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The effect of investment on bargaining positions. Over-investment in the case of international agreements on climate change

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The effect of investment on bargaining positions. Over-investment in the case of international agreements on climate change.

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Abstract

A theory of international agreements is presented in which investment in R&D by firms in each country affects negotiations between countries on climate change. It seeks in particular to analyse the effects of investment on the bargaining position of states in international negotiations on a global public good, namely greenhouse gas emission reductions. Governments negotiate targets and firms bear the cost of emission reductions. Ex-ante investment by firms cuts the cost of future emission reductions. The public good nature of the problem implies that investment improves the government's bargaining position. The anticipation of Nash bargaining, and of the transfers needed to ensure participation in the agreement, will therefore induce firms to over-invest relative to the second-best.

1 Introduction

This paper presents a theory of international agreements in which the investment in R&D by firms in each country affects the negotiations between countries. It seeks in particular to analyse the effects of investment on the bargaining position of states in international negotiations on a global public good and shows that the anticipation of Nash bargaining will cause firms to over-invest relative to the second-best solution. The example of global public good used throughout this paper is that of greenhouse gas (GHG) emissions reductions in order to mitigate climate change. Investment in R&D by decentralised firms is non-reversible and is likely to strongly affect the cost of reducing (abating) GHG emissions in the future.

GHGs, such as carbon dioxide, accumulate in the atmosphere, thus capturing more heat from the sun, hence the term "greenhouse". The growth of man-made emissions throughout the industrial era is thought to be exacerbating this phenomenon, causing climate change at a global scale, now and in the decades and centuries to come. The global nature of the problem has led politicians to seek a global response in reducing emissions. International talks on this issue within the framework of the United Nations Framework Convention on Climate Change (UNFCCC) have agreed that greenhouse gas abatement targets are to be negotiated periodically at global level. The first negotiating round yielded the Kyoto Protocol in 1997 and targets for its signatories to be reached by 2008-2012; negotiations have now started on the post-Kyoto era. The outcome of these re-negotiations is clearly uncertain. However, when investments in R&D are made by firms to reduce the cost of emission cuts, they have a long-term effect, well beyond the commitment period of an agreement.

The aim of this paper is to understand the impact of these investments on future negotiations towards emissions reduction targets, and more specifically on the bargaining position of countries. The main finding of this paper is that the anticipation of bargained agreements between governments will affect the investment decision of firms. A two period-two country model is therefore presented in which firms invest in R&D to reduce with certainty the cost of future emission cuts. The rest of the economic activity of these firms within each country, any possible trade in goods and their effects on social welfare are abstracted from, as I focus on a partial equilibrium, concentrating solely on the emissions reduction problem. The first-best social-planner's choice of investment and abatement cannot be reached due to the inefficiencies introduced by the timing of the game: firms would choose not to invest, and it would then be too costly for the government to implement and emission reductions target. The first-best can however be approached by introducing emission permit markets when there is a large number of firms. This is considered as the second-best case and would be possible to reach if investment were verifiable and firms and governments could sit at the same negotiating table. However, the investment being non-contractible and sunk at the time of the international negotiations, governments set their abatement targets through a Nash bargaining procedure. If necessary, a transfer between the two countries will be devised to ensure participation in the agreement. Regulation is ruled out, as it would lead to a certain type of hold-up problem, as discussed further on in the paper. Governments could also choose to implement either national or international emissions permit markets. I will also argue that, in the context of this model, international permit markets do not yield any additional welfare gain, and will therefore focus on national permits. Once the emission targets and possible transfers have been decided upon, firms must meet their assigned targets by reducing emissions or buying permits, with their cost of doing so determined by the investment they have made in the past. The positive effect of investment is greater on the social welfare in the outside option case of non-cooperation than in the cooperative case in which some of the benefits of investment are reaped by the other country. The results thus show that investment improves the bargaining position of governments because emissions reductions are a global public good shared by the two parties to the contract. Anticipating the effect of their investment on the negotiations will induce firms, surprisingly, to over-invest with respect to the first best.

The existing literature has considered how the anticipation of international agreements affects firms' investment ex ante. In the case of non-public goods, it has identified the presence of a hold-up problem in international agreements. The hold-up problem has been described at length in the literature on the theory of the firm (Williamson

1985, Grossman and Hart 1986, Hart and Moore, 1988). McLaren (1997) analyses international trade agreements as incomplete contracts: firms in a country might anticipate future negotiations in favour of free trade and invest accordingly, e.g. by making irreversible investments in the export industry. Firms in this context act as decentralised agents and will reduce the bargaining power of the country when it later needs to negotiate. By having a modified outside option, the country is shown to be put at a strategic disadvantage by its firms' previous investments. For this reason, a country's government would benefit from never committing itself to negotiate on free trade in order to solve the hold-up problem. A similar type of argument is derived by Wallner (2003) for EU enlargement and allows one to revalue the welfare effects of EU membership. Because of the incompleteness of contracts, the surplus enhancement made by a country's corporate investments will be shared through a transfer, reducing the benefit to the investing country. Harstad (2005) studies how majority rules can affect incentives for decentralised agents to invest in anticipation of public projects, and how multilateral hold-up problems may arise in the context of the EU Constitution. This paper contributes to this literature by considering the case of international negotiations on a global public good in which decentralised agents in the two parties to the bargaining procedure make specific investments. The anticipation of Nash bargaining leads firms to over-invest relative to the second-best.

There is also a large body of literature on how various policies might affect investment and innovation in environmentally-friendly technologies. Jaffe et al. (2003) provide an overview of both theoretical and empirical contributions to these questions. Empirically, the impact of regulation and price changes on innovation has found support for both autonomous progress and induced innovation (Newell et al., 1999 and Popp, 2002). On the theory side, the focus has been on comparing the effects of prescriptive regulation and different market-based policies on efficient innovation (e.g. Downing and White, 1986, Jung et al., 1996). This area of research has focused on the effects on investment *after* the agreement or policy has been implemented. However, Gersbach and Glazer (1999) invert the timing and study how investment levels by firms ex ante affect the choice of policy instruments for reducing emissions at the national level. This is the timing we adopt in the present paper. Gersbach and Glazer identify a hold-up problem for a government seeking to reduce emissions through regulation within the boundaries of its country. Marketable emission permits are shown to solve the hold-up problem and induce firms to invest in a Pareto efficient manner. By considering continuous rather than binary investment decisions, I do not exactly replicate their result, except in the limit when the number of firms is infinite. I also extend their approach by considering firms' investments in the context of international negotiations on emissions reductions and find the result of over-investment thus improving on the existing literature.

In the next section, I present the two period-two country model set up. It is then solved by backward induction under different scenarios. Starting in section 1.2 with the first-best case, I show how it can only be approached by the second-best global welfare maximisation cooperative outcome with emission permits. This is taken as my benchmark. Section 1.3 then demonstrates that with firms anticipating Nash bargaining, they will over-invest. Section 1.4 concludes.

2 Set-up

The setting is that of two countries, Home and Foreign, which share a public good: greenhouse gas abatement, where World, Home and Foreign reductions are respectively noted M^W, M, and M^* and $M^W = M+M^*.(M \geq 0, M^* \geq 0)$.

