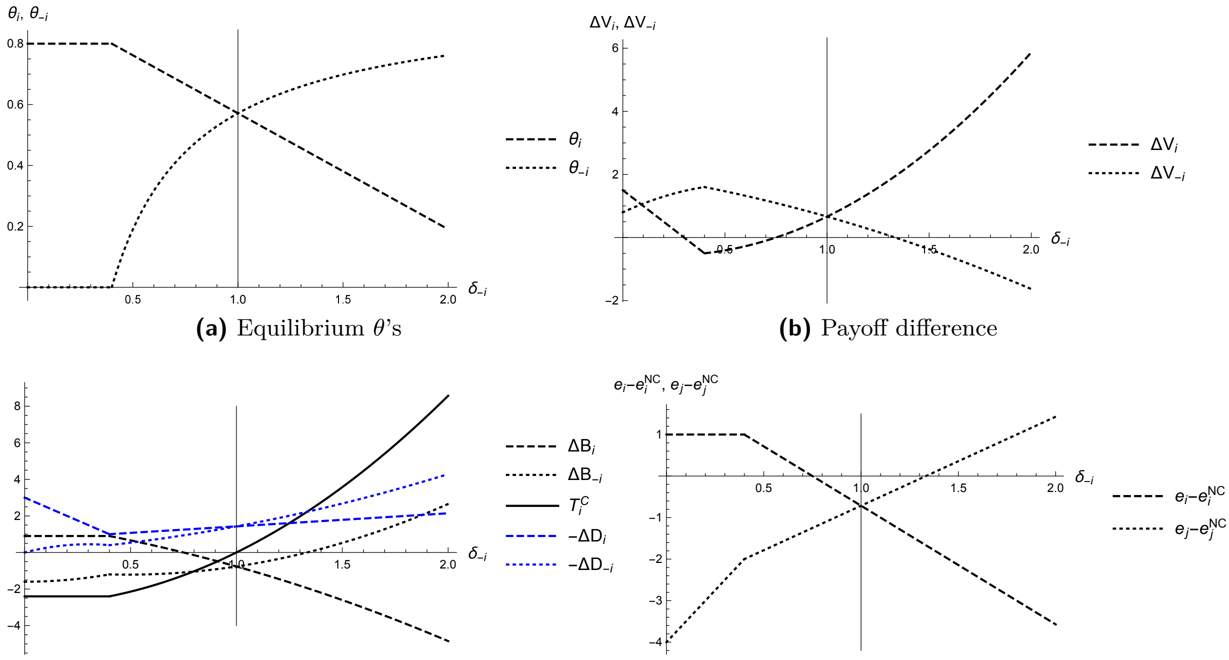
As the solid black line in Figure 1(c) indicates, the transfer is quite substantial for low values of ϕ_{-i} and becomes smaller the lower the difference in marginal abatement costs between the two countries. When there is no transfer between the two countries, it is unsurprising that both principals gain from cooperation (see Figure 1b), because the incentives to influence the transfer cancel out due to symmetry (although the principals still end up choosing delegates that have a lower valuation of damages than they have themselves). While both principals gain from the international agreement in terms of lower aggregate emissions in the whole domain of ϕ_{-i} ($\Delta D_i > 0$ and $\Delta D_{-i} > 0$; see the blue lines in Figure 1c), they lose in terms of lower domestic production benefits (see the dotted black lines in the same figure) due to lower aggregate emissions. The lower damages under cooperation outweigh the lower benefits for both countries. However, the high transfer from country $-i$ to country i at low values of ϕ_{-i} makes it unattractive for principal $-i$ to start negotiations about a permit market in the first place. This proves that only when marginal abatement costs are sufficiently similar does it pay off for both countries to cooperate and establish an international permit market (see Figure 1b). Furthermore, as we would expect and as shown in Figure 1(d), the country with the lower marginal abatement costs reduces emissions relatively more than the other country under cooperation as compared to non-cooperation.

Identical curvature of benefit functions (identical marginal abatement costs). In this case, the ratio ϕ_i/ϕ_{-i} is (almost) unity, i.e., the countries have (almost) identical marginal abatement costs for the same levels of abatement. By Proposition 3, we can either have a unique interior Nash equilibrium or a unique corner Nash equilibrium on the first stage. Defining $\phi_i = \phi_{-i} \equiv \tilde{\phi}$, the payoff differences for the principals in country i and $-i$ are given by:

$$(\Delta V_i, \quad \Delta V_{-i}) = \\ = \begin{cases} \Big(\frac{\tilde{\phi}}{50}(8\delta_{-i}^2 + 30\delta_i\delta_{-i} - 25\delta_i^2), \quad \frac{\delta_{-i}\tilde{\phi}}{10}(3\delta_{-i} - 10\delta_i) \Big) & \text{for} \quad \frac{\delta_i}{\delta_{-i}} \leq \frac{2}{5} \ , \\ \Big(\frac{\tilde{\phi}}{98}(4\delta_{-i} - 3\delta_i)(3\delta_i + 10\delta_{-i}), \quad \frac{\tilde{\phi}}{98}(4\delta_i - 3\delta_{-i})(3\delta_{-i} + 10\delta_i) \Big) & \text{for} \quad \frac{2}{5} < \frac{\delta_i}{\delta_{-i}} < \frac{5}{2} \ , \\ \Big(\frac{\delta_i\tilde{\phi}}{10}(3\delta_i - 10\delta_{-i}), \quad \frac{\tilde{\phi}}{50}(8\delta_i^2 + 30\delta_{-i}\delta_i - 25\delta_{-i}^2) \Big) & \text{for} \quad \frac{\delta_i}{\delta_{-i}} \geq \frac{5}{2} \ . \end{cases} \tag{39}$$

It can easily be shown that ΔV_i and ΔV_{-i} are both strictly larger than zero in a corner

Figure 2: Comparison of regimes C and NC with identical curvature of benefit functions (assuming $\delta_i = 1$, as indicated by the vertical lines)



(a) Equilibrium θ's

(b) Payoff difference

(c) Components of payoff difference

(d) Emissions reductions

equilibrium for $\delta_i/\delta_{-i} < 3/10$ (or for $\delta_i/\delta_{-i} > 10/3$ in the other corner equilibrium), while in the case of an interior equilibrium both principals benefit for $3/4 < \delta_i/\delta_{-i} < 4/3$. Altogether, this implies that for both principals to benefit from cooperation, marginal damages either need to be sufficiently similar (with a ratio in the range between 3/4 and 4/3) or sufficiently different (with a ratio less than 3/10).

