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# Strategic Climate Policy with Offsets and Incomplete Abatement

## Carbon Taxes Versus Cap-and-Trade

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## Abstract

This paper provides a first analysis of optimal offset policies by a “policy bloc” of fossil fuel importers implementing a climate policy, facing a (non-policy) fringe of other importers, and a bloc of fuel exporters. The policy bloc uses either a carbon tax or a cap-and-trade scheme, jointly with a fully efficient offset mechanism for reducing emissions in the fringe. The policy bloc is then shown to prefer a tax over a cap-and-trade scheme, since 1) a tax extracts more rent as fuel exporters reduce the export price, and more so when the policy bloc is larger relative to the fringe; and 2) offsets are more favorable to the policy bloc under a tax than

under a cap-and-trade scheme. The optimal offset price under a carbon tax is half the tax rate; under a cap-and-trade scheme the quota and offset price are equal. The domestic carbon and offset price are both higher under a tax than under a cap-and-trade scheme when the policy bloc is small; when it is larger the offset price can be higher under a cap-and-trade scheme. Fringe countries gain by mitigation in the policy bloc, and more under a carbon tax since the fuel import price is lower, and since the price obtained when selling offsets is often higher (always so for a large fringe).

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# **Strategic Climate Policy with Offsets and Incomplete Abatement: Carbon Taxes Versus Cap-and-Trade\***

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## 1. Introduction

Today only countries under Annex B of the Kyoto Protocol, who have ratified the Protocol, have policies which include formal climate policy targets. These countries might, sooner or later, be joined by other high-income countries (including the U.S.) and later perhaps by major emerging economies, in establishing formal climate policies. What seems out of the question, for the foreseeable future, is that a set of comprehensive climate policies will be enacted for all greenhouse gas emitters.

Countries with comprehensive climate policy policies comprise no more than 25 percent of global carbon emissions today. Their policy takes the form of a binding cap on emissions valid for the period 2008-2012. This cap includes an “offset” scheme, the so-called Clean Development Mechanism (CDM), whereby abatement of carbon emissions, to comply with the overall cap, can be purchased from countries that do not have a climate policy. An objective of the CDM is to make it easier (and less costly) for emitters in the policy countries to abide with these countries’ overall emissions cap.

Climate policy could, alternatively, take the form of a carbon tax. No comprehensive carbon tax policy is so far used or seriously contemplated.<sup>1</sup> To most observers the differences between a climate policy involving a carbon tax, and a cap equivalent to (expected) emissions under a tax, are small and not decisive for the choice of policy.<sup>2</sup> Two, widely recognized, differences are that under uncertainty the effects differ as only the emissions level will vary under a tax, while only

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<sup>1</sup> A few smaller nations, including Norway already from 1991, have enacted unilateral and relatively comprehensive carbon taxes. But these countries constitute a very small fraction of global emissions; and their carbon tax rates are too low to matter neither locally nor globally.

<sup>2</sup> We will here focus on carbon emissions from fossil fuels. While there are other greenhouse gas emissions, fossil-fuel based emissions are the most important and likely to become more so over time.

the emissions price will vary under a cap;<sup>3</sup> and that the government's ability to recuperate income may be greater under a tax as many or most emissions permits are often handed out for free to emitters under a cap. Both differences speak in favor of a tax over a cap.<sup>4</sup>

This paper focuses on two other differences between taxes and caps that have so far been less widely discussed. First, carbon taxes and c-a-t schemes work differently when policy countries are net fossil fuel importers, and exporters behave strategically. Secondly, offset schemes may work differently under the two policies. Both differences, it is shown, tend to favor taxes over c-a-t for the countries implementing (or benefiting from) a climate policy.

In my model it is assumed that all countries can be split meaningfully into two groups, importers, and exporters, of fossil fuels. Most major countries belong to the first group, including all countries that may wish to establish a climate policy. The exporting group is smaller, notably the OPEC countries and Russia.<sup>5</sup> The importing group is divided into a "policy bloc" of fuel-importing countries (today, Annex B countries that have ratified Kyoto) is assumed to pursue a climate policy; and a "fringe" (today, all fuel-importing emerging and developing countries, plus the U.S.) with no policy. The latter group acts without coordination, each perceiving no market power in fuel markets.

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<sup>3</sup> Weitzman's (1974) static analysis supports the view that when uncertainty takes the form that benefits (in terms of reduced climate change) of mitigation policy are less uncertain than costs in the short run (which, arguably, is the case in practice), a tax solution is preferred on welfare grounds. For dynamic analyses supporting the same basic view, see Hoel and Karp (2001, 2002), Pizer (2002), and Karp and Costello (2004).

<sup>4</sup> A third, politically important, difference between taxes and caps is in terms of transparency of gains and losses to different affected parties. Under c-a-t it is much easier to make these distributional implications obscure. This may be a political reason why many countries seem to opt for c-a-t solutions, despite of the drawbacks pointed out. We will here ignore such issues by focusing entirely on more standard economic arguments.

<sup>5</sup> Norway is an outlier which, arguably, belongs to both groups.

The producer and policy blocs are each assumed to coordinate their policies fully *within* each bloc. Policies are not coordinated *across* blocs. The model is static in focusing on short-run demand and supply relations. Dynamic issues, in particular the exhaustibility of fossil fuels and the dynamics of climate change, are not studied.<sup>6</sup> In particular, Sinn's (2008) "green paradox" argument that carbon pricing could lead to increased emissions in the short run, is ignored.<sup>7</sup>

The policy bloc establishes an offset scheme for inducing abatement in the fringe, out of two potential motivations. First, overall emissions can thus be further reduced, perhaps more cheaply than through mitigation in bloc countries alone. Secondly, reduced fuel demand in the fringe may help to reduce aggregate fossil fuel demand and thus the fuel export price. Under c-a-t, I assume that the entire market for quotas is competitive with a unitary trading price in both the policy bloc and fringe. Fringe country emitters must then be paid an amount per abated emissions equal to the quota price facing policy country emitters. Under a carbon tax the idea of an offset scheme is less familiar, and it is less obvious how this should be modeled. I here assume that offsets are purchased from fringe countries by the policy bloc at a given offset price, set by this bloc, which clears the offset market in fringe countries. This offset price could then in principle be either

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<sup>6</sup> This requires a dynamic model for a more complete analysis. For related dynamic presentations, see e.g. Bergstrom (1982), Karp (1984), Karp and Newbery (1991); and more recently, Rubio and Escriche (2001), Rubio (2005), Liski and Tahvonen (2004), and Salo and Tahvonen (2001).