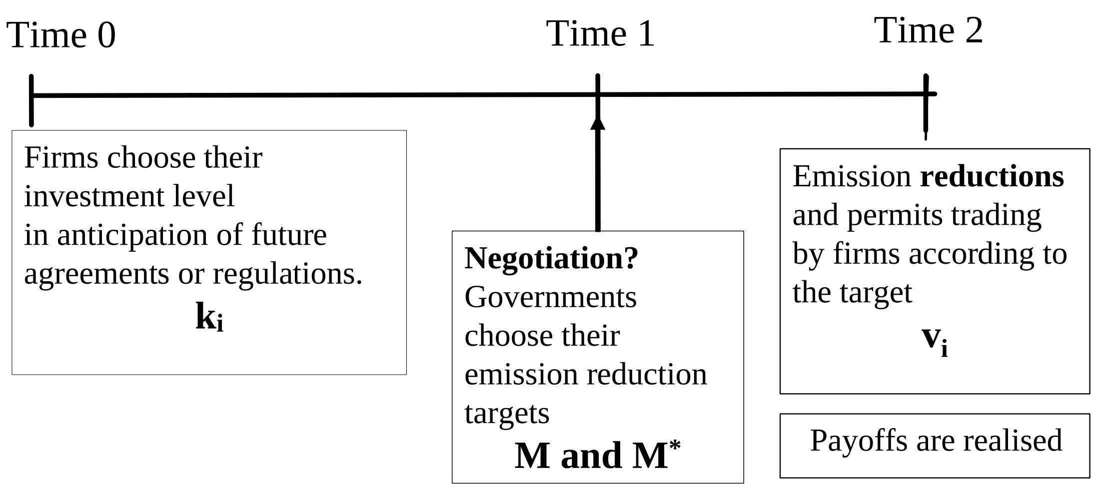
Reducing GHG emissions, reduces climate change and increases social welfare by $a(M + M^*)$ at Home and $a^*(M + M^*)$ in Foreign. Apart from their different preferences for the public good when $a \neq a^*$, the two countries are symmetric. Firms in each country bear the cost of reducing emissions.

There are n identical firms in each country. For simplicity, the number of firms is assumed to be fixed, and there is no entry and exit. Even if the firm makes negative profits on the emissions side of its activities in my setting, it does not exit: the model only considers the abatement part of a firm's behaviour, and does not take into account its main production activity. More than one firm is needed in each country in order to model emissions permits markets. At time 0, each firm can choose to invest such as to reduce the long-term marginal cost of abatement.

This investment is denoted by k_i and costs $m(k_i)$ to each firm i. Because it does not reduce emissions at the time it is made, a good example of such an investment would be R&D in ways to reduce a firm's emissions in the future. I do not consider investments whose effect on reductions is immediate, such as the building of a wind-turbine. It is assumed that the investment is irreversible, and therefore sunk. At time 1, each country decides on the level of emissions reductions M or M^* it wants to achieve. It divides the burden equally among all firms. At that point, the country can either enter into an international agreement, or act on its own accord, i.e. selfishly. It may also decide to implement an emissions permit trading system within its borders, or even internationally. However, given the assumptions made in this setting, national and international markets yield equivalent solutions, as shown in Appendix A. There are no additional welfare gains of implementing an international market given that under cooperation, governments already internalise the inter-country externality in their decisions on the national permits scenario. Alternatively, a country may simply choose to impose a regulation or a tax. In this paper, regulation is ruled out, as it would lead firms to hold up their investment, as shown in Appendix B. This is a replication of the result by Gersbach and Glazer (1999). I also abstract from the free-riding problem by assuming that a third party can verify and implement internationally agreed abatement targets.

At time 2, the firms need to fill the emissions permits quota they were allocated given the agreed target, $\frac{M}{n}$. They can either reduce the emissions themselves and/or trade permits with other firms. I denote by v_i the amount of reductions firm i decides to do itself at a cost $C(v_i, k_i)$. It is a function of k_i, the investment made at time 0 to reduce the cost of abatement. The more it invested in R&D in the past, the cheaper it is to abate. Payoffs are then realised. There is no discounting. The timeline is represented in Figure (1).

Figure 1: Timeline



If investments were verifiable and contractible, there could be an agreement between countries and firms specifying ex-ante the optimal level of R&D investment to be made in each country. However, in an international context it is hard to imagine that a third party be able to verify the amount of R&D made by firms in each country. Therefore, given investments are irreversible, it is only once they have been made that countries negotiate and choose together their respective level of emissions reductions. With Nash bargaining, transfers can be made between countries to encourage them to cooperate. These transfers could in practice also be replaced by the choice of international permit quotas. Ex ante, each firm will choose investment to maximise its profit by anticipating which scenario will occur: full cooperation or a Nash bargained agreement. I restrict my analysis to pure strategies.

Social welfare depends positively on total world abatement, and negatively on the cost of emission reductions and of investment by domestic firms. The rest of the economic activity within each country is abstracted from and not included in the model. At Home social welfare is defined by W, where a is the preference parameter for reductions:

$$W = a(M + M^*) - \sum_{i=1}^{n} C(v_i, k_i) - \sum_{i=1}^{n} m(k_i) \tag{1}$$

In Foreign, a^* is the preference parameter for world abatement:

$$W^* = a^*(M + M^*) - \sum_{i=1}^{n} C(v_i^*, k_i^*) - \sum_{i=1}^{n} m(k_i^*) \tag{2}$$

The cost of reducing emissions is symmetric across all firms in both countries. It is increasing in the level of reductions and I make the hypothesis of an increasing marginal cost of reduction ($\frac{\partial C(v_i,k_i)}{\partial v_i} > 0, \frac{\partial^2 C(v_i,k_i)}{\partial v_i^2} > 0$). The cost of reducing emissions is decreasing in the level of prior investment, but at a decreasing rate ($\frac{\partial C(v_i,k_i)}{\partial k_i} < 0, \frac{\partial^2 C(v_i,k_i)}{\partial k_i^2} > 0$). There is no uncertainty as to how R&D investment will affect the cost of abatement. The following functional form is chosen:

- $C(v_i, k_i) = \dfrac{v_i^2}{2k_i}$

  Finally, the cost of the investment is assumed to be quadratic.

- $m(k_i) = k_i^2$

This multistage game can therefore defined as follows. There are $2n+2$ *players*: the Governments in Home and Foreign, and n firms in each country. The Governments' *strategy spaces* consist of the emissions targets, respectively $M \geq 0$ and $M^* \geq 0$, and their decision to implement emission permits market (international or national), regulate the firms or none of these. The strategy of a firm at Home is defined by the pair (v_i, k_i) with emission reductions $v_i \geq 0$ and investment $k_i \geq 0$; for firms in Foreign, (v_i^*, k_i^*) with emission reductions $v_i^* \geq 0$ and investment $k_i^* \geq 0$. The Governments' *payoffs* are respectively Home and Foreign welfare: $W = a(M + M^*) - \sum_{i=1}^{n} \dfrac{v_i^2}{2k_i} - \sum_{i=1}^{n} k_i^2$ and $W^* = a^*(M + M^*) - \sum_{i=1}^{n} \dfrac{v_i^{*2}}{2k_i^*} - \sum_{i=1}^{n} k_i^{*2}$, while the firms' payoffs are negative and equal to te cost of abatement plus the cost of investment: $\Pi = -C(v_i, k_i) - m(k_i) = -\dfrac{v_i^2}{2k_i} - k_i^2$ and $\Pi^* = -C(v_i^*, k_i^*) - m(k_i^*) = -\dfrac{v_i^{*2}}{2k_i^*} - k_i^{*2}$. Finally, the timing of the game consists of three stages. At time 0, Firms in Home and Foreign choose their investment level k_i and k_i^*. At time 1, Governments in Home and Foreign choose their emission reduction targets, M and M^* and finally at time 2, firms in Home and Foreign reduce their emissions by v_i and v_i^*.