Again, we graphically illustrate the intuition behind this result using Figure 2, which is based on a numerical example (see the Appendix). As can be seen from Figure 2(a), principal i chooses a more environmentally concerned agent as long as she suffers from higher marginal damages than the principal in the other country (to the left of the vertical line). The reason for this, simply, is that the high-damage principal benefits more from emissions reductions and is thus in favor of more ambitious climate policy than the other principal, even if this comes at the expense of a financial transfer to the other country. For low values of δ_{-i}, principal $-i$ even chooses an agent with zero valuation of environmental damages (unique corner Nash equilibrium; see Proposition 3). Ideally, this principal would even like to choose an agent who appreciates global warming and thus has a negative preference parameter (a case that we exclude in our analysis).

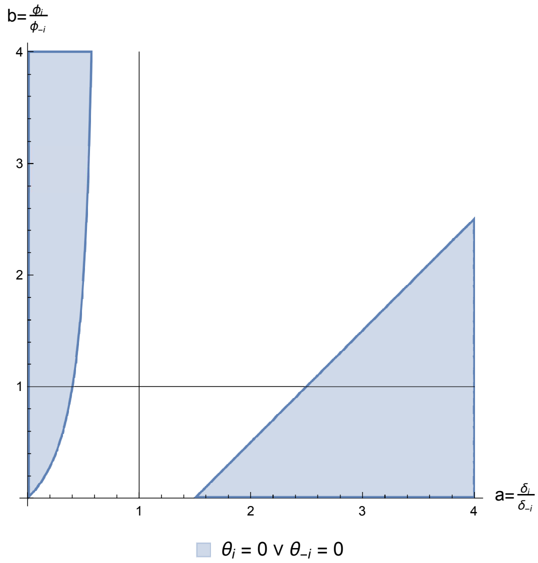
The transfer is—for low values of δ_{-i}—quite substantial and then decreases up to the point where the countries are exactly identical (see Figure 2c). As in the case before, it is not surprising that both principals gain from cooperation when both benefit and damage functions are almost identical (Figure 2b). The intuition here is again that the principals cannot do much in this case to shift the burden of abatement to the other country, or influence the transfer. Both principals' incentives are too well aligned.

What is more surprising though is that both principals also gain from cooperation when damages are very asymmetrically distributed. The fact that the low-damage principal (principal $-i$ to the left of the vertical line in Figure 2b and principal i to the right of this line) always benefits from cooperation, despite the lower production benefits and the relatively low environmental gain (Figure 2c), is explained by the high transfer she receives. The high transfer from country i to country $-i$ also leads to principal i being worse off under cooperation for some interval of δ_{-i}. However, as the preference parameter of the appointed agent in country $-i$ hits the lower bound at zero, principal i's payoff difference between the regimes C and NC starts increasing again. This is due to the fact that at the lower bound of zero for θ_{-i}, principal $-i$ is not able to improve the bargaining position of her agent in the negotiations anymore and the same holds true for principal i. In this case, i.e., for decreasing δ_{-i}, the negotiations are more successful in terms of internalizing the environmental externality than the non-cooperative outcome. In particular, aggregate emissions remain constant because of the corner solution while the regime NC leads to higher global emissions due to the decreasing valuation of environmental damages of principal $-i$. Relative to the non-cooperative outcome, the high-damage principal (principal i) is thus much better off under the negotiations than in the non-cooperative regime in terms of global emissions (see the increasing $-\Delta D_i$ for decreasing δ_{-i} in Figure 2c). In fact, while global emissions are lower under cooperation compared to non-cooperation, country i's emissions are higher for low values of δ_{-i} (see Figure 2d), which leads to increased domestic production benefits. To sum up, the fact that both principals gain for very asymmetric damages is caused by the corner solution.

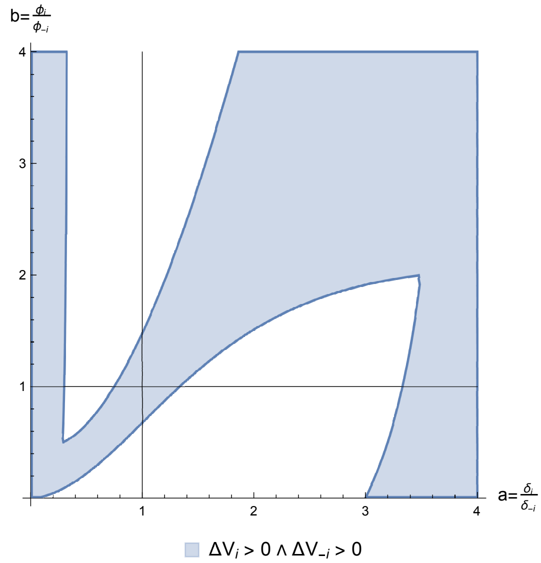
General case. To analyze the case when marginal damages *and* marginal abatement costs differ across countries and principals, we impose without loss of generality: $\delta_i = a\delta_{-i}$ and $\phi_i = b\phi_{-i}$, where $a, b > 0$. That is, we allow for all possible combinations of the parameters $\delta_i, \delta_{-i}, \phi_i$ and ϕ_{-i}. The parameter a then depicts the ratio of marginal damages, while b depicts the ratio of marginal abatement costs for the same levels of abatement in the two countries.

Figure 3 illustrates the parameter combinations of a and b for which we have a corner Nash equilibrium on the second stage (3a) and for which it is beneficial for both principals to enter negotiations on establishing an international permit market (3b). The straight black

Figure 3: Comparison of regimes C and NC in the general case



(a) Parameter space for which the Nash equilibrium is a corner solution



(b) Parameter space for which cooperation is mutually beneficial

lines depict ratios of $\delta_i/\delta_{-i} = 1$ and $\phi_i/\phi_{-i} = 1$, respectively, illustrating the knife-edge cases analyzed above. It is important to note that these two diagrams are exactly the same for all values of δ_{-i} and ϕ_{-i}. The reason for this is that these two parameters enter ΔV_i and ΔV_{-i} in a multiplicative way and thus only scale the principals' payoff differences but do not change their signs, and they also do not enter the values of the equilibrium preference parameters.