<sup>7</sup> A main issue here is the profile of both current and expected future carbon taxes. It can be shown that if the future carbon tax is expected to increase at a particularly rapid rate (in excess of the rate of discount), an increase in the general level of carbon taxation could induce Sinn's paradox by increasing emissions in the short run. Another factor is that if climate policy partly takes the form of support to developing a backstop for replacing fossil fuels, emissions may be worsened in the short run by more stringent climate policy; see e.g. Strand (2007), Ploeg and Withagen (2010), and Hoel (2010) with further discussion of the green paradox.

higher or lower than the carbon tax charged to policy bloc emitters. Importantly also, we assume no informational problems in implementing offsets and that all offsets are “additional”.<sup>8</sup>

The preference for taxes over c-a-t for fuel importers were shown by Berger, Fimreite, Golombek and Hoel (1992), and Berg, Kverndokk and Rosendahl (1997). Strand (2010) considers a similar model only with no offset market. Strand (2011) considers two fuels, one imported (oil) and one produced by consumer countries. Importers’ oil demand is then somewhat elastic under a cap, allowing some rent extraction by importers. A tax policy here still dominates a cap policy for fuel importers. See Wirl (2010) for a recent dynamic model (focusing on unitary importer and exporter blocs), where taxes are also shown to dominate over caps as climate policy instruments for fossil fuel importers.

## 2. Model 1: The Policy Bloc Sets a Carbon Tax

### 2.1 Basics

Consider the following aggregate utility function related to fossil-fuel consumption for countries with a climate policy (the “policy bloc”):

$$(1) \quad W_1 = R_1 - \frac{1}{2}\gamma_1 R_1^2 - pR_1 - c_1 R - q\Delta R_F,$$

where  $\gamma_1 > 0$ .  $p$  = the fossil fuel import price.  $R_1$  is the fossil-fuel consumption for the policy bloc, while  $R$  is global fossil-fuel consumption, while  $c_1$  = a climate externality cost per unit of global fossil fuel consumption for this group of countries. Equation (1), and other demand and

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<sup>8</sup> While full additionality is our benchmark assumption, less than full additionality is likely to be the norm in practice, for a variety of reasons; see e.g. Rosendahl and Strand (2009). Less than full additionality will in practice make offsets less efficient and thus less attractive for the policy bloc.

supply functions, all take “linear-quadratic” forms standard in the literature (and as in related work by Strand (2009, 2011)). We assume (with little loss of generality) that fossil-fuel importers produce no fuels, and that producer countries consume no fossil fuels and export all their production.

Let  $R_F$  denote fuel consumption in the fringe. In equation (1), the last term represents an assumption that the countries in the policy bloc are able to induce a reduction of the fringe’s fossil fuel consumption through a subsidy  $q$  to those units of fossil fuel consumption in the fringe that yield the smallest net benefit from such consumption (so that this abatement is done in the most efficient way possible). This term expresses the net outlay by the policy bloc, related to such incentive payments from the policy bloc to the fringe. Such payments would represent a mechanism under a carbon tax scheme that would correspond closely to the effect of standard offset markets under a c-a-t scheme (such as the CDM). The “offset price”,  $q_1$  (with subscript 1 denoting “model 1”), here however differs somewhat from the offset trading price under a c-a-t scheme, in particular as it is not necessarily identical to the domestic tax on emissions. The difference lies in the fact that under a c-a-t scheme, market mechanisms would tend to equalize external carbon trading prices with quota prices within the c-a-t scheme; which does not take place here.

Under model 1, the policy bloc thus uses two instruments. First, it imposes an excise tax,  $t_1$ , per unit of the imported fossil fuel. This leaves the consumer fuel price in these countries at  $p+t_1$ . Fossil fuels are imported by many small agents, each of whom behaves competitively. The public (private sector) demanding fossil fuels in this group of countries maximizes

$$(2) \quad V_1 = R_1 - \frac{1}{2} \gamma_1 R_1^2 - (p + t_1) R_1$$



with respect to  $R_1$ , yielding the first-order condition

$$(3) \quad R_1 = \frac{1-p-t_1}{\gamma_1}.$$

$\gamma_1$  is the inverse demand sensitivity of fossil fuels with respect to price in the policy bloc.

There also exists a fringe of fuel-importing countries with no climate policy (with subscripts F), with aggregate utility function (in the absence of transfers from the policy bloc)

$$(4) \quad W_{F0} = R_{F0} - \frac{1}{2}\gamma_F R_{F0}^2 - pR_{F0} - c_F R,$$

where subscript 0 denotes the case with no transfers.  $c_F$  is the climate-related externality of global fossil fuel consumption for the fringe. These countries in aggregate behave competitively.

In the absence of transfers these countries would maximize

$$(5) \quad V_{F0} = R_{F0} - \frac{1}{2}\gamma_F R_{F0}^2 - pR_{F0}$$

with respect to  $R_{F0}$ , yielding the first-order condition

$$(6) \quad R_{F0} = \frac{1-p}{\gamma_F},$$

where  $\gamma_F (> 0)$  is the inverse demand sensitivity for the fringe. (2) and (5) imply an assumption that the two blocs have identical demand functions for the fossil fuel apart from the parameters  $\gamma_1$  and  $\gamma_F$  which may differ. Both functions are assumed to be linear and in both cases with a limit price (at which demand vanishes) of unity, but the functions have different slopes,  $1/\gamma_1$  and  $1/\gamma_F$ . Call the slope of the (global) aggregate demand function  $1/\gamma$ . Define  $\gamma_1 = \gamma/h$ ,  $\gamma_F = \gamma/(1-h)$ , where  $h$  and  $1-h$  are the relative sizes of the policy bloc and the fringe (corresponding to their relative

levels of fuel consumption in the case where the fuel consumer price is the same in both blocs; or if the blocs are in other respects homogeneous,  $h$  and  $1-h$  would correspond to the relative sizes of the “policy bloc” and the “fringe”).