The model is solved by backward induction for the cases of the first-best social planner choice, cooperative outcome and Nash bargaining. In each of these last two possibilities, I focus on national permit trading schemes (Appendices A and B show how international permits give equivalent results and regulation can be ruled out). This allows me to solve the hold-up problem that would occur under regulation, and concentrate rather on the effect of international bargaining on investment choices.

3 Cooperative outcome and first-best

This section derives the first-best emissions reductions and investment levels and then shows how they can be approached using as policy instrument an emission permits market when n, the number of firms increases.

3.1 First-best

The socially optimal solution is characterised by two elements the investment levels and emission reductions by each firm in each country. By maximising $W + W^*$given by equations (1) and (2), the first-best levels of investment that would be chosen by a social planner are:

$$k_i^{FB} = k_i^{FB*} = \frac{(a+a^*)^2}{4} \tag{3}$$

and the optimal level of abatement by each firm is:

$$v_i^{FB} = v_i^{FB*} = \frac{(a+a^*)^3}{4} \tag{4}$$

These first-best reductions and investments would not be affected by the timing. However, the timing of the game introduces some inefficiencies in the game: firms, maximising their pay-off, and therefore minimising their cost, will have an incentive not to invest at time 0, such that the optimal choice of governments will be to choose a zero target (at time 1, once the investment is sunk, the first-best abatement as a function of investment, is $v_i^{FB} = (a+a^*)\, k_i$). This is equivalent at the international level to the hold-up problem identified by Gersbach and Glazer (1999) at the national level, described in appendix A. As shown in the following sub-section, the first-best can be approached (and reached if $n \to \infty$) by using as an instrument emission permits.

3.2 Emission permit markets

This sub-section shows how national emission permit markets allow to overcome the hold-up problem when n tends to infinity. An international emission permit market is shown to have the same property in appendix B. With emission permits markets, the decisions of firms at time 2 and time 0 will differ.

At time 2, firms take as given the investment they made at time 0 and the target that was set at the intergovernmental negotiation at time 1. The possibility of a firm deciding to exit and not abate is ruled out by assuming it makes sufficient profits in its main activity to remain active, and compensate for the negative profit it makes on the emissions reductions. It is assumed that the governments distribute M equally across firms: each firm receives a fraction n of the total abatement target M fixed by the government in time 1. This target can be reached in two ways. Either the firm reduces its emissions, by v_i, at a cost $C(v_i, k_i)$ dependent of its investment. Or it buys permits on the national market at price p. The firm maximises its profit, which is composed of the revenue of sales of permits minus the cost of reducing emissions, $C(v_i, k_i)$. A firm may sell at price p any abatement it has made in excess of its quota $\frac{M}{n}$, which is $[v_i - \frac{M}{n}]$. If it reduces below its quota ($v_i < \frac{M}{n}$), it will have to buy permits at price p and this will negatively affect its profits. Hence, the maximisation problem for firm i at Home at time 2 is:

$$Max_{v_i} \pi_i = p[v_i - \frac{M}{n}] - \frac{v_i^2}{2k_i} \tag{5}$$

The cost $m(k_i)$ of the investment k_i is not taken into account at this stage, as it is paid at time 0 and therefore sunk at time 2. The first-order condition of this maximisation problem is:

$$v_i = pk_i \tag{6}$$

The higher the price of permits, the more a firm will reduce its own emissions. Investment at time 1 reduces the cost of abatement, and therefore increases emission reductions. As the emission permit market is national, the market clearing condition dictates that total emission reductions within the country must be equal to the total amount of quotas M^F (F for first-best), the target chosen by government at time 1.

$$\sum_{i=1}^{n} v_i = M^F \tag{7}$$

This allows us to derive the equilibrium price:

$$p^{FN} = \frac{M^F}{\sum_{i=1}^{n} k_i} \tag{8}$$

The price is increasing in the target set by the government, as this boosts the supply of permits. It is decreasing in total investment by national firms, as by reducing the cost of self-abatement, investment reduces demand for permits.

Given the price and the profit function, total profits for firm i at time 2 are:

$$\pi_i = \frac{{M^F}^2 k_i}{2\left(\sum_{i=1}^n k_i\right)^2} - \frac{{M^F}^2}{n\sum_{i=1}^n k_i} \tag{9}$$

The profit is increasing in the number of firms, as this reduces the quota $\frac{M}{n}$ assigned to the firm by the government and therefore increases, for a given realised reduction v_i, the amount of permits it has in surplus and can sell. The effect of M^F on firm-level profit is negative, as it is imposed by government as an extra cost on top of the company's usual operations ($\frac{\partial \pi_i^F}{\partial M^F} < 0$ as in equilibrium, all firms within the country will act symmetrically and $k_i = k_j$). The effect of investment k_i on profits at time 2 is positive, as the cost of investment is sunk and it reduces the cost of meeting the target, both through a lower price of permits and a smaller cost of abatement.

In the aggregate, the revenue from permits sales and costs of permit purchases will cancel out, so that the total cost for all n firms in Home to meet the government's target M^F is:

$$\sum_{i=1}^n C(v_i, k_i) = \frac{{M^F}^2}{2\left(\sum_{i=1}^n k_i\right)} \tag{10}$$

The higher the national target, the higher the cost of reaching it. The cost is decreasing in aggregate investment. The same expression applies in the other country, so that the total cost for all n firms in Foreign to meet the government's target M^{F*} is:

$$\sum_{i=1}^n C(v_i^*, k_i^*) = \frac{{M^{F*}}^2}{2\left(\sum_{i=1}^n k_i^*\right)} \tag{11}$$

At time 1, anticipating the firms' reactions at time 2 and therefore the aggregate cost equations in each country, governments decide on the targets M^F and M^{F*} they wish to set. In the first-best complete contract with full cooperation, the two countries act as one, internalising the effect of their emissions on the other country. They choose the first-best targets by maximising joint total social welfare:

$$Max_{M^F, M^{F*}}(a+a^*)(M^F + M^{F*}) - \frac{(M^F)^2}{2\left(\sum_{i=1}^n k_i\right)} - \frac{(M^{F*})^2}{2\left(\sum_{i=1}^n k*_i\right)} \tag{12}$$

The first-order conditions confirm that each country takes into account the externality of its emissions reductions on the other country's welfare. Each target is thus increasing in both preference parameters a and a^* and in the aggregate investment of firms at time 0. Governments, at time 1, act according to the first-best. They will equate the marginal benefit of total reductions with the marginal cost of the reduction in each country. This result is an application of the Coase theorem, leading to an efficient outcome. With the specified functional forms, the first-best national permits targets will thus be, as above:

$$M^F = (a+a^*)\left(\sum_{i=1}^n k_i\right) \text{ and } M^{F*} = (a+a^*)\left(\sum_{i=1}^n k_i^*\right) \tag{13}$$

The presence of a third party able to enforce the agreement allows the optimal provision of the public good to be reached. The implied welfare levels, taking the investment as sunk, are the following:

$$V^F = a(a+a^*)\sum_{i=1}^n k_i^* + \left(\frac{a^2 - {a^*}^2}{2}\right)\sum_{i=1}^n k_i \tag{14}$$

$$V^{F*} = a^*(a+a^*)\sum_{i=1}^{n} k_i + \left(\frac{{a^*}^2 - a^2}{2}\right)\sum_{i=1}^{n} k_i^* \tag{15}$$

Welfare is increasing in the aggregate investment of the other country, as it will allow a higher target to be set at no extra cost. However, if Home's preference for abatement a is lower than Foreign's, a^*, Home's social welfare will be decreasing in its own aggregate investment. This is because, in a cooperative setting, the marginal cost of reductions is equated to the marginal benefit of reductions for both countries, and not the marginal benefit of Home which in this case would be lower. This is an important element for explaining my results below.