As Figure 3(b) demonstrates, the formation of an international permit market is most beneficial for both principals in the following three cases:

1. Their marginal damages are very different.
2. A high-damage, low-abatement cost country (high δ_i, high ϕ_i) negotiates with a low-damage, high-abatement cost country (low δ_{-i}, low ϕ_{-i}).
3. Marginal damages *and* marginal abatement costs are (almost) identical.

Regarding case 1): This parameter combination is favorable for cooperation to emerge for two reasons. First, when the principals' marginal damages differ a lot, then the high-damage principal has a high willingness to pay for emissions reductions and is thus willing to pay a high transfer to the other principal (through the permit market), while the low-damage principal benefits a lot from this transfer compared to a non-cooperative regime in which no transfers are made. Second, as we have seen earlier, it is beneficial for the high-damage principal that both principals run into the corner solution because the low-damage principal cannot delegate to an agent with a negative preference parameter. The parameter combinations for which we have a corner Nash equilibrium are depicted in Figure 3(a). For low values of δ_{-i}, principal $-i$ chooses an agent with $\theta_{-i} = 0$, while for high values of δ_{-i}, principal i chooses an agent with $\theta_i = 0$. In particular, when marginal damages differ by a factor of slightly more than three, i.e., when a is slightly lower than one third or slightly higher than three, cooperation is almost always beneficial to both principals, irrespectively of the difference in marginal abatement costs, i.e., irrespectively of b. Put differently, whenever marginal damages are sufficiently different from each other, then differences in marginal abatement costs (almost) do not influence the joint advantageousness of international cooperation in the form of an international permit market (see Figure 3b).

As concerns case 2): Cooperation is also more frequently mutually beneficial for both principals when $a, b < 1$ or $a, b > 1$, i.e., in the areas southwest and northeast of the point (1,1) in Figure 3(b), in which a high-damage, low-abatement cost country meets a low-damage, high-abatement cost country. The intuition for this result is that the roles in this combination of countries are clearly defined and thus strategic delegation incentives are not as strong as for other combinations of countries. For example, while one country has a high willingness to pay for emissions reductions and can also abate at low cost, the other country is not willing to do much and incurs a high cost of reducing emissions. Therefore, neither principal has strong incentives to shift the burden of abatement to the other country by downplaying its willingness to pay for emissions reductions. Instead, the principal of the high-damage, low-abatement cost country knows that it needs to do most abatement on its own, while the other principal does not care much about abatement.

The combination of a high-damage, low-abatement cost country and a low-damage, high-abatement cost country is very unlikely to occur in the real world, as developed countries typically have high marginal damages and at the same time rather high marginal abatement costs (for a certain level of abatement), while exactly the opposite is true for developing countries and emerging market economies. Therefore, this combination does not seem very relevant for real-world policies.

Finally, in case 3), cooperation is beneficial for both principals when marginal abatement costs and marginal damages are identical or almost identical. In particular, as Figure 3(b) illustrates, this is the case if marginal abatement costs and the principals' valuation of marginal damages differ at most by a factor of around 1.2 (or 1/1.2=0.83 if we swap indices). The intuition behind this is that in this case, the principals face the same or very similar strategic delegation incentives: they appoint agents with the same or similar preference parameters and cannot influence the transfer a lot in their favor. A very small transfer is thus the result of similar strategic delegation incentives by the principals and facilitates mutually beneficial cooperation.

From the discussion in this section, a few interesting results arise.

Proposition 5 (Advantageousness of international cooperation)
Cooperation in the presence of delegation is mutually beneficial in the following three cases:

- *Principals' valuation of marginal damages differs by a factor of roughly three or more.*
- *A high-damage, low-abatement cost country meets a low-damage, high-abatement cost country.*
- *Both the principals' valuation of marginal damages* and *marginal abatement costs differ at most by a factor of 1.2.*

This proposition also implies that cooperation may well be harmful to one principal due to strategic delegation, in which case cooperation is likely to either not emerge at all or break down, at least in the long run. A similar result has been obtained by Loeper (2017) for the general case of international negotiations over public goods. In contrast to the study by Loeper, we show that asymmetries across countries do matter for cooperation in order to be mutually beneficial. More importantly, Proposition 5 demonstrates that high efficiency gains due to large ex-ante differences between countries' marginal abatement costs—the standard argument in favor of emissions trading—may not be sufficient for an international permit market to be mutually beneficial. The obtained results also entail clear-cut policy recommendations: considering political economy incentives, matching relatively symmetric countries or countries with very different marginal damages seems to be the most promising avenue for international permit markets to emerge (and last).

9 An international agreement without transfers

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

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

$$\max_{\omega_i,\omega_{-i}} \quad \Big[W_i^{C,NT} - W_i^D(\Omega^D(\Theta))\Big] \times \Big[W_{-i}^{C,NT} - W_{-i}^D(\Omega^D(\Theta))\Big] \ , \tag{40}$$

where (W_i^D, W_{-i}^D) are the welfare levels under the same threat point as before.

The first-order condition for the optimal $\omega_i, i = 1, 2$, is given by:

$$\Big[B_i'(\omega_i) - \theta_i D_i'\Big]\Delta W_{-i} - \theta_{-i} D_{-i}' \Delta W_i = 0 \ . \tag{41}$$

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

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

$$\omega_i^{C,NT}(\Theta) = \epsilon_i - \theta_i\delta_i\phi_i \left[1 + \Big(\frac{\theta_{-i}\delta_{-i}\phi_{-i}}{\theta_i\delta_i\phi_i}\Big)^{\frac{1}{3}}\right] \ , \tag{42}$$

$$E^{C,NT}(\Theta) = \epsilon - \theta_i\delta_i\phi_i \left[1 + \Big(\frac{\theta_{-i}\delta_{-i}\phi_{-i}}{\theta_i\delta_i\phi_i}\Big)^{\frac{1}{3}}\right] - \theta_{-i}\delta_{-i}\phi_{-i} \left[1 + \Big(\frac{\theta_i\delta_i\phi_i}{\theta_{-i}\delta_{-i}\phi_{-i}}\Big)^{\frac{1}{3}}\right] \ . \tag{43}$$

Based on these equations, we obtain

Corollary 3 (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, $\Omega^{C,NT}(\Theta) = (\omega_1^{C,NT}(\Theta), \omega_2^{C,NT}(\Theta))$:*

$$\frac{d\omega_i^{C,NT}(\Theta)}{d\theta_i} < 0 \ , \quad \frac{d\omega_{-i}^{C,NT}(\Theta)}{d\theta_i} \leq 0 \ , \quad \frac{dE^{C,NT}(\Theta)}{d\theta_i} < 0 \ . \tag{44}$$

Proof. See Appendix.