The second policy of the policy bloc is to pay a subsidy  $q_1$  per unit of “foregone fossil fuel consumption” in the fringe; i. e., consumption that would have materialized, had it not been for this subsidy.<sup>9</sup> In the case studied here, the policy bloc is assumed to provide incentives to the fringe, through incentive payments  $q_1$  per unit of reduction in fossil fuel consumption below the “benchmark” described by (6). We assume that this leads to an effective fuel price at the margin equal to  $p+q_1$ , and such that the policy bloc makes up this difference through a subsidy to fringe fuel consumers. The induced fuel consumption in the fringe is then assumed to be

$$(7) \quad R_F = \frac{1-h}{\gamma} (1-p-q_1).$$

The subsidy is assumed to be paid only on the amount of fuel consumption avoided in the fringe by the incentive payment, called  $\Delta R_F = R_{F0} - R_F$ , given by

$$(8) \quad \Delta R_F = \frac{1-h}{\gamma} q_1.$$

Aggregate fossil-fuel demand, from both blocs combined, is now

$$(9) \quad R = R_1 + R_F = h \frac{1-p-t_1}{\gamma} + (1-h) \frac{1-p-q_1}{\gamma} = \frac{1-p-h t_1 - (1-h)q_1}{\gamma}.$$

Assume a single (unified) producer country or region with aggregate utility function

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<sup>9</sup> This again requires full additionality: all off sets paid for are “real” in the sense that no offset payments are made unless these payments lead to additional abatement. As discussed in the final section, this is an idealized situation not likely to occur in reality.

$$(10) \quad W_2 = \Pi_2 + sR - c_2R,$$

where  $\Pi_2$  is net profit of petroleum producers,  $sR$  is excise tax revenue for governments in fuel exporting countries, while  $c_2R$  denotes negative emissions externalities as evaluated by the exporter. Net profits of producers are

$$(11) \quad \Pi_2 = (p - s)R - p_0R - \frac{1}{2}\phi R^2,$$

where  $p_0$  is a lower bound for marginal fuel extraction cost. Maximizing (11) with respect to  $R$  yields the fossil-fuel supply function

$$(12) \quad p = p_0 + s + \phi R.$$

$\phi (> 0)$  here represents the (inverse) supply sensitivity of petroleum output.  $s$  is the unit producer excise tax.  $p_0 + s > 0$ ; thus the supply elasticity is less than unit.

The externality cost of one unit of carbon emissions, for all fuel importers, is called  $c$ . Assume for simplicity that the externality cost for the policy bloc is proportional to the size parameter  $h$ . Thus the marginal externality cost for the policy bloc is  $hc$ , and for the fringe  $(1-h)c$ .<sup>10</sup> Individual fringe countries are however small and ignore this factor in their own decision. The global externality cost per fossil fuel unit equals  $c + c_2$ , which would correspond to a Pigou tax imposed by a benevolent global regulator, given that markets are otherwise competitive.

Solving (9) and (12) for  $R$  and  $p$  as functions of the tax parameters  $t_1$ ,  $q_1$  and  $s$  yields

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<sup>10</sup> This assumption is made for convenience and with the aim to facilitate analysis of parametric changes in  $h$ , below. Given that we always have a (sizeable) bloc with no policy, we could equally have assumed that the marginal externality cost for this bloc differs from that for the policy bloc. Indeed, we know that the impacts of climate change are likely to vary substantially across countries. A more realistic calibration of the model to the world economy would need to take such differences into consideration.

$$(13) \quad R = \frac{1 - p_0 - s - ht_1 - (1-h)q_1}{\gamma + \phi}$$

$$(14) \quad p = \frac{\gamma}{\gamma + \phi}(p_0 + s) + \frac{\phi}{\gamma + \phi}(1 - ht_1 - (1-h)q_1).$$

We also derive fuel demand for each of the two blocs as functions of the taxes  $s$  and  $t_1$  and the offset price  $q_1$ , as follows:

$$(15) \quad R_1 = \frac{h}{\gamma(\gamma + \phi)} [\gamma(1 - p_0 - s) - (\gamma + (1-h)\phi)t_1 + (1-h)\phi q_1]$$

$$(16) \quad R_F = \frac{1-h}{\gamma(\gamma + \phi)} [\gamma(1 - p_0 - s) + \phi ht_1 - (\gamma + \phi h)q_1].$$

A higher  $q_1$  increases  $R_1$  (but lowers  $R$ ), since  $p$  is reduced thus incentivizing higher policy bloc fuel demand. Indeed, this is the basic purpose for the policy bloc of “subsidizing offsets” in the fringe.

## 2.2 The policy bloc solution

An authority representing all countries in the policy bloc sets  $t_1$  and  $q_1$  to maximize  $W_1$  in (1), considering its own fuel demand response (15), the aggregate fuel demand response (13), and the export price response (14), to changes in  $t_1$  and  $q_1$ ; while the exporter tax,  $s$ , is taken as exogenous. This yields the following set of first-order conditions for the policy bloc:

$$(17) \quad \frac{dW_1}{dt_1} = (1 - \gamma_1 R_1 - p) \frac{\partial R_1}{\partial t_1} - R_1 \frac{\partial p}{\partial t_1} - hc \frac{\partial R}{\partial t_1} = 0$$

$$(18) \quad \frac{dW_1}{dq_1} = (1 - \gamma_1 R_1 - p) \frac{\partial R_1}{\partial q_1} - R_1 \frac{\partial p}{\partial q_1} - hc \frac{\partial R}{\partial q_1} - 2 \frac{1-h}{\gamma} q_1 = 0,$$

where we recognize from (3) that

$$1 - \gamma_1 R_1 - p = t_1.$$

The following two equations now solve simultaneously for  $t_1$  and  $q_1$ , expressed as functions of the exporter tax,  $s$  (taken as exogenous by the policy bloc):

$$(19) \quad t_1 = \frac{2h\gamma}{2(\gamma + \phi)^2 - h(1+h)\phi^2} [\phi(1 - p_0 - s) + (\gamma + \phi)c]$$

$$(20) \quad q_1 = \frac{h\gamma}{2(\gamma + \phi)^2 - h(1+h)\phi^2} [\phi(1 - p_0 - s) + (\gamma + \phi)c] = \frac{1}{2} t_1.$$

$t_1$  and  $q_1$  are here set, interestingly, in a strict two-to-one ratio. When  $h$  is small,  $t_1$  and  $q_1$  are both small: it is then unattractive for the policy bloc to charge high domestic carbon taxes, nor induce much carbon offsets in the fringe, for two separate reasons. First, a low  $h$  implies that the climate externality for the policy bloc,  $hc$ , is small, so that the related ‘‘Pigou’’ tax is small. Secondly, a low  $h$  implies small market power of the policy bloc in the fossil fuel market.

The offset incentive price  $q$ , in (20), is set at exactly half the level of the domestic tax  $t_1$  in the policy bloc. This is related to the fact that offset payments go to foreign actors (and not parties within the policy bloc). This affects the optimal volume of foreign offsets negatively relative to the volume of domestic offsets through the domestic carbon tax  $t$ . When the policy bloc then acts in a unified fashion, as a monopsonistic purchaser of offsets from fringe countries (which themselves act non-cooperatively), offset purchases will be limited in this particular way, to maximize the net return for the policy bloc from such purchases.