In a full cooperative setting in which firms' investments can be verified and government targets enforced, and with national emission permit markets, I compute firm-level investment. At time 0, firm i will maximise profits by anticipating that negotiations between governments at time 1 will yield the target set out in equations (13) and that its revenue at time 2, π_i, will be as in equation (9). It then solves the following maximisation problem:

$$Max_{k_i} \pi_i - k_i^2 \tag{16}$$

The first-order conditions yield an efficient level of investment by equating the marginal cost of investment at time 0 with its anticipated marginal benefit. Given time 1's target choice, this marginal benefit is the decrease in C_i, the cost of reducing emissions, given the expectation of the target. Firms at Home would therefore invest at time 0 an amount k_i^{SB} while those in Foreign will invest k_i^{SB*}.

$$k^{SB} = \frac{(n-2)(a+a^*)^2}{4n} \text{ and } k_i^{SB*} = \frac{(n-2)(a+a^*)^2}{4n} \tag{17}$$

These investment levels show that the first-best investment levels can only be reached using as an instrument emission permits markets when n is infinite. This differs slightly from the Gersbach and Glazer (1999) result in which the investment and therefore abatement decisions are binary and where the first-best is therefore reached through permits for an n above a certain finite threshold. In this model, investment by each firm is a continuous choice. The incentive to invest when emission permits exist comes from the potential profits from deviating from a non-investment situation and becoming a permit seller in the future. The higher the number of firms, the higher the profits (as seen in equation (7)), and hence the higher the return on investment. In other words, the larger the number of firms, the higher the costs of choosing to invest less and being a permit buyer from other firms relative to being a permit seller. We also notice here that firms anticipate that, when there is full cooperation, there will be no free riding. Countries will choose their targets by taking into account the effect of their emissions on the other country's welfare (which explains why both a and a^* are in equation (17)). Governments will choose higher targets, which in turn imposes a greater responsibility on firms. This gives firms an incentive to invest more than when countries do not cooperate as shown in section 4.1.

Given the symmetry of both countries and the fact that they act jointly, their firms in aggregate will invest the same amount.

In this section, I have shown how the timing of the game modifies the incentives of firms and hence prevents the first-best investments and reductions to be attained with no instrument. It is then shown how they can be approached by cooperation, using emission permit markets as instruments when the number of firms is infinite. The levels reached with the permits will be considered as our second-best cooperative benchmark for the remainder of this paper. I now consider the case of a Nash bargained agreement.

Having set-out the baseline case of full cooperation with national permits in which the first best investment and reductions are obtained, I now consider the case of a Nash bargained agreement.

4 Nash Bargaining

This section shows how firms anticipating a Nash bargained agreement will over-invest. Targets in this setting cannot be set in advance nor be made contingent on investment levels. Given that investments are assumed to be non-verifiable, countries are bound to negotiate at time 1 taking the investment levels of their firms as given. The investments are assumed to be irreversible. If they were reversible, there would be no benefit of negotiation. Given the sunk investments, the surplus of cooperation over non-cooperation will be shared according to a Nash bargaining process. The behaviour of firms at time 2, given the agreed target and/or transfer will be similar to the second-best case. The difference between the two types of solutions stems from the way in which governments bargain at time 1. In view of the public nature of the emission reductions, cooperation in fixing the targets is Pareto superior to non-cooperation. Given the results of the previous section, it is assumed that there are national permits markets in place. It is also assumed that social welfare is transferable in so far as the negotiation, based on the bargaining power of each country, will devise a transfer which ensures that both countries participate in the agreement. In the case of an international permits market, the transfer would not be made in this way, but through a different allocation of national emission allowances, which is closer to reality. The two cases are shown to be equivalent in Appendix A. First, I present the non-cooperation case, in order to measure thereafter the surplus of cooperation over non-cooperation.

4.1 Non-cooperation

Anticipating the revenue functions of firms at time 2 as in the full cooperation case, one can compute the social welfare in the event that the government fixes the national emissions reduction target without taking into account the externality on the other country. This is called the non-cooperative case. As proved in Appendix B, the government will not use regulation but national permits. At Home, the government maximises social welfare. Investments of time 0 are sunk and irreversible. The government maximises welfare achieved from the target, anticipating the cost of reaching that target, with national permits trading at time 2 will be such as derived in equation (10). The maximisation problem is therefore:

$$Max_M a\left(M + M^*\right) - \frac{M^2}{2\left(\sum_{i=1}^{n} k_i\right)} \tag{18}$$

at Home and a parallel equation holds in Foreign. The first-order condition thus dictates the optimum choice of targets for the non-cooperative governments to be:

$$M^{NC} = a\sum_{i=1}^{n} k_i \text{ and } M^{NC*} = a^*\sum_{i=1}^{n} k_i^* \tag{19}$$

Unlike the second-best case, each government only integrates its own preference parameter, respectively a and a^*, in its choice of target. The more social welfare benefits from abatement, the higher the target. Aggregate investment positively affects the target, as it reduces the cost of emission reductions. Given these targets, the social welfare levels for each country implied by a non-cooperative outcome at time 1 are computed in equations (20). The cost of investment at time 0 is not accounted for, given that it is sunk.

$$V^{NC} = \frac{a\sum_{i=1}^{n} k_i}{2} + aa^*\left(\sum_{i=1}^{n} k_i^*\right) \text{ and } V^{NC*} = \frac{a^*\sum_{i=1}^{n} k_i^*}{2} + aa^*\left(\sum_{i=1}^{n} k_i\right) \tag{20}$$

The Home social welfare functions in the non-cooperative case is increasing in Home investment, as this will reduce the cost of abatement and increase the agreed reductions. It is also increasing in Foreign firms' aggregate investment and in a^* as these will raise the target chosen non-cooperatively by the foreign government, and hence the reductions. Given these are a positive externality on Home, social welfare will be improved. The same applies to Foreign. These levels of social welfare are used in the following two parts to compute the surplus of the agreement.

At time 0, anticipating the target that would be imposed by governments in an non-cooperative behaviour, firms in Home and Foreign will invest such as to maximise their payoff at time 2:

$$k_i^{NC} = \frac{(n-2)a^2}{4n} \text{ and } k_i^{NC*} = \frac{(n-2)a^2}{4n} \tag{21}$$

This leads to the following proposition.

Proposition 1 *Firms anticipating their country will act non-cooperatively in setting the target for emission reductions will invest less than in the first-best and second best,* $k_i^{NC} \leq k_i^{SB} \leq k_i^{FB}$*. This level of investment is efficient when governments decide not to cooperate and n is infinite.*

Proof. Firms anticipate that the abatement targets will be lower in the non-cooperative case, given that governments do not take into account the externality caused by the country's emissions. Therefore, firms invest less as the marginal return to their investment is lower. This can be seen by comparing equations 17 and 21. Given the governments choose not to cooperate, the investment by firms is equal to the levels chosen by the social planner, if the number of firms is infinite. As in the cooperative outcome, the permits markets can be used as an instrument to solve the inefficiency introduced by the timing. The efficient level of investment under non-cooperation is indeed given by:

$$k_i = \frac{a^2}{4}$$

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This proposition also confirms the results by Gersbach and Glazer (1999). As shown in Appendix B, this efficient level of investment would not be chosen in the case governments were to choose regulation rather than permits.