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.

At the stage of delegation, the principal in country i selects an agent with preference parameter θ_i to maximize

$$V_i^{C,NT}(\Theta) = B_i(\omega_i^{C,NT}(\Theta)) - D_i(E^{C,NT}(\Theta)) \ , \tag{45}$$

given the Nash bargaining outcome $\Omega^{C,NT}(\Theta) = (\omega_i^{C,NT}(\Theta), \omega_{-i}^{C,NT}(\Theta))$ 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 now missing.

The first-order condition for principal i yields:

$$B_i'(\omega_i^{C,NT}(\Theta))\frac{d\omega_i^{C,NT}(\Theta)}{d\theta_i} - D_i'\frac{dE^{C,NT}(\Theta)}{d\theta_i} = 0 \ . \tag{46}$$

There is no algebraic solution to this system of two equations. We show in the Appendix that there exists a Nash equilibrium $\Theta^{C,NT} = (\theta_1^{C,NT}, \theta_2^{C,NT})$. In contrast to the regime with transfers, though, it cannot be shown analytically that there exists a *unique* Nash equilibrium. Furthermore, we cannot establish that the agents' equilibrium preference parameters are always smaller than the principals' preference parameters.[16] Numerically, however, we have not been able to generate conditions under which one of the equilibrium preference parameters would exceed unity (or equal zero, which would be equivalent to a corner solution).

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 yields 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. Additionally, as we have seen earlier, aggregate emissions are also lower under the international permit market because of cooperation.

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

$$\theta_i^{C,NT} = \frac{3}{5} \ . \tag{47}$$

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

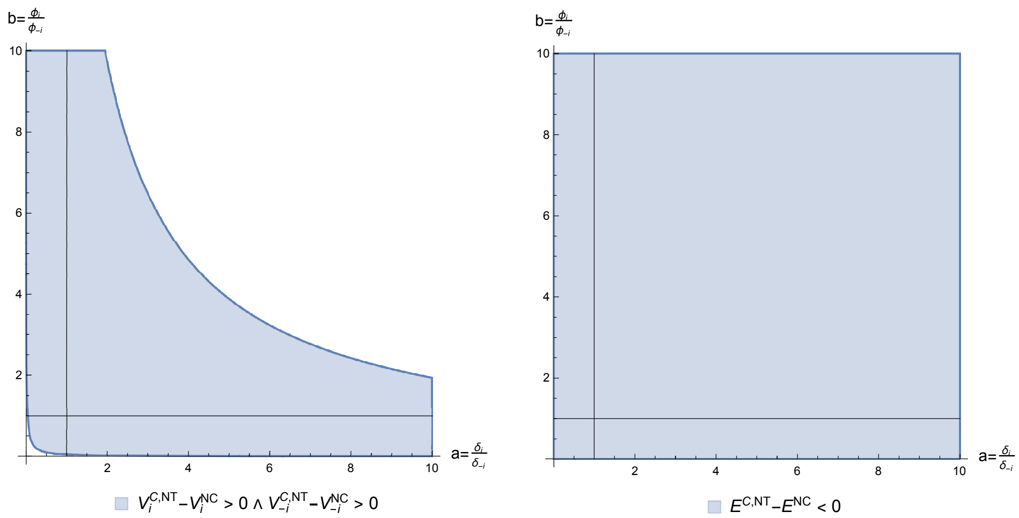
$$\theta_i^{C} = \frac{4}{7} < \frac{3}{5} \ . \tag{48}$$

Thus, the strategic delegation incentives are stronger for the principals of perfectly symmetric countries when transfers between countries are possible. Even though transfers are zero in equilibrium for symmetric countries, their mere existence creates extra incentives for strategic delegation. As we shall see in the diagrams below, this leads to higher global

[16] Using equations (41) and (46), we can rearrange terms to obtain: $1 - \theta_i = \theta_{-i}D'_{-i}\Delta W_i/(D'_i\Delta W_{-i}) - (d\omega_{-i}^{C,NT}/d\theta_i)/(d\omega_i^{C,NT}/d\theta_i)$. While the first addend is weakly larger than zero, the second one is strictly negative. Thus, θ_i could theoretically exceed unity.

emissions and lower welfare of both principals, as compared to an international agreement without transfers. In other words, the principals of perfectly symmetric countries are definitely worse off when transfers enter the game.

Figure 4: Comparison of regimes C, NT and NC



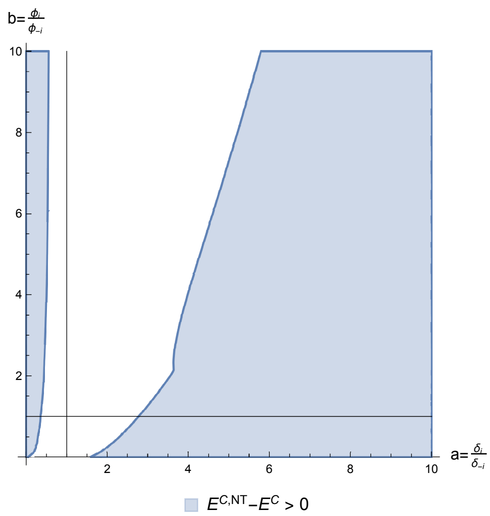
(a) Parameter space for which both principals are better off under C, NT than under NC

(b) Parameter space for which aggregate emissions are *lower* under C, NT than under NC