Consider next a constrained optimal carbon tax given that the offset price is exogenous, and in general not optimal. We may, for such a case, express  $t_1$  as follows:

$$(21) \quad t_1 = \frac{h}{(\gamma + \phi)^2 - h^2 \phi^2} [\gamma(\gamma + \phi)c + \gamma\phi(1 - p_0 - s) + (1 - h)\phi^2 q_1].$$

We see that when  $q_1$  is set higher (corresponding also to a larger volume of offsets),  $t_1$  is set higher in response. Intuitively, a greater amount of offsets in the fringe leads to a lower fuel export price which “gives room for” (or makes profitable) a higher carbon tax in the policy bloc.

### 2.3 The exporter solution

The producer/exporter bloc maximizes bloc welfare,  $W_2$ , with respect to its fuel export tax  $s$ , taking the supply function (12) from its own individual producers, the price relation (14), and the importer-determined tax rate and offset price,  $t_1$  and  $q_1$ , as given. The first-order condition for this problem is

$$(22) \quad \frac{dW_2}{ds} = (p - p_0 - \phi R - c_2) \left( -\frac{1}{\gamma + \phi} \right) + R \frac{\gamma}{\gamma + \phi} = 0,$$

which yields the following condition for optimal  $R$  in terms of the export price,  $p$ :

$$(23) \quad R = \frac{p - p_0 - c_2}{\gamma + \phi}.$$

We may now solve for  $s$ ,  $p$  and  $R$ , as functions of the tax  $t$  and subsidy rate  $q_1$  set by the policy bloc. We find the following solution for  $s$ :

$$(24) \quad s = \frac{\gamma}{2\gamma + \phi} (1 - p_0 - ht_1 - (1 - h)q_1) + \frac{\gamma + \phi}{2\gamma + \phi} c_2$$

As expected, the exporter's optimal fuel tax,  $s$ , is reduced in response to increases in both  $t_1$  and  $q_1$ . This effect is stronger for  $t_1$  ( $q_1$ ) when  $h > (<) 1/2$ , and the fraction of the policy bloc in total fuel demand is greater (smaller) than one half. An interesting consequence is that when offsets are applied ( $q > 0$ ), the exporter's fuel tax is lower.

## 2.4 Overall Nash Equilibrium solution

The simultaneous solution to (19) and (24) for  $t_1$  and  $s$ , given  $t_1 = 2q_1$ , here constitute a Nash Equilibrium of the non-cooperative tax-setting game between the policy bloc and the fuel exporting bloc. This solution can be characterized by

$$(25) \quad t_1 = \frac{4h\gamma}{D_1} [\phi(1 - p_0 - c_2) + (2\gamma + \phi)c]$$

$$(26) \quad s = \frac{2}{D_1} \{ [2\gamma(\gamma + \phi) - h(1+h)\gamma\phi](1 - p_0) + [2(\gamma + \phi)^2 - h(1+h)\phi^2]c_2 - h(1+h)\gamma^2c \},$$

where

$$D_1 = 2(\gamma + \phi)[2(2\gamma + \phi) - h(1+h)\phi].$$

To interpret these expressions we will mainly rely on simulations, based on simplifying parametric assumptions, in section 4.

Two further features of the solution will be considered here. The first is what we may call the “incentivized emissions” level, which describes net emissions as an outcome of incentive mechanisms applied ( $t_1$ , and  $q_1$ ), both in the policy bloc and in the fringe. This emissions level corresponds notionally to a cap to be discussed under model 2 in the next section. It can be defined by

$$(27) \quad R_{I1} = R_1 - \Delta R_F = \frac{1}{\gamma} \left[ h(1-p) - \frac{1}{2}(1+h)t_1 \right].$$

This magnitude is simulated in section 4 below, for some parametric cases. We find quite generally that  $R_{I1} > 0$  (regardless of parameter values, the emission rate in the policy bloc always exceeds the amount of emissions offset in the fringe).

The second feature is the amount of abatement taking place in the policy bloc versus fringe (in terms of reducing  $R$ ), by the tax and offset policies applied. From (13) (remembering that  $t_1 = 2q_1$ ) we find that  $R$  is reduced more (less) in the policy bloc than in the fringe given that  $h > (<)$   $1/3$ . Thus in particular, when  $h = 1/3$ , it is optimal for the policy bloc to implement equally much abatement in each of the two blocs.

### 3. Model 2: The Policy Bloc Sets a Cap

#### 3.1 Basics

In our second model, the policy bloc sets a cap on its emissions, still taking fringe demand as exogenous. A difference from Strand (2010) is that the cap can now be achieved in part through a given amount of “offsets” by the fringe. Such implemented “offsets” give room for a higher emissions rate within the policy bloc itself, given that the cap has already been set. Call the overall cap  $R_P$ , and the allowable amount offsets  $R_{FP}$ . Emissions by the policy bloc,  $R_1$ , are then given by  $R_P + R_{FP}$  (the reason being that the offsets  $R_{FP}$  give room for this much extra emissions in the policy bloc, over and above the cap that the bloc has set). Denote still by  $R_F$  the actual fringe emissions, and by  $R_{F0}$  fringe emissions in the (counterfactual, but here still well defined) case where no offsets would be induced in the fringe; then  $R_F = R_{F0} - R_{FP}$ . Actual emissions,  $R$ , are then given alternatively as  $R_1 + R_F$ , or as  $R_P + R_{F0}$ . We will in this model assume free trading



of emissions rights within the policy bloc, at a unified quota price, which we denote by  $t_2$  (so as to apply parallel symbols with the tax case).<sup>11</sup> Equilibrium in the quota market requires emissions offsets to be purchased from the fringe at the price  $t_2$ .<sup>12</sup>

I will put two constraints on the number of allowable offsets, in the amount  $R_{PF}$ . First,  $R_{PF}$  must be non-negative. Secondly, this number is, reasonably, is no greater than the amount of abatement that would take place in the fringe, given that a uniform carbon price equal to  $t$  would be enforced in the fringe. A carbon price no greater than  $t_2$ , which we may call  $q_2$ , would then implement the offset quota  $R_{OF}$ . I simplify by assuming that offsets are always implemented efficiently. By this I mean that for any one unit of potential emissions that are actually offset through incentive payments from the policy bloc to the fringe, the mitigation cost is lower than for any one unit of residual emissions (where offsets are not taking place).<sup>13</sup> Formally, we can treat the strategy of the policy bloc as setting the quota trading price of emission rights within the bloc, which will be dual to the quantity solution. This implies that the policy of the policy bloc may be viewed as determined in the same way as under policy 1, with the bloc setting a tax at the level of the equilibrium quota trading price under the optimal cap. The basic strategy of the fringe is also the same in this case as under policy.