4.2 Nash-bargained agreement

In the case of national emissions permits markets, a Nash bargaining process allows for the allocation of the surplus of cooperation over non-cooperation through a transfer. The transfer must be agreed upon in order to make each country at least as well off in the agreement as in its outside option where it would act non-cooperatively and freeride. It gives governments the incentives to participate in the agreement. The agreed targets, functions of aggregate investment levels, will be similar to the Pareto efficient reductions agreed to in the first-best, given in equations (13).

For Home, I substract social welfare under non-cooperation, given in equation (20), from social welfare with cooperation and national permits (equation (14)) and obtain the surplus:

$$S = a^2 \sum_{i=1}^{n} k_i^* - \frac{{a^*}^2}{2} \sum_{i=1}^{n} k_i \tag{22}$$

The effect of Home firms' investment on Home's social welfare is smaller under cooperation than under non-cooperation due to the public good nature of abatement. This is a key element of the model, and the results detailed below crucially depend on it. Part of the benefits from investment are captured by Foreign when there is full cooperation as reductions are higher when the Home government takes into account the positive effect of its abatement on Foreign. For example, one can take the case in which investment is given and Home does not benefit from reductions ($a = 0$). In the non-cooperative case, its social welfare is zero and it does not abate. In the cooperative case, it takes into account the fact that its reductions positively affect Foreign, assuming Foreign does benefit from global reductions ($a^* > 0$). It would then decide to reduce its emissions, and the higher the exogenous investment, the higher the abatement, as it equates the global marginal benefit of reductions to the national marginal cost which is increasing in investment. In this extreme case, the cooperative social welfare for

Home is negative, and therefore so is the surplus of cooperation over non-cooperation. This explains why Home's surplus depends negatively on Home's investment. Similarly, the surplus for Foreign is:

$$S^* = {a^*}^2 \sum_{i=1}^{n} k_i - \frac{a^2}{2} \sum_{i=1}^{n} k_i^* \tag{23}$$

Adding up equations (22) and (23) confirms that the total surplus is always positive or zero, as shown in equation (24). In my example above with $a = 0$ and $a^* > 0$, although Home's social welfare under cooperation and surplus would have both been negative, the counterparts in Foreign would have been positive and higher in absolute value, so that the total surplus is positive. This ensures there will always be gains from negotiation.

$$S^T = \frac{{a^*}^2}{2} \sum_{i=1}^{n} k_i + \frac{a^2}{2} \sum_{i=1}^{n} k_i^* \geq 0 \tag{24}$$

It reflects the public good nature of emissions abatement. Home aggregate investment will only have a positive effect on total surplus if Foreign cares about reductions and $a^* > 0$, because in that case, there will be a positive effect on Foreign's surplus of Home internalising the externality of its emissions. The negative effect of a country's investment on its own surplus that was explained above is smaller than the positive effect it has on the other country's benefit of cooperating.

Assuming equal bargaining power, the Nash maximand will be maximised in order to derive the transfer needed from Home to Foreign to ensure participation in the agreement[1].

$$Max_t(V^F - t - V^{NC})^{\frac{1}{2}}(V^{F*} + t - V^{NC*})^{\frac{1}{2}} \tag{25}$$

The first-order condition of this maximisation problem yields the equilibrium transfer.

$$t = \frac{S^2 - S^{*2}}{2(S + S^*)} \tag{26}$$

$$= \frac{3}{4}a^2 \sum_{i=1}^{n} k_i^* - \frac{3}{4}{a^*}^2 \sum_{i=1}^{n} k_i \tag{27}$$

Notice that if countries had the same preferences and the same amount of aggregate investment, the transfer would be zero. The transfer from Home to Foreign shares the surplus, and ensures that both Home and Foreign agree to the agreement. The transfer from Home to Foreign is increasing in Home's surplus: the more a country relatively benefits from cooperation versus non-cooperation, the more it will need to compensate the other country to ensure it participates in the agreement.

As a result of this transfer, social welfare levels under a Nash bargaining agreement with national permits markets (NB) will be:

$$V^{NB} = V^F - t = \frac{a^2 + 4aa^*}{4} \sum_{i=1}^{n} k_i^* + \frac{2a^2 + {a^*}^2}{4} \sum_{i=1}^{n} k_i \tag{28}$$

$$V^{NB*} = V^{F*} + t = \frac{{a^*}^2 + 4aa^*}{4} \sum_{i=1}^{n} k_i + \left[\frac{2{a^*}^2 + a^2}{4}\right] \sum_{i=1}^{n} k_i^* \tag{29}$$

[1] With equal bargaining power, the transfer is equivalent to sharing equally the surplus of the agreement, such that $V^{NB} = V^{NC} + \frac{1}{2}\left[(V^{NB} + V^{NB*}) - (V^{NC} + V^{NC*})\right]$, where V^{NB} is the welfare under Nash-Bargaining. This is can be shown, as $V^{NB} = V^F - t$ such that $(V^{NB} + V^{NB*}) = (V^F - t) + (V^{F*} + t)$ and therefore, $t = (V^F - V^{NC}) + \frac{1}{2}\left[(V^{NB} + V^{NB*}) - (V^{NC} + V^{NC*})\right]$ and $S^W = \left[(V^{NB} + V^{NB*}) - (V^{NC} + V^{NC*})\right]$.

The resultant social welfare functions are increasing in the aggregate investment levels of both countries and in both the preference parameters a and a^*. This is different from the full cooperation case where a country's welfare function could be decreasing in its own investment. In the Nash bargaining case, the transfer ensures participation in the agreement and therefore, in all cases, social welfare will be increasing in aggregate investment.

Given there is no government budget, it is assumed that the firms in each country pay the cost or receive the benefit of the transfer. Firms anticipating that their government will decide on targets at time 2 through Nash bargaining, with equal bargaining power, assume they will have to have to meet an emissions reduction target or buy permits as in the first-best case for $\frac{M^F}{n}$, but also pay a share n of the transfer which is needed to ensure participation in the agreement. Their maximisation problem in determining their investment level at time 0 will therefore be the following:

$$Max_{k_i}\pi_i - \frac{t}{n} - k_i^2 \tag{30}$$

in which the revenue at time 2 is defined in equation (9) and k_i^2 is the investment cost. A comparable situation occurs in Foreign. This yields the following investment by firms at time 0 in Home and Foreign respectively in the case of Nash bargaining with a national permits market:

$$k_i^{NB} = \frac{(n-2)(a+a^*)^2}{4n} + \frac{3a^{*2}}{8n} \text{ and } k_i^{NB*} = \frac{(n-2)(a+a^*)^2}{4n} + \frac{3a^2}{8n} \tag{31}$$

The investment choices yield the following proposition:

Proposition 2 *In the case of a global public good, firms anticipate their government will agree on targets under a Nash bargained agreement with a national emission permit market and will over-invest relative to the cooperative level of investment: $k_i^{FB} \geq k_i^{NB} \geq k_i^{SB}$ and $k_i^{FB*} \geq k_i^{NB*} \geq k_i^{SB*}$. Investment is higher than the second-best level. It is lower than the first-best unless the number of firms is infinite.*

Proof. The investment decisions are derived in equations (17) in the cooperative outcome and equations (31) such that the proposition follows. ■