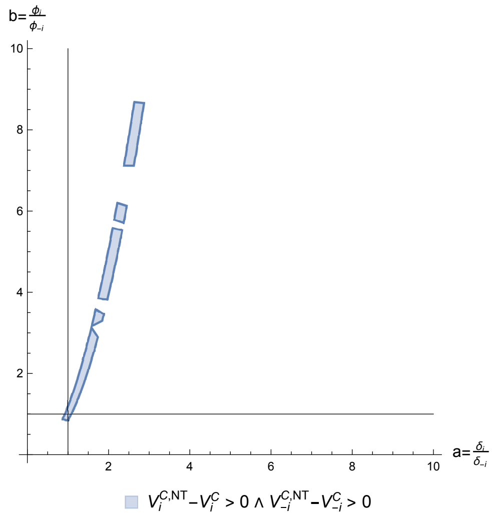
For the more realistic case when countries are asymmetric with respect to marginal emission benefits *and* marginal damages, we rely on numerical illustrations (the details of which can again be found in the Appendix). Figure 4(a) depicts the parameter space for which both principals are better off under cooperation in the absence of transfers compared to the non-cooperative regime. As before, these two diagrams are independent of the assumed values of the parameters. This figure demonstrates that an agreement without transfers is beneficial to both principals unless countries are very asymmetric with respect to both marginal abatement costs *and* marginal damages (as perceived by the principals), i.e., in the lower left and upper right corners of the diagram. Compared to Figure 3(b), the parameter space for which cooperation is mutually beneficial is substantially larger in the absence of transfers, at least when asymmetries with respect to both dimensions are not too strong (note that the maximum of a and b in these diagrams is now 10, whereas it was 4 in the diagrams of Figure 3). Furthermore, as before, cooperation *always* leads to lower aggregate emissions compared to the non-cooperative regime (see Figure 4b), also in the absence of transfers. We summarize these results as follows.

Proposition 6 (Advantageousness of international cooperation w/o transfers) *In the absence of transfers, cooperation in the presence of delegation always leads to lower* *aggregate emissions compared to the non-cooperative regime:* $E^{C,NT} < E^{NC}$*. Cooperation is mutually beneficial if the asymmetries with respect to marginal damages (as perceived by the principals) and marginal abatement costs are not too strong.*

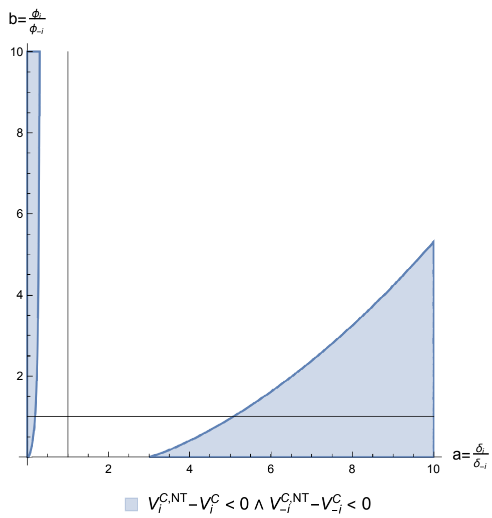
Figure 5: Comparison of regimes C, NT and C



(a) Parameter space for which aggregate emissions are *higher* under C, NT than under C



(b) Parameter space for which both principals are better off under C, NT than under C



(c) Parameter space for which both principals are better off under C than under C, NT

Finally, we compare aggregate emissions and payoffs of both principals under the cooperative regimes with and without transfers. As Figure 5(a) shows, aggregate emissions can either be higher or lower in the absence of transfers. Interestingly, as the diagram strongly resembles Figure 3(a), it seems likely that whenever the principals run into a corner solution under an international permit market, aggregate emissions are lower under this market compared to a cooperative regime with non-tradable permits; otherwise, aggregate emissions are lower under the latter regime. Figure 5(b) shows that there exist very few parameter combinations of a and b for which both principals simultaneously achieve higher welfare in the absence of transfers than under an international permit market. However, this does not imply that the opposite is true for the remaining parameter combinations, as can be seen in Figure 5(c). Therefore, no clear picture emerges when we compare cooperation with and without transfers, except for the case of symmetric countries, where it is always better for both principals if there is no international permit market. We summarize these results in the following proposition.

Proposition 7 (Comparison of cooperation regimes with and without transfers) *Aggregate emissions may be higher or lower under an international permit market compared to a cooperative regime with domestic permit markets:* $E^{C,NT} \gtrless E^{C}$*. Furthermore, a cooperative regime without transfers is a Pareto improvement for both principals (compared to a cooperative regime with transfers) only for very few parameter combinations and in particular when countries are perfectly symmetric.*

In light of the above results, it is more promising in the presence of strategic delegation to negotiate an international agreement without transfers if countries are not too asymmetric with respect to both marginal damages and marginal abatement costs, as this increases the parameter space for which both principals find an agreement to be mutually beneficial. By concluding such an international agreement, the principals also achieve emissions reductions compared to a fully non-cooperative world.

10 Conclusion

This paper attempted to gain a better understanding of the complex relationship between national politics (in the form of delegation or voting) and the formation of international policies, with a focus on international permit markets. We found that the principals in both countries have an incentive to appoint agents that care less about environmental damages than they do themselves. Even with a linear damage function, the potential gains from permit trading in the international market are enough to create strategic considerations in the delegation decision.

The good news is that strategic delegation does not fully erode the benefits from cooperation: global emissions are still lower than if the principals were to choose policies non-cooperatively. We then asked whether countries benefit from cooperation in terms of welfare. Our results indicate that the countries' characteristics play a fundamental role in the success of international negotiations. When countries are almost identical in terms of marginal damages and marginal abatement costs or when they have very different marginal damages, both principals gain from cooperation. For less extreme scenarios, we find that both countries benefit when a high-damage, low-abatement cost country negotiates with a low-damage, high-abatement cost country, which is, however, an unrealistic combination.

Finally, we show that, when non-tradable instead of tradable emissions caps are negotiated, global emissions are lower and both principals are better off as compared to non-cooperation when the asymmetries are not too strong with respect to both marginal damages (as perceived by the principals) *and* marginal abatement costs. While a cooperative regime with non-tradable caps is a Pareto improvement over an international permit market only for few parameter combinations, non-tradable caps are more likely to lead to mutually beneficial agreements that are able to achieve emissions reductions. Our results thus suggest that transfers between countries—implicit in our model through the permits allocation—are not necessarily beneficial for successful negotiations as has often been suggested by the literature. Our results caution against arguing for establishing more international permit markets on the grounds of economic efficiency. With regards to political economy, such markets might not last for long when governments realize that these markets are not necessarily within their best interest. We also showed that vastly diverging marginal abatement costs are not sufficient for an international carbon market to be mutually beneficial.