A consequence of this is that the *amount* of offsets in the fringe, to be financed by the policy bloc, is still given by (8). The *offset price* is however different here. Remember that we now

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<sup>11</sup> Whether or not domestic quotas are auctioned off, or given out to emitters for free, plays no formal role here.

<sup>12</sup> This is a requirement for offset market equilibrium: domestic emitters in the policy bloc must be indifferent between abating one unit of emissions, and purchasing one unit of offsets whereby abatement is avoided.

<sup>13</sup> Note that this is not an obvious outcome, since, in general, the unit incentive pay by policy bloc emitters to the fringe,  $t_2$ , is generally higher than the carbon price that would otherwise implement the actual offsets taking place in the fringe, which is  $q$ .

require the offset price in the fringe to equal the domestic quota price in the policy bloc countries (equivalent to the tax  $t_2$ ) as a condition for market clearance in the overall quota market. Thus in the last expression in (1),  $q_2$  is now replaced by the domestic trading price in the policy bloc,  $t_2$ . Importantly, no similar constraint on the offset trading price was imposed in model 1, where instead policy bloc country governments were assumed to implement offsets directly via transfer payments to fringe countries, and where the offset trading price could be set freely, and optimally.

### 3.2 Importer solution

Relations (10)-(16), from model 1, are still valid here. Also, the fuel demand functions of the policy bloc and the fringe, as viewed by each, can now still be viewed as given by (3) and (6), where  $t$  in (3) is interpreted as the quota price within the c-a-t scheme in the policy bloc. In fact, little changes formally from the point of view of fuel demanders, who are at the same time emitters.<sup>14</sup> (15) still describes the strategy of the policy bloc, interpreted alternatively as the conditions for its optimal energy demand  $R_1$ , or its optimal quota price  $t$ , in either case taking the fuel import price,  $p$ , as determined by (12), where  $s$  is taken as exogenous.

Differentiating (1) with respect to  $t$  and  $q$  in this case gives the following set of equations:

$$(28) \quad \frac{dW_1}{dt_2} = (1 - \gamma_1 R_1 - p) \frac{\partial R_1}{\partial t_2} - R_1 \frac{\partial p}{\partial t_2} - hc \frac{\partial R}{\partial t_2} - \frac{(1-h)q_2}{\gamma} = 0.$$

$$(29) \quad \frac{dW_1}{dq_2} = (1 - \gamma_1 R_1 - p) \frac{\partial R_1}{\partial q_2} - R_1 \frac{\partial p}{\partial q_2} - hc \frac{\partial R}{\partial q_2} - \frac{1-h}{\gamma} t_2 = 0.$$

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<sup>14</sup> This is entirely analogous to the tax and a quota solution being formally identical for fuel consuming countries facing a given fuel import price, under full certainty and with full auctioning of emissions quotas.

The system (28)-(29) here however constitutes a saddle-point solution, where the partial derivative with respect to  $t_2$  provides a partial maximum, and the partial with respect to  $q_2$  provides a partial (local) minimum.<sup>15</sup> (28) takes the form

$$(28a) \quad t_2 = -\frac{1-h}{h} q_2 + \frac{h\gamma}{(\gamma + \phi)^2 - h^2\phi^2} \{ \phi(1-p_0-s) + (\gamma + \phi)c \}$$

(28a) must here be invoked alone to solve for  $t_2$ , together with the constraint  $q_2 \leq t_2$  (since under the problem as set up here, when  $q_2 = t_2$ , all offsets are realized that have a cost less than or equal to  $t_2$ ). Setting  $q_2 = t_2$  we find:

$$(30) \quad t_2 = q_2 = \frac{h^2\gamma}{(\gamma + \phi)^2 - h^2\phi^2} \{ \phi(1-p_0-s) + (\gamma + \phi)c \}.$$

Comparing (30) to (19),  $t_2$  is always lower here than in the tax case (for any given export tax  $s$ ); but the difference is small when  $h$  is close to one. When  $h$  is relatively low, by contrast, the difference is greater; the ratio of  $t_2/t_1$  converges to zero as  $h$  goes to zero.

In this model, all net rent arising in the offset market flows to potential emitters in the fringe. This follows from the assumption of perfect competition and free arbitrage in the offset market, so that all units in that market (whether domestic in the policy bloc or purchased from the fringe) need to be traded at a uniform price.<sup>16</sup>

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<sup>15</sup> The local minimum for  $q_2$  at the saddle point equals zero.

<sup>16</sup> Alternatively, one might open up for price differentiation, e.g. with bargaining between policy bloc purchasers and fringe sellers of emission quotas, offset trades would be more lucrative for the policy bloc. One such case is treated under model 1, where the government purchases quotas directly from fringe emitters, at lowest possible prices, independent of  $t$  (below this level).

It is thus optimal for the policy bloc to fully utilize all offsets with cost below  $t_2$ . Offsets are in general more costly to the policy bloc in this case than under model 1 (where they could be bought at a “discount” relative to the domestic tax  $t_1$ ); here they must always be paid at full cost  $t_2$ . But this also serves to reduce the internal price of carbon within the policy bloc,  $t_2$ , below  $t_1$  (the carbon tax) in model 1.

Remember that under model 1 there was no condition that offset quotas be purchased at the carbon tax rate; generally the offset price in that case,  $q_1$ , was independent of, and lower than, the carbon tax,  $t_1$ . The fact that quotas can be purchased more cheaply leads to a positive volume of offsets in the fringe, in the amount  $(1-h)q/\gamma$ . This also serves to lower the fuel import price.

In fashion similar to (21) under model 1, we can also in model 2 study the behavior of the carbon price in the policy bloc (here, the quota price) when the offset volume is not optimal, but lower than the level that clears the market in fringe countries. This is equivalent to setting  $q_2$  at lower levels (and below  $t_2$ ) in (28a). It is here immediate that a lower  $q_2$  increases  $t_2$ ; this is the direct opposite conclusion to that under model 1. The reason is that, here, there is for a given  $h$  (and given  $s$ ) a given total quota in the optimal solution. Fewer offsets then “give room for” less domestic emissions in the policy bloc, which corresponds to a higher quota price.