Due to the inefficiency introduced by the timing of the game, the first-best cannot be reached per se. Using an emission permits market as policy instrument allows the first-best levels of investment to be approached in the second-best when the number of firms is large. The investment under Nash-bargaining with emission permits markets is higher than this level, and will approach the first-best as the number of firms approaches infinity: $\frac{\partial\left(k_i^{FB}-k_i^{NB}\right)}{\partial n} \leq 0$ and $\lim_{n\to\infty} k_i^{NB} = k_i^{FB}$. The over-investment can be explained in the following way. Due to the public good nature of emission reductions, a firm's higher investment reduces the surplus of cooperation over non-cooperation, as detailed above. This improves the government's bargaining position and reduces the transfer paid by its country (or increases the transfer received). In order to participate in the agreement, the government wants its country to be compensated for the higher investment its firms have realised in R&D as it reduces the cost of abating world emissions if cooperative abatement levels are chosen, whatever the preference of that country for reductions. The transfer is negatively related to domestic firms' investment. As each firm pays a share n of the transfer, it will then benefit from a lower transfer. The return to investment differs from the cooperative outcome because of the negative effect of investment on the transfer from Home to Foreign. Therefore, the anticipation of Nash bargaining increases a firm's return on its investment with respect to the second-best. This yields over-investment. Although the transfer would be zero if the countries were symmetric, there would still be over-investment as firms do not integrate the effect of foreign firms on the transfer and only consider the effect of their own investment. The government needs to be compensated for the fact that by cooperating, Foreign benefits from its reductions and therefore from its investment. This is reflected in the over-investment component $\frac{3a^{*2}}{8n}$ depending on a^*, Foreign's preference for world reductions, and not a. Appendix A proves that this result holds equivalently in the case of international permits markets, in which case the transfers are replaced by a different allocation of targets.

Given these investment levels, the equilibrium agreed targets will be higher than the second-best, and the social welfare levels will be greater than the second-best for the country with the lowest preference for emissions reductions (a), and lower for the country with the highest preference. If countries have an equal preference ($a = a^*$), then the social welfare levels will be equal under the second-best and Nash bargained agreement.

The over-investment result is of a completely different nature to the hold-up identified by Gersbach and Glazer (1999), as it occurs through the bargaining-position effect of investment. It uses however these authors' result by introducing up front permits and not regulation, as justified in Appendix B. By operating in a one-country set-up, their paper does not consider the same type of issue at all. This paper's focus is rather on how investment by firms affects international bargaining positions and how this feeds back into the level of investment in R&D.

The results in Proposition 1.2 contradicts the results of McLaren (1997) and Wallner (2003) who demonstrated a hold-up problem whereas I here show there is over-investment by firms who anticipate a negotiation. This is due to the global public good nature of the problem. The benefits from emission reductions in one country also affect the welfare of the other country. As a result, at the point of negotiation, the first best welfare, and the outside option non cooperative welfare are both a function of the investment of both countries. So is the surplus of the agreement where k_i and k_i^* are both in equations (22) and (23). This means that for example, home's investment has an effect on the relative bargaining position of both countries. Most importantly, and in contrast to the mechanism at play in the previous papers of the literature, the surplus is reduced by firms' investment, thus improving the bargaining position. Another important mechanism behind my result, is that firms do not anticipate the fact that firms in the other country are investing. If they would take the other country's investment into account (or if both countries were integrated), they would invest at a second-best level.

The over-investment is caused by the Nash bargaining and is different from a classic freerider problem. If the contract were fully cooperative, the possibility of verifying R&D investment, and thus writing a full contract between firms and governments, would solve the over-investment. In the Nash bargaining, the outcome is better than non cooperative solution, however the unverifiability creates the over-investment.

The result presented above is obtained by isolating the firms' efforts in reducing GHG emissions. Not taking into account their main activity abstracts from other determinants of firms' investment in R&D, such as profitability and competitiveness issues. Also, it concentrates only on the effect of the anticipation of future agreements, while it is certain that past agreements will also be affecting investment choices. The result obtained in this partial equilibrium could therefore be weighted in future research against other effects present in a general equilibrium. However, the model does shed light on a particular mechanism and yields the over-investment result, something that has not been pointed up in the literature so far.

5 Conclusion

In the ongoing debate on climate change and how best to deal with it, the importance of R&D into new technologies has often been stressed. Given the global character of the problem, it is bound to be dealt with in international negotiations. How R&D investment affects these negotiations, and how the anticipation of such agreements affects firms' behaviour ex ante is therefore a very relevant question.

This paper has developed a model where international agreements on GHG emissions reductions are viewed as Nash bargained outcomes. It seeks to understand the effect of R&D investment by firms in a given country on the bargaining position of that country at the international level. By considering the case of a global public good, it mainly contributes to the literature that regards international agreements as incomplete contracts. It shows that the end result of under-investment in the case of international negotiations depends on the nature of the problem being negotiated and thus differs from previous results in the literature. The novel finding is that, in the case of global public goods, there will be no hold-up, but rather over-investment by firms that anticipate a Nash bargaining procedure. As their investment reduces the surplus of the agreement by affecting social welfare to a lesser extent under cooperation than under non-cooperation, it improves the bargaining position of their country. The return on their sunk investment is higher and they invest more. Also, regulation is ruled out in the paper in order to avoid another type of hold-up problem previously identified in the literature when there are no permits markets. By avoiding this hold-up, the model concentrates on the effect of investment on international bargaining and isolates the novel over-investment result.

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A National vs. International emissions permits markets

This appendix confirms that in the setting of this paper, national and international emissions permits markets are equivalent. Considering the case where countries would have agreed at time 1 to allow for cross border permits trading, the maximisation problem for firm i at Home is identical and leads to the same first order condition as in equations (5) and (6).

The international nature of the emission permits market implies that firms can now trade across borders. The market clearing condition equates total world emission reductions and total world targets by governments as denoted in equation (32) where FBI stands for "First-best - International permits market".

$$\sum_{i=1}^{n} v_i + \sum_{i=1}^{n} v_i^* = M^{FBI} + M^{FBI*} \tag{32}$$

The international price for permits will thus be:

$$p^{FBI} = \frac{\left(M^{FBI} + M^{FBI*}\right)}{\left(\sum_{i=1}^{n} k_i + \sum_{i=1}^{n} k_i^*\right)} \tag{33}$$

The international price is consequently a function of world total reduction targets and world aggregate investment. In parallel with equation (9), the total revenue for firm i at Home at time 2 when there is international permits trading, not accounting for investment at time 1 which is sunk, is then:

$$\pi_i^I = \frac{\left(M^{FBI} + M^{FBI*}\right)^2 k_i}{2\left(\sum_{i=1}^{n} k_i + \sum_{i=1}^{n} k_i^*\right)^2} - \frac{\left(M^{FBI} + M^{FBI*}\right)^2 m}{n\left(\sum_{i=1}^{n} k_i + \sum_{i=1}^{n} k_i^*\right)} \tag{34}$$

The share of aggregate reductions that is committed to by the Home government is denoted m. It affects firm level profits negatively. The effect of investment k_i on profits at time 2 is positive, as the cost of investment is sunk and it reduces the cost of meeting the target, both through a lower price of permits and a smaller cost of abatement. The effect of aggregate reductions $\left(M^{FBI} + M^{FBI*}\right)$ on profits will be determined by relative investment by domestic and foreign firms and the share of abatement m. Contrarily to the national permits case, the revenue of permits sales and costs of permits purchase will not necessarily cancel out, such that the total cost for all n firms in Home to meet the government's target M^{FBI} when there are international permits is:

$$\sum_{i=1}^{n} C(v_i, k_i) = \frac{\left(M^{FBI} + M^{FBI*}\right)^2 m}{\left(\sum_{i=1}^{n} k_i + \sum_{i=1}^{n} k_i^*\right)} - \frac{\left(M^{FBI} + M^{FBI*}\right)^2 \sum_{i=1}^{n} k_i}{2\left(\sum_{i=1}^{n} k_i + \sum_{i=1}^{n} k_i^*\right)^2} \tag{35}$$

The cost is increasing in the share of aggregate reductions agreed to by Home, as this will shift an extra burden to firms in the country. In most cases, aggregate national cost will be increasing in the aggregate international target, unless again m is small and Home firms have invested more than Foreign. This expression is identical to equation (10) if the countries are symmetric and $M^{FBI} = M^{FBI*}$.