As mentioned earlier, we employed a linear damage function for two reasons. First, this specification can be regarded as a reasonable approximation to reality. Second, it eliminates an additional source of strategic interaction in the model and thus poses the least favorable conditions for strategic delegation to occur. In other papers, the assumed convexity of the damage function is the only source of strategic interaction (e.g., Siqueira, 2003; Buchholz et al., 2005), and it is therefore interesting to discuss what this assumption would change in our model. The most obvious change is that permit choices by the agents in the threat point of the negotiations would then be strategic substitutes. Furthermore, the strategic substitutability in the choice of the agents' preference parameters by the principals would become stronger, as the principals would have an additional reason to shift the burden of abatement to the other country (their marginal damage is not constant anymore). Overall, with stronger strategic interaction among the agents and among the principals, it appears likely that the principals would choose agents with lower preference parameters in equilibrium than in the case of a linear damage function, and that this would deteriorate the prospects of successful cooperation.

Appendix

Section 5

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

(ii) Uniqueness: Solving the best response functions (12) for ω_i for the functional forms we assumed yields the following equations:

$$\omega_i = \epsilon_i - \theta_i\delta_i\phi_i \; , \quad E = \epsilon - \theta_i\delta_i\phi_i - \theta_{-i}\delta_{-i}\phi_{-i} \; . \tag{A.2}$$

Thus, a unique level of country-specific and total emissions $\omega_i^D(\Theta)$ and $E^D(\Theta)$ in the Nash equilibrium for any given vector Θ exists. Note that agent i chooses a corner solution, i.e., $\omega_i = \epsilon_i$, for $\theta_i = 0$. □

Section 6

Proof of Corollary 1

Differentiating the closed-form solutions in Proposition 2 for both countries i and $-i$ with respect to θ_i yields:

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

$$\frac{dE^C(\Theta)}{d\theta_i} = -\delta_i\phi < 0 \; , \quad \frac{dp^C(\Theta)}{d\theta_i} = \delta_i > 0 \; , \quad \frac{dT_i^C(\Theta)}{d\theta_i} = -\frac{3}{2}\theta_i\delta_i^2\phi_{-i} \leq 0 \tag{A.3b}$$

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

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

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

□

Section 7

Proof of Proposition 3

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

$$\begin{aligned}\frac{d^2 V_i^C(\Theta)}{d\theta_i^2} =& p^C(\Theta)\frac{d^2\omega_i^C(\Theta)}{d\theta_i^2} + \frac{dp^C(\Theta)}{d\theta_i}\left[2\frac{d\omega_i^C(\Theta)}{d\theta_i} - \frac{de_i^C(\Theta)}{d\theta_i}\right] \\ =& -\frac{1}{2}\delta_i^2(2\phi_i + 3\phi_{-i}) < 0 \ . \end{aligned} \tag{A.4}$$

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

(ii) Uniqueness:
As both reaction functions are linear, we can theoretically have the following four cases, as illustrated by Figure 6. We define $\theta_i(\theta_{-i}^0) = 0$ and $\theta_{-i}(\theta_i^0) = 0$.

a) Unique interior Nash equilibrium if and only if:

$$\theta_i(0) < \theta_i^0 \quad \wedge \quad \theta_{-i}(0) < \theta_{-i}^0 \ . \tag{A.5}$$

Both conditions hold simultaneously if and only if:

$$\frac{2\phi_i}{3\phi_i + 2\phi_{-i}} < \frac{\delta_i}{\delta_{-i}} < \frac{2\phi_i + 3\phi_{-i}}{2\phi_{-i}} \ . \tag{A.6}$$

Note that the reaction functions also intersect exactly once, which is why there cannot be a continuum of interior Nash equilibria (along with two corner Nash equilibria). Plugging one reaction function into the other yields equation (29). This proves the first part of Proposition 3.

b) One interior Nash equilibrium and two corner Nash equilibria if and only if:

$$\theta_i(0) > \theta_i^0 \quad \wedge \quad \theta_{-i}(0) > \theta_{-i}^0 \ . \tag{A.7}$$

It can easily be shown that both conditions cannot hold simultaneously. Thus, no such equilibria exist.