### **3.3 Exporter solution**

Consider now the strategy of fuel exporters. This now changes more dramatically from the case under model 1. Exporters will no longer face an importer tax but instead a cap in the amount  $R_p$ . For the fringe there is no change in strategy. Thus, instead of (9), the exporter will be perceived to face the following aggregate demand function for fuel:

$$(31) \quad R = R_1 + R_F = R_p + R_{F0} = R_p + (1-h) \frac{1-p}{\gamma}$$

where  $R_p$ , the emissions cap set by the policy bloc, now is taken as a fixed number by the exporter. We may now solve (12) and (31) for  $p$  and  $R$  to yield

$$(32) \quad p = \frac{1}{\gamma + (1-h)\phi} [\gamma(p_0 + s) + \gamma\phi R_p + (1-h)\phi]$$

$$(33) \quad R = \frac{\gamma}{\gamma + (1-h)\phi} R_p + \frac{1-h}{\gamma + (1-h)\phi} (1-p_0 - s)$$

The exporter, taking (32)-(33) and  $R_p$  as given, faces the following responses to changes in  $s$ :

$$(34) \quad \frac{\partial p}{\partial s} = \frac{\gamma}{\gamma + (1-h)\phi}, \quad \frac{\partial R}{\partial s} = -\frac{1-h}{\gamma + (1-h)\phi}.$$

This yields the following condition for the exporter's optimal strategy in this case:

$$(35) \quad \frac{dW_2}{ds} = (p - p_0 - \phi R - c_2) \left( -\frac{1-h}{\gamma + (1-h)\phi} \right) + R \frac{\gamma}{\gamma + (1-h)\phi} = 0,$$

with the corresponding optimal condition on  $R$ :<sup>17</sup>

$$(36) \quad R = \frac{1-h}{\gamma + (1-h)\phi} (p - p_0 - c_2).$$

Even though the exporter considers  $R_p$  as exogenous in its own optimization,  $R_p$  is here assumed to be set optimally by the policy bloc, as part of the market equilibrium.<sup>18</sup> Note also that  $R$  and  $p$  are still determined by (11)-(12). We then find  $s$ ,  $p$  and  $R$  as functions of  $t_2$  and  $q_2$ , as follows:

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<sup>17</sup> We remark that this solution is relevant, and reasonable, only when  $h$  is "not too large". In fact, no solution with positive production exists in this model when  $h$  tends to unity.

$$(37) \quad s = \frac{\gamma}{(2-h)\gamma + (1-h)\phi} (1 - p_0 - ht_2 - (1-h)q_2) + \frac{(1-h)(\gamma + \phi)}{(2-h)\gamma + (1-h)\phi} c_2$$

It is of interest to consider how the equilibrium export price changes with  $h$  when the importer carbon price,  $t_2$ , is at a given level. The export price can here be expressed as

$$(38) \quad p - p_0 = \frac{\gamma + (1-h)\phi}{(2-h)\gamma + (1-h)\phi} (1 - p_0 - ht_2 - (1-h)q_2) + \frac{(1-h)\gamma}{(2-h)\gamma + (1-h)\phi} c_2$$

Comparing to the carbon tax case,  $p$  is greater here for any given  $t$  (where  $t = t_1$  is the carbon tax in model 1, and  $t = t_2$  the quota price in model 2). We find:

$$(39) \quad \frac{dp}{dh} = \frac{\gamma^2}{[\gamma + (1-h)(\gamma + \phi)]^2} (1 - p_0 - ht_2 - (1-h)q_2 - c_2) - \frac{\gamma + (1-h)\phi}{\gamma + (1-h)(\gamma + \phi)} \frac{d(ht_2)}{dh}$$

This expression is always positive for given  $ht_2$  (so that  $t_2$  falls proportionately). But it is also positive when  $ht_2$  increases in  $h$ , provided that the first term dominates the second. This is always so when  $h$  is initially small;  $t_2$  is then also small (from (40) below); and  $d(ht_2)$  must consequently be small. We thus find that *when  $h$  is small at the outset, the export price always increases when the policy bloc comprises a larger fraction of total fuel demand* ( $h$  increases). This is diametrically opposite to the conclusion under model 1, where the policy bloc was assumed to use a carbon tax. We will also find, in the simulations in section 4 below, that  $p$  can increase in  $h$ , also for larger  $h$  values (when  $c$  is low).

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<sup>18</sup> In this case, we note,  $t$  is interpreted not as a tax but instead as the equilibrium emissions quota price at which emissions quotas (proportional to fuel consumption) are traded within the policy bloc, and with parties in the fringe which engage in offsets.

### 3.4 Overall solution

Overall equilibrium is in this case found by solving (30) and (37) for  $t_2$  and  $s$  (noting that  $q_2 = t_2$ ).

This yields

$$(40) \quad t_2 = \frac{h^2 \gamma}{D_2} \{ [(2-h)\gamma + (1-h)\phi]c + (1-h)\phi(1-p_0 - c_2) \}$$

$$(41) \quad s = \frac{(1-h)[(\gamma + \phi)^2 - h^2 \phi^2]c_2 + \gamma[\gamma + (1-h^2)\phi](1-p_0) - h^2 \gamma^2 c}{D_2}$$

where

$$D_2 = (\gamma + \phi)[2\gamma + (1-h^2)\phi] - h[(\gamma + \phi)^2 - h^2 \phi^2]$$

We here first find that  $t$  (the quota trading price of carbon) always converges to  $c$  as  $h$  converges to one. The relationship between  $t_2$  and  $h$  is always rising for low  $h$ , but could either fall or rise when  $h$  is larger; this becomes clear from the simulations below.

$s$  is in general greater here than in model 1, and more so when  $h$  is higher (for  $h = 0$  the two expressions are identical, as we are back to the case of no climate policy). The exporter then adopts a more aggressive taxation strategy in this case. The reason is the smaller demand elasticity faced by the exporter.

Also in this case we may consider implications of the overall optimal solution for the optimal “cap” to be set, analogously with the amount of “incentivized emissions” (from (27)) under model 1. The optimal cap is here defined by  $R_{C2}$ , and given by

$$(42) \quad R_{C2} = R_1 - \Delta R_F = \frac{1}{\gamma} [h(1-p) - t_2].$$

Simulations in section 4 below show that quite generally  $R_{C2} > 0$  independent of  $h$ . This is the similar to what was found in model 1. The intuition is also here that for low  $h$  (where, conceivably, the cap could be negative), the emissions price is too low to really matter in terms of emissions reductions.

Next, compare also here the amounts of abatement taking place in the policy bloc versus the fringe. From (13), (15) and (16) and inserting  $q_2 = t_2$  we now simply have

$$(43) \quad R_1 = \frac{h}{2} (1 - s - t_2) = hR$$

$$(44) \quad R_F = \frac{1-h}{2} (1 - s - t_2) = (1-h)R.$$

Thus in this case fuel demand in both the policy bloc and fringe is proportional to the size of either bloc. Thus fuel consumption is efficiently allocated across consumer countries, for any given global emissions target. This follows simply from  $t_2 = q_2$ : effective carbon prices are the same in both consumer regions.