A similar equation holds in Foreign, such that the total cost for Foreign and Home firms is:

$$\sum_{i=1}^{n} C(v_i, k_i) + \sum_{i=1}^{n} C(v_i^*, k_i^*) = \frac{\left(M^{FBI} + M^{FBI*}\right)^2}{2\left(\sum_{i=1}^{n} k_i + \sum_{i=1}^{n} k_i^*\right)} \tag{36}$$

which is increasing in the aggregate target fixed and decreasing in aggregate cost. Anticipating this cost function and selecting an international permits market structure, governments will maximize joint social welfare when choosing the first best targets at time 1:

$$Max_{M^{FBI}, M^{FBI*}} (a + a^*) \left(M^{FBI} + M^{FBI*}\right) - \frac{\left(M^{FBI} + M^{FBI*}\right)^2}{2\left(\sum_{i=1}^{n} k_i + \sum_{i=1}^{n} k_i^*\right)} \tag{37}$$

The first order condition of this maximisation problem is expressed in equation (38).

$$\left(M^{FBI} + M^{FBI*}\right) = (a + a^*) \left(\sum_{i=1}^{n} k_i + \sum_{i=1}^{n} k_i^*\right) \tag{38}$$

This equation does not pin down a particular value for each target, but rather an optimal total value of targets. This is due to the presence of international permits implying that the first best allocation of costs will occur naturally through the market and that only the aggregate level of reductions affects welfare. As governments already internalise the inter-country externality in their decisions on the national permits scenario, there is no additional welfare gain to an international trade in permits. The total emission reductions target needed to reach first best can be allocated to each country indifferently, given that permits will ensure that this target is achieved at least cost by equating marginal costs across countries. The effect on social welfare however is affected by m, the share of total abatement allocated to Home. The allocation of particular targets to each country is assumed to be the result of a bargaining process between the two governments: although the total reductions are chosen optimally, the burden of the cost does vary with this allocation. The solution is thus indeterminate. For simplicity, I assume the outcome of these negotiations will be such that social welfare levels are identical to the case where permits cannot be traded across borders, as given in equations (14) and (15). This will ensure participation in the agreement:

$$V^{FBI} = V^{FN} \text{ and } V^{FBI*} = V^{FN*} \tag{39}$$

Given this assumption, the targets fixed in the international permits market case will be equal to the national case:

$$
\begin{aligned}
M^{FBI} &= M^{FN} = m \times (a+a^*)\left(\sum_{i=1}^{n} k_i + \sum_{i=1}^{n} k_i^*\right) = (a+a^*)\left(\sum_{i=1}^{n} k_i\right) \\
\text{or, } m &= \frac{\left(\sum_{i=1}^{n} k_i\right)}{\left(\sum_{i=1}^{n} k_i + \sum_{i=1}^{n} k_i^*\right)}
\end{aligned} \tag{40}
$$

The investment behaviour of firms at time 1 will not vary between the national and the international permits cases, as the Home target, cost functions (equations (10) and (35)) and revenue function (equations (9) and (34)) they anticipate for time 2 are identical. With the simplifying assumption on the determination of m, equation (41) therefore holds.

$$
k_i^{SB} = k_i^{SBI} \text{ and } k_i^{SB*} = k_i^{SBI*} \tag{41}
$$

These investment levels of firms constitute my benchmark of the second-best, whether with national or international permits markets.

The international emissions permits market gives a more realistic outcome to the case of Nash bargaining, as it will allow for another form of transfer between countries. Rather than assuming a pure monetary transfer it could be envisaged as a different allocation of targets M^{NBI} and M^{NBI*} (NB for Nash Bargaining - International permits market), in which the total reduction of emissions remains at its first best level.

$$
M^{NBI} + M^{NBI*} = M^{FBI} + M^{FBI*} = (a+a^*)\left(\sum_{i=1}^{n} k_i + \sum_{i=1}^{n} k_i^*\right) \tag{42}
$$

If the transfer was positive, it corresponds to Home having a higher allocated target M^{NBI} and Foreign a lower target M^{NBI*} and Home firms having to buy permits from Foreign firms. The assumption that welfare levels under national and international permits would not differ, as summarised in equation (39), carries over to the Nash bargained agreement. The social welfare levels with international permits must then correspond to equations (28) and (29) defining the Nash bargaining and national markets outcome. The only difference should be that instead of reaching it through a transfer, a different allocation of the total reductions, m^{NB} will be agreed to.

$$
V^{NBI} = a(M^{NBI} + M^{NBI*}) - \frac{\left(M^{NBI} + M^{NBI*}\right) m^{NBI}}{\left(\sum_{i=1}^{n} k_i + \sum_{i=1}^{n} k_i^*\right)} + \frac{\left(M^{NBI} + M^{NBI*}\right)^2 \sum_{i=1}^{n} k_i}{2\left(\sum_{i=1}^{n} k_i + \sum_{i=1}^{n} k_i^*\right)^2} = V^{NB} \tag{43}
$$

The same applies in Foreign with $V^{NBI*} = V^{NB*}$. As a result, the agreed target for each country can be defined and related to the transfer.

$$
\begin{aligned}
M^{NBI} &= M^{FI} + \frac{t}{(a+a^*)} \\
&= \left[\frac{4a^2 + 2aa^* + a^{*2}}{4(a+a^*)}\right] \sum_{i=1}^{n} k_i + \frac{3a^2}{4(a+a^*)} \sum_{i=1}^{n} k_i^*
\end{aligned} \tag{44}
$$

$$
\begin{aligned}
M^{NBI*} &= M^{FI*} - \frac{t}{(a+a^*)} \\
&= \left[\frac{4a^{*2} + 2aa^* + a^2}{4(a+a^*)}\right] \sum_{i=1}^{n} k_i^* + \frac{3{a^*}^2}{4(a+a^*)} \sum_{i=1}^{n} k_i
\end{aligned} \tag{45}
$$

The aggregate target corresponds to the first best level ($M^{FI} + M^{FI*}$), and therefore to the Nash bargained case with national permits. However, individual targets differ as they replace the monetary transfer. As in the national markets case, if transfers are zero, the only difference between the first best with permits and the Nash bargained agreement, is in the anticipation that firms make on the effect of their investment on the outcome of negotiations. In the international permits market case, they would receive emission quotas of $\frac{M^{NBI}}{n}$, but no transfer to contribute to . This corresponds to a profit at time 2 of π_i^{NBI}. The profit maximisation problem at time 0 will hence be :

$$Max_{k_i}\pi_i^{NBI} - k_i^2 \tag{46}$$

in which π_i^{NBI}, the anticipated revenue at time 2 will incorporate the agreed target M^{NBI}. At time 0, firm i will hence choose an investment level of k_i^{NBI} (Home) or k_i^{NBI*} (Foreign):

$$k_i^{NBI} = \frac{(n-2)(a+a^*)^2}{4n} + \frac{3a^{*2}}{8n} \tag{47}$$

$$k_i^{NBI*} = \frac{(n-2)(a+a^*)^2}{4n} + \frac{3a^2}{8n} \tag{48}$$

These are similar to the investment levels chosen under a national permits market, k^{NB} and k^{NB*}, given that governments will be shifting the cost of the agreement and of reductions to firms, be it through the transfer or the emissions targets. By comparison with the second-best cooperative outcome with international permits, it follow that:

$$k_i^{NBI} > k_i^{SBI} \text{ and } k_i^{NBI*} > k_i^{SBI*} \tag{49}$$

Proposition 1.2 therefore carries over to the case with international permits The intuition behind this surprising result is similar to that of the national permits case. When choosing their investment level, firms equate the marginal cost of investment at time 0 with the expected marginal benefit of investment on the return or profit at time 2. In the international permits market case, this return is a function of aggregate investment levels, aggregate reductions agreed and the share of reductions negotiated by Home, such that the marginal benefit of investment depends on several elements, as presented in equation 50.