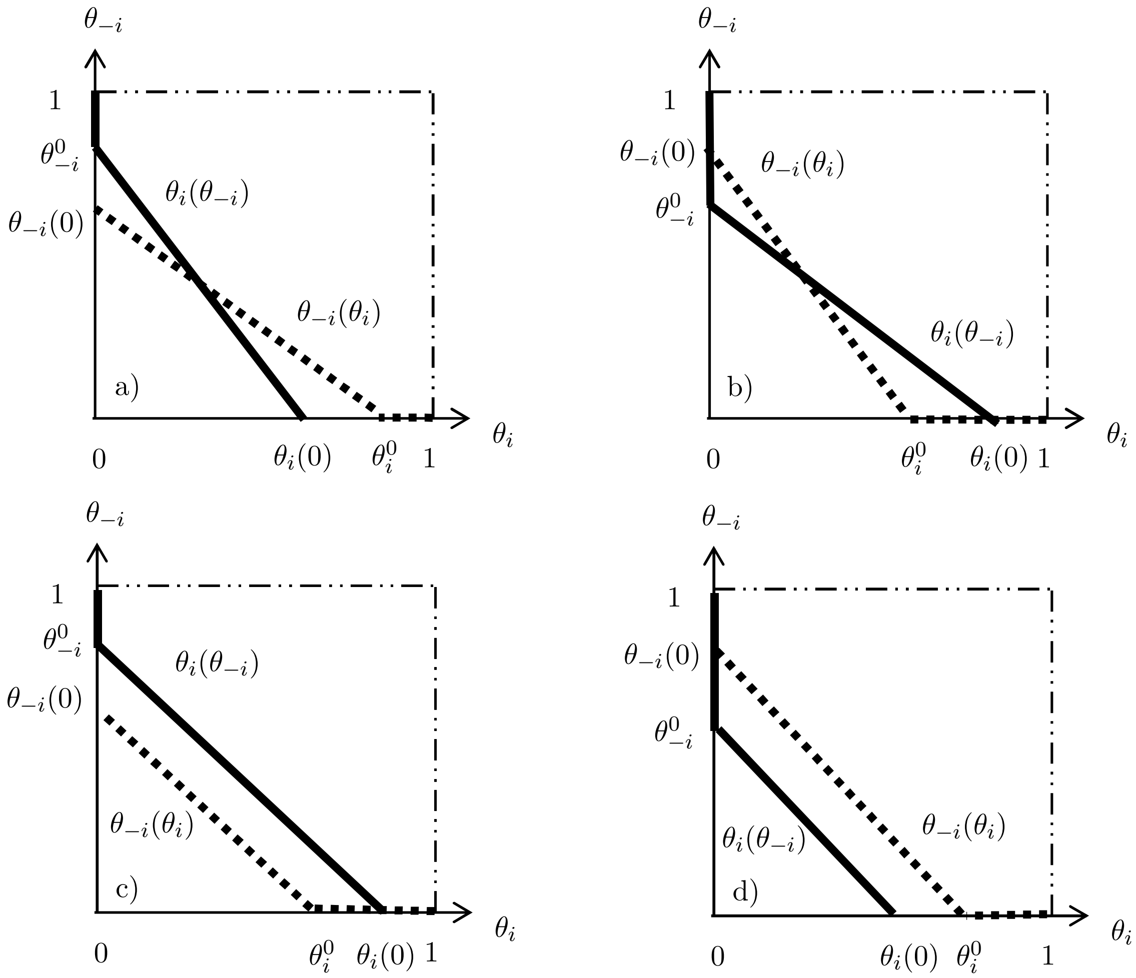


Figure 6: Potential Nash equilibria of the delegation stage.

c) Unique corner Nash equilibrium if and only if:

$$\theta_i^0 \leq \theta_i(0) \quad \wedge \quad \theta_{-i}(0) < \theta_{-i}^0 \ . \tag{A.8}$$

Both conditions hold simultaneously if and only if:

$$\frac{\delta_i}{\delta_{-i}} \geq \frac{2\phi_i + 3\phi_{-i}}{2\phi_{-i}} > 1 \ . \tag{A.9}$$

In this case, the equilibrium is described by $(\theta_i^C, \theta_{-i}^C) = \Big(2\phi/(2\phi + \phi_{-i}), 0\Big)$, where principal i exhibits the higher marginal damage, i.e., $\delta_i > \delta_{-i}$.

d) Unique corner Nash equilibrium if and only if:

$$\theta_i(0) < \theta_i^0 \quad \wedge \quad \theta_{-i}(0) \leq \theta_{-i}^0 \ . \tag{A.10}$$

Both conditions hold simultaneously if and only if:

$$\frac{\delta_i}{\delta_{-i}} \leq \frac{2\phi_i}{3\phi_i + 2\phi_{-i}} < 1 \ . \tag{A.11}$$

In this case, the equilibrium is described by $(\theta_i^C, \theta_{-i}^C) = \Big(0, 2\phi/(2\phi + \phi_i)\Big)$, where principal i exhibits the lower marginal damage, i.e., $\delta_i < \delta_{-i}$. Cases (c) and (d) thus prove the second part of Proposition 3.

Finally, the third part of the proposition can easily be seen, as the intercept of each reaction function is smaller than unity, and the slope of the reaction functions is negative. □

Proof of Corollary 2

For an interior Nash equilibrium, we differentiate equation (29) with respect to $\delta_i, \phi_i, \delta_{-i}, \phi_{-i}$ and obtain:

$$\frac{d\theta_i^C}{d\delta_i} = \frac{4\delta_{-i}\phi_i\phi}{3\delta_i^2(2\phi_i^2 + 2\phi_{-i}^2 + 3\phi_i\phi_{-i})} > 0 \ , \tag{A.12a}$$

$$\frac{d\theta_i^C}{d\phi_i} = -\frac{2\phi_{-i}\left[\phi_i^2(\delta_i + 2\delta_{-i}) + 4\phi_{-i}^2(\delta_{-i} - \delta_i) - 4\phi_i\phi_{-i}(\delta_i - 2\delta_{-i})\right]}{3\delta_i(2\phi_i^2 + 2\phi_{-i}^2 + 3\phi_i\phi_{-i})^2} \gtreqless 0 \ , \tag{A.12b}$$

$$\frac{d\theta_i^C}{d\delta_{-i}} = -\frac{4\phi_i\phi}{3\delta_i^2(2\phi_i^2 + 2\phi_{-i}^2 + 3\phi_i\phi_{-i})} < 0 \ , \tag{A.12c}$$

$$\frac{d\theta_i^C}{d\phi_{-i}} = \frac{2\phi_i\left[\phi_i^2(\delta_i + 2\delta_{-i}) + 4\phi_{-i}^2(\delta_{-i} - \delta_i) - 4\phi_i\phi_{-i}(\delta_i - 2\delta_{-i})\right]}{3\delta_i(2\phi_i^2 + 2\phi_{-i}^2 + 3\phi_i\phi_{-i})^2} \gtreqless 0 \ . \tag{A.12d}$$

For a corner Nash equilibrium in which principal i exhibits the higher marginal damage, i.e., $\delta_i > \delta_{-i}$), we differentiate $\theta_i^C = 2\phi/(2\phi + \phi_{-i})$ and $\theta_{-i}^C = 0$ with respect to the same parameters:

$$\frac{d\theta_i^C}{d\delta_i} = 0 \ , \quad \frac{d\theta_i^C}{d\phi_i} = \frac{2\phi_{-i}}{(2\phi + \phi_{-i})^2} \ , \qquad \frac{d\theta_i^C}{d\delta_{-i}} = 0 \ , \quad \frac{d\theta_i^C}{d\phi_{-i}} = -\frac{2\phi_i}{(2\phi + \phi_{-i})^2} \ , \tag{A.13a}$$

$$\frac{d\theta_{-i}^C}{d\delta_i} = 0 \ , \quad \frac{d\theta_{-i}^C}{d\phi_i} = 0 \ , \qquad \frac{d\theta_{-i}^C}{d\delta_{-i}} = 0 \ , \quad \frac{d\theta_{-i}^C}{d\phi_{-i}} = 0 \ . \tag{A.13b}$$

□

Section 8

Delegation under non-cooperation among agents

If agents do not bargain but decide non-cooperatively about permit issuance on domestic permit markets (which they also do in the threat point of the negotiations), the principal in country i will select an agent with preference parameter θ_i in order to maximize

$$V_i^D = B_i(\omega_i^D(\Theta)) - D_i(E^D(\Theta)) \ , \tag{A.14}$$

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

$$B_i'(\omega_i^D(\Theta))\frac{d\omega_i^D(\Theta)}{d\theta_i} - D_i'(E^D(\Theta))\frac{dE^D(\Theta)}{d\theta_i} = 0 \ , \tag{A.15}$$

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

$$(1-\theta_i)D_i'(E^D(\Theta))\frac{dE^D(\Theta)}{d\theta_i} = 0 \ , \tag{A.16}$$

which implies that there is no incentive for strategic delegation: principals choose agents with the same preferences as theirs. We summarize this finding in the following proposition.