## 4. Simulations

I now simulate the model solutions in a simplified case, setting  $p_0 = c_2 = 0$ ,  $\gamma = \varphi = 1$ .<sup>19</sup> For model 1, the parametric examples yield the following expressions for  $t_1$  (and where  $q_1 = \frac{1}{2} t_1$ ),  $s$ , and  $R$  (the level of fossil fuel consumption):

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<sup>19</sup> I thank Sauleh Siddiqui for help with the simulations.



$$(25a) \quad t_1 = \frac{3c+1}{6-h(1+h)} h$$

$$(26a) \quad s = \frac{4-h(1+h)(1+c)}{2[6-h(1+h)]}$$

$$(13a) \quad R = \frac{1}{2} - \frac{2+h(1+h)c}{2[6-h(1+h)]}.$$

For model 2 the expressions for  $t_2$ ,  $s$  and  $R$  are (noting that  $q_2 = t_2$  in this case):

$$(40a) \quad t_2 = \frac{h^2}{6-4h-2h^2+h^3} [1-h+(3-2h)c]$$

$$(41a) \quad s = \frac{2-h^2-h^2c}{6-4h-2h^2+h^3}$$

$$(13b) \quad R = \frac{1-h}{3-2h} (1-ht_2).$$

These functions, and including  $p = s + R$ , are simulated using continuous domain  $[0, 1]$  for  $h$ , and values 0,  $\frac{1}{4}$  and  $\frac{1}{2}$  for  $c$ .

Figures 1-4 illustrate solution values as functions of  $h$ , for a “benchmark” case of  $c = 0$  (no climate concern). Everything is then driven by strategic concerns. Four sets of variables are shown:  $t$  and  $q$  (importer fuel/carbon tax or quota price; in figure 1);  $s$  (exporter fuel tax, in figure 2);  $R$  (consumed amount of the resource, in figure 3); and  $p$  (fuel export price; in figure 4); as functions of  $h$  (the policy bloc as share of all fuel-demanding countries). Here, as noted, the offset price in model 1 (in red) is always half the carbon tax (blue). Both are higher than the quota price (equal to the offset price) for model 2 (green). While the carbon tax in model 1 and

the quota price in model 2 diverge early, the difference is greater when  $h$  is high.<sup>20</sup> Both these variables decrease in  $h$  under an importer tax policy, but increase in  $h$  under an importer cap policy. The carbon price set by the policy bloc is dramatically higher with a carbon tax than with c-a-t when  $h$  is high. While the carbon tax increases strongly in  $h$ , the quota price in the c-a-t case also increases in  $h$  up to a certain point, but is reduced when  $h$  increases further. Two factors here have opposite effects: a higher  $h$  makes the policy bloc more collusive and more aggressive in its pricing; but a higher  $h$  also makes the exporter (much) more aggressive which reduces the scope for rent extraction by the policy bloc. Interestingly, the policy bloc's import tax or carbon price is everywhere positive even though there is no climate concern in this case.

----- Figures 1-4 in about here -----

Another result is that fossil fuel consumption drops in  $h$ , slightly in the tax case, and more dramatically in the cap case. In the tax case this is “good” for importers as the import price is substantially reduced when  $h$  increases.

Figures 5-8 are not dramatically different from figures 1-4, but there are differences, which are greater when  $h$  is higher. A climate concern by the policy bloc hardly affects the bloc's policy at all when  $h$  is very small, but affects it much more when  $h$  is high. The carbon tax and quota and offset prices are now also much higher. In particular, the quota price under model 2 is now uniformly rising in  $h$ .  $q_2$  now (slightly) exceeds  $q_1$  for high  $h$  (greater than about 0.65). This more aggressive tax strategy of the policy bloc leads to a greater reduction in both the import price, and total fossil fuel consumption, when  $h$  increases.

----- Figures 5-8 in about here -----

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<sup>20</sup> As noted, however, the model is less suitable for describing what happens under a cap solution for high  $h$  values.

Figures 9-12 show the case of “high” climate concern for fuel importers. The carbon quota price under model 2, and the carbon tax under model 1, now differ by less, at least for high  $h$ . There is also a larger range of  $h$  for which  $q_2 > q_1$ . The tax in model 1, and the quota price in model 2, are now driven much more by the climate concern. While this concern is still negligible when  $h$  is small, it is big when  $h$  is large (since this concern is proportional to  $h$  which is the fraction of cooperating economies in setting the tax or quota). There is as before a big difference in the export tax between the two models. This difference is now however reduced slightly as  $h$  tends to 1. Fossil fuel demand now drops dramatically with  $h$  also in model 1.

----- Figures 9-12 in about here -----

We find, overall, that the carbon tax under a tax scheme ( $t_1$ ) is substantially higher than the domestic quota price in the policy bloc under a c-a-t scheme ( $t_2$ ), for all alternatives of the carbon externality  $c$ . This difference is however not uniformly greater when  $h$  is higher. There are two main factors at play for explaining this relation.

The first factor is (as seen from figure 3) that the exporter tax is higher under an importer cap than under an importer tax; and more so when  $h$  is higher. The importer’s optimal response to such exporter behavior is to set a higher carbon price in the tax case (when the exporter tax, and thus the export price, is lower).<sup>21</sup>

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<sup>21</sup> In fact, in the limit as  $h$  tends to unity, under a cap the Nash equilibrium solution in this model entails the exporter setting the export price at its maximal level choking off all demand; and the carbon quota price then being equal to zero. This is of course an unrealistic economic model; see Strand (2010) for an elaboration and discussion of alternative equilibrium concepts for this case.

The second factor is related to the offset market and its functioning in the two models. In the tax case, under model 1, the domestic carbon tax in the policy bloc is independent of the offset price (effective within the fringe); there is no direct effect of the offset market on the domestic carbon tax. In model 2, by contrast, there is such an effect since the offset carbon price is now tied directly to the carbon price within the policy bloc (as the two must be the same). This factor tends to put a great downward pressure on the carbon price when the policy bloc is small and the fringe correspondingly large ( $h$  is small). In this case the offset market becomes a very large share of the overall abatement activity. When the fringe is small ( $h$  large), by contrast, this factor has much less influence (as the offset market then also becomes much less important). There is then much less downward pressure on the carbon price from an offset market in the cap case.

These two factors work in opposite directions with respect to the relationship between  $t_1$  and  $t_2$  when  $h$  increases. We find, in particular, that when  $c = 0$ , the difference between these two is strongly increasing in  $h$ . When  $c = 1/4$ , this difference is still increasing but now almost “flat” over a large range for  $h$ . When  $c = 1/2$ , the difference is reduced for higher  $h$ .