$$\frac{d\pi_i^{NBI}}{dk_i} = \frac{\partial\pi_i^{NBI}}{\partial k_i} + \frac{\partial\pi_i^{NBI}}{\partial(M^{NBI}+M^{NBI*})}\frac{\partial(M^{NBI}+M^{NBI*})}{\partial k_i} + \frac{\partial\pi_i^{NBI}}{\partial m^{NBI}}\frac{\partial m^{NBI}}{\partial k_i} \tag{50}$$

Comparing to the second-best marginal benefit with international permits, the first two terms of this expression will be identical, given that the aggregate reductions are equal in both cases. The last term comprises two parts. The effect of the share of aggregate reductions for Home on firms' return at time two is equal in both cases too, $\frac{\partial\pi_i^{NBI}}{\partial m^{NBI}} = \frac{\partial\pi_i^{FI}}{\partial m^{FI}} < 0$. It is negative, as a higher share of abatement for the country means more of the cost being borne by firms. The second part, $\frac{\partial m^{NBI}}{\partial k_i}$, is where the over-investment result comes from, as it is the only element that differs between the full cooperative and Nash bargaining cases. In the case of a Nash bargained agreement, firms anticipate their investment will reduce the surplus for Home government of cooperation over non-cooperation, thus improving its bargaining position and decreasing m^{NBI}. This is an effect of investment which does not occur in the full cooperation case, such that $\frac{\partial m^{NBI}}{\partial k_i} < \frac{\partial m^{FI}}{\partial k_i}$. As a consequence, given the negative effect of m^{NBI} on time 2 profits, the return to investment will be higher in the bargained outcome, and hence investment will be greater.

Intuitively, as in the national permits case, the government's bargaining position is improved when firms have invested more in R&D. For example, if it does not care much about climate change, but enters a Nash bargained agreement, its firms investment will reduce the cost of world aggregate reductions. The country will be compensated for its investment and the benefit it brings to the other country, by being allocated a lower share of the total abatement.

B Ruling out regulation

In this appendix, the outcome of firms anticipating regulation by government is compared to the national or international permits equilibrium. This justifies why I did not consider the alternative of regulation in this paper. It replicates in a different set-up the result of Gersbach and Glazer (1999).

If governments do not allow for trading, the problem of the firm at time 2 is different to what has been set out so far. Each firm must abate by the amount it is assigned to by regulation. In this case, the behaviour of firms at time 2 is determined by the target imposed by government at time 1, M^R. It is assumed that as firms are symmetric, the government will assign equal amounts to each firm. Given the specified cost function, the cost for Home firm i to meet the target will be:

$$C(v_i, k_i) = \frac{M^{R2}}{2n^2 k_i} \tag{51}$$

The aggregate cost for each country to meet the target it has chosen will thus be increasing in the chosen target and decreasing in the number of firms and the aggregate investment.

$$\sum_{i=1}^{n} C(v_i, k_i) = \frac{M^{R2}}{2n^2} \sum_{i=1}^{n} \frac{1}{k_i} \tag{52}$$

A similar cost function can be derived for Foreign. If all firms are symmetric and invest the same amount, this is equal to the total cost of reducing emissions as in the national permits case, given in equation (10). Given the anticipation of costs in equation (52), the government maximises social welfare, considering the cost of investment by firms at time 0 as sunk:

$$Max_M a\left(M + M^*\right) - \frac{M^2}{2n^2} \sum_{i=1}^{n} \frac{1}{k_i} \tag{53}$$

The resultant first-order conditions and the choice of target in the event of no cooperation and regulation (NCR) will lead to the following targets for each country:

$$M^{NCR} = an^2 \sum_{i=1}^{n} k_i \text{ and } M^{NCR*} = a^* n^2 \sum_{i=1}^{n} k_i^* \tag{54}$$

The targets are increasing in domestic aggregate investment and in the preference parameter for emissions reductions. In the case of cooperation between countries in fixing their target, the maximisation problem of governments is:

$$\begin{aligned} &Max_{M^{FR}, M^{FR*}} (a + a^*)(M^{FR} + M^{FR*}) \\ &\qquad - \frac{M^{FR^2}}{2n^2} \sum_{i=1}^{n} \frac{1}{k_i} - \frac{M^{FR*^2}}{2n^2} \sum_{i=1}^{n} \frac{1}{k_i^*} \end{aligned} \tag{55}$$

The resultant targets are increasing in the preference parameters of both countries:

$$M^{FR} = (a + a^*)n^2 \sum_{i=1}^{n} k_i \text{ and } M^{FR*} = (a + a^*)n^2 \sum_{i=1}^{n} k_i^* \tag{56}$$

As can be seen in equations (54) and (56), both in the non-cooperative and cooperative case, targets will be a function of the aggregate investment by firms. Hence, when firms invest at time 0, they will anticipate that to minimize their future costs they should invest nothing at all. This is the hold-up problem identified by Gersbach and Glazer (1999) in a single-country setting. In that case, it would be extremely costly for the government to remain committed to its regulation. The only way to induce firms to invest would be to commit to a strong penalty for not meeting the regulation. However, these authors consider that the government is unable to commit itself to the stringency of the regulation. By making the same assumption, I here replicate their result.

As in their setting, the hold-up problem they have identified can be solved by assuming that the government makes a commitment to issue marketable permits rather than opting for regulation. If firms acted cooperatively, they could collude, invest nothing and make sure that the government issues no permits, as shown in equations (13), (19) and (40), in which the chosen target is always positively related to aggregate investment. Yet, there will be an incentive for firms to deviate from such a collusion, by deciding to invest. If one firm decides to invest, it will induce the government at time 1 to issue permits. In the case of national permits, as can be seen from equation (8), if only firm j had invested, $p^{FN} = \frac{M^{FN}}{k_j}$ such that it will be the only one to make the emission reductions and will sell the other firms permits as $v_j = M^{FN}$. Given the revenue of equation (5), it would make a positive profit on the emissions market as long as there are at least two firms and that the other has not invested and will therefore not abate:

$$\pi_j^{FN} = \frac{(2n-3)M^{FN2}}{2k_j} \tag{57}$$

Profits will attract other firms into investing, so that they, too, become permit sellers, and in equilibrium, all firms will invest.

The same logic holds when considering international permits. Given the international price of equation (33), if one firm in one of the two countries deviates and invests, $p^{FI} = \frac{(M^{FI}+M^{FI*})}{k_j}$. With the original definition of revenue in equation (34), firm j's return at time 2 is then given by equation (58).

$$\pi_j = \frac{(n-2)\left(a+a^*\right)^2 k_j}{2n} \tag{58}$$

As long as there is a total of at least three firms in both countries, this anticipated revenue will be positive and induce other firms to invest, too. In equilibrium, when firms anticipate that governments will introduce an international permits market, all firms will invest. The result differs slightly to that of Gersbach and Glazer (1999) given that the investment decision is continuous and not binary, such that investment will be increasing in the number of firms in the country. However the main mechanism at play remains equivalent to that in their paper.

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