Proposition 8 (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,* $\Theta^D = (\theta_i^D, \theta_{-i}^D) = (1,1)$ *in which the principals in both countries simultaneously choose agents with the same preferences as theirs: self-representation is the equilibrium strategy.*

Proof: As the reaction functions of the principals are orthogonal, there is exactly one point of intersection.

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

$$\omega_i^D(\theta_i) = \epsilon_i - \delta_i\phi_i \ , E^D = \epsilon - \delta_1\phi_1 - \delta_2\phi_2 \ . \tag{A.17}$$

Proof of Proposition 4

To show that global emissions are lower in the equilibrium under delegated cooperation,

$E^C(\Theta^C)$, as compared to the purely non-cooperative equilibrium, $E^D(\Theta^P)$, in which principals choose emissions permits for their domestic markets non-cooperatively, we have to distinguish two cases. In both cases, we plug $\theta_i^P = \theta_{-i}^P = 1$ into equation (13) and obtain:

$$E^D(\Theta^P) = \epsilon - (\delta_i \phi_i + \delta_{-i}\phi_{-i}) \ . \tag{A.18}$$

1. Unique interior NE under delegated cooperation:
   In an interior equilibrium, we insert equation (29) for each $i = 1, 2$ into equation (21) and obtain:

$$E^C_{\text{interior}}(\Theta^C) = \epsilon - \frac{2\phi^2(\delta_i\phi_i + \delta_{-i}\phi_{-i})}{2\phi_i^2 + 2\phi_{-i}^2 + 3\phi_i\phi_{-i}} < E^D(\Theta^P) \ . \tag{A.19}$$

2. Unique corner NE under delegated cooperation:
   Assume that $\delta_i > \delta_{-i}$ such that $\theta_i^C = 2\phi/(2\phi + \phi_{-i})$ and $\theta_{-i}^C = 0$. Plugging these equilibrium preference parameters of the delegated agents into equation (21) yields:

$$E^C_{\text{corner}}(\Theta^C) = \epsilon - \frac{2\delta_i\phi^2}{2\phi + \phi_{-i}} < E^D(\Theta^P) \ . \tag{A.20}$$

□

Additions to Section 8.2

For the numerical illustrations, we use the following parameter combinations:

- Figure 1: $\epsilon_i = \epsilon_{-i} = 10, \quad \delta_i = \delta_{-i} = 1, \quad \phi_i = 5$
- Figure 2: $\epsilon_i = \epsilon_{-i} = 15, \quad \phi_i = \phi_{-i} = 5, \quad \delta_i = 1$
- Figure 3: $\epsilon_i = \epsilon_{-i} = 10$, δ_{-i} and ϕ_{-i} can take on any values to generate the exact same two diagrams (in the assumed positive domain)
- Figure 4: $\epsilon_i = \epsilon_{-i} = 10$, δ_{-i} and ϕ_{-i} can take on any values to generate the exact same two diagrams (in the assumed positive domain)
- Figure 5: $\epsilon_i = \epsilon_{-i} = 10$, δ_{-i} and ϕ_{-i} can take on any values to generate the exact same three diagrams (in the assumed positive domain)

Business-as-usual emissions in the simulations are chosen such that emissions are strictly positive in all regimes for the considered ranges of a and b. For the regime C, NT for which no analytical closed-form solutions exist, we first compute equilibrium values for a and b in intervals of 0.01 and then use interpolating functions to plot emissions and welfare in Figures 4 and 5. The Mathematica code can be obtained from the authors upon request.

Section 9

Proof of Corollary 3

Differentiate equations (42) and (43) with respect to θ_i:

$$\frac{d\omega_i^{C,NT}(\Theta)}{d\theta_i} = -\delta_i\phi_i\left[1+\frac{2}{3}\Big(\frac{\theta_{-i}\delta_{-i}\phi_{-i}}{\theta_i\delta_i\phi_i}\Big)^{\frac{1}{3}}\right] < 0 \ , \tag{A.21a}$$

$$\frac{d\omega_{-i}^{C,NT}(\Theta)}{d\theta_i} = -\frac{1}{3}\delta_i\phi_i\Big(\frac{\theta_{-i}\delta_{-i}\phi_{-i}}{\theta_i\delta_i\phi_i}\Big)^{\frac{2}{3}} \leq 0 \ , \tag{A.21b}$$

$$\frac{dE^{C,NT}(\Theta)}{d\theta_i} = -\delta_i\phi_i\left[1+\frac{2}{3}\Big(\frac{\theta_{-i}\delta_{-i}\phi_{-i}}{\theta_i\delta_i\phi_i}\Big)^{\frac{1}{3}}+\frac{1}{3}\Big(\frac{\theta_{-i}\delta_{-i}\phi_{-i}}{\theta_i\delta_i\phi_i}\Big)^{\frac{2}{3}}\right] < 0 \ . \tag{A.21c}$$

□

Existence of Nash equilibrium at stage one for regime w/o transfers

In this part, we prove that there exists a Nash equilibrium at stage one in the regime in which no financial transfers are feasible.

The maximization problem of country i's principal is strictly concave:

$$\begin{aligned}\frac{d^2V_i^{C,NT}(\Theta)}{d\theta_i^2} =& B_i''\Big(\frac{d\omega_i^{C,NT}}{d\theta_i}\Big)^2 + B_i'\frac{d^2\omega_i^{C,NT}}{d\theta_i^2} - D_i'\frac{d^2E^{C,NT}}{d\theta_i^2}\\ =& B_i''\Big(\frac{d\omega_i^{C,NT}}{d\theta_i}\Big)^2 + D_i'\left[\frac{dE^{C,NT}/d\theta_i}{d\omega_i^{C,NT}/d\theta_i}\frac{d^2\omega_i^{C,NT}}{d\theta_i^2} - \frac{d^2E^{C,NT}}{d\theta_i^2}\right] < 0 \ ,\end{aligned} \tag{A.22}$$

where we made use of the first-order condition (46) and the comparative statics given in Corollary 3.

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

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ZEW – Leibniz Centre for European Economic Research

L 7,1 · 68161 Mannheim · Germany
Phone +49 621 1235-01
info@zew.de · zew.de