The offset price is half the carbon price in the tax case, and equal to the quota price in cap case. The offset price is generally lower in the c-a-t case than in the carbon tax case for low  $h$  and /or low  $c$ ; but higher in the c-a-t case when both  $h$  and  $c$  are high. When  $h$  is low, the dominating factor is the “drag” (in the direction of low carbon prices) that the constraint that the offset price and the quota price in the policy bloc be equal in the c-a-t case. When  $h$  is high, by contrast, pricing in the offset market means little for the efficiency of the internal policy within the policy bloc. We then see that when  $c$  is relatively high (and the quota price also at similar level in the c-a-t case for high  $h$ ), the constraint that  $q_2 = t_2$  pushes  $q_2$  above the level of  $q_1$  in such cases.

Our final figures 13-15 depict the “incentivized quotas”  $R_{I1}$  in (28), and  $R_{C2}$  in (49). Under our numerical example these two expressions are

$$(27a) \quad R_{I1} = \frac{h}{2} \left[ 1 - s - \frac{1}{2}(3-h)t_1 \right]$$

$$(42a) \quad R_{C2} = h(1-s-R) - t_2.$$

$R_{C2}$  corresponds to the optimal quota (accounting for offsets) set by the policy bloc under c-a-t.  $R_{I1}$  has a similar interpretation except as applied to the carbon tax case (combined with a government-managed offset scheme). The “optimal quota” is similar for low  $h$  values (in fact slightly greater in the c-a-t case); but much smaller under c-a-t for high  $h$  values. The fact that it is greater for low  $h$  values is due to less mitigation taking place in the c-a-t case for such values (as the carbon price, including the offset price, is lower in the c-a-t case than in the tax case for low  $h$  values). For higher  $h$  the overwhelming factor is that overall fuel demand is driven down by the increase in the export tax,  $s$ , in the c-a-t case but not in the carbon tax case.

----- Figures 13-15 in about here -----

## 5. Conclusions and Final Comments

This paper has analyzed a carbon tax versus an emissions cap (c-a-t) as climate policy strategy for a fossil fuel-demanding “climate policy bloc”, which faces a fuel-demanding group of countries with no climate policy (a “fringe”), and a fuel-exporting bloc disinterested in climate policy. The policy bloc can purchase “offsets” from the fringe, and does so in an optimal manner. Under a carbon tax,  $t_1$ , offsets are bought directly from the fringe by policy bloc

countries at price  $q_1$ .<sup>22</sup> It is assumed that all “available” offsets, with marginal implementation cost at or below  $q$ , are realized. In the c-a-t case, I assume that offsets are bought by emitters through an offset market where the offset price must equal the emission quota price.

To my knowledge this is the first attempt in the literature to analyze optimal offset policies in the context of a comprehensive model of mitigation. I assume that the offset market functions differently in the two cases. In the carbon tax case it works as a (government-managed) offset scheme (where offsets are purchased directly by a central authority operating on behalf of all the policy bloc countries), with an offset price that may differ from the carbon tax. In the c-a-t case, by contrast, it is a standard (CDM-type) market-based offset mechanism. In my view these assumptions are reasonable, as descriptions of practical in which to organize an offset market in the two cases.

Individual countries in the fringe will fare best under a carbon tax, and the policy bloc makes up a large fraction of overall fuel demand. With a smaller the fringe, each country in the fringe benefits more from being a “free rider” on a carbon tax set by the policy bloc. A large policy bloc translates into great market power of this bloc in the fossil fuel markets. The optimal carbon tax is then higher for a larger policy bloc; and it puts more downward pressure on the export price for a given tax. This all translates into a lower fuel export price, which benefits the fringe.

A similar benefit for the fringe, due to a large policy bloc, does not materialize under a cap policy. The fuel export price is then in most cases set *higher* by exporters when the policy bloc comprises a larger share of total demand; not *lower* as under a carbon tax.

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<sup>22</sup> As noted we have not specified in detail how such a scheme is to be enforced. These problems are essentially the same as those with enforcing the current CDM, and there making sure that emissions reductions are “real” (i.e. represent emissions reductions below emitters’ actual “baselines”).

I show that the optimal carbon price in the policy bloc is in either model influenced by both a climate (“Pigouvian”) motive, and a strategic motive whereby the policy bloc recognizes that it is able to influence the exporter’s fuel price through its tax. The positive carbon tax leads to a lower fuel import price, which benefits all fuel importers, including the fringe. The tax is set higher when the policy bloc is larger, for two separate reasons: First, the “Pigou” element is greater for a larger bloc; secondly, the strategic element, working to increase the tax so as to reduce overall fuel demand and consequently the fuel export price, is greater when the policy bloc is larger. Note that as a consequence of the higher carbon tax set by the policy bloc, fringe countries are helped; and they are helped more when the policy bloc is larger as a fraction of total fuel demand.

When the policy bloc sets a carbon tax (in model 1), the optimal offset price valid for the fringe is exactly half the optimal carbon tax within the bloc. This is related to the fact that the policy bloc, operating in a unified way in setting the offset price, behaves as a monopsonist versus the fringe, setting the offset price lower than its own tax; recognizing that the offset revenue goes to parties outside of the policy bloc itself.<sup>23</sup> The objectives of using offsets are however basically the same as those of taxing, namely reducing carbon emissions, and reducing the export price of fuel through the reduction in overall fuel demand. Note that there is no formal tie between the carbon tax and the offset price in this case; the two are set independently, and optimally. The fact that offsets are used has only a relatively small impact on the optimal level of the carbon tax, which is to *increase* the carbon tax when offsets are also used. A way to view this

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<sup>23</sup> The result that the offset price is exactly half of the tax follows from the linearity of demand and supply functions in our model, and does not generalize to other functions. More generally, the offset price will be lower than the carbon tax; but not necessarily one half.

result is that the use of an (efficient) offset mechanism increases the overall efficiency of carbon pricing and this also applies to the basic carbon tax within the policy bloc.

In section 3 (model 2) I assume that the policy bloc sets and enforces a cap on overall carbon emissions, which equals the policy bloc's own emissions minus offsets purchased from the fringe (with more offsets, the policy bloc is "allowed" to emit more). This leads to a major strategic difference from the carbon tax case, as now one part of demand is fixed (regular demand from the fringe, which is not offset, is still variable). Once the cap has been set, overall fuel demand is then less sensitive to the fuel export price than in the tax case of model 1. This leads the monopolistic exporter to set a higher fuel tax and thus export price, which is disadvantageous for all importers, when compared to the carbon tax case. A larger policy bloc now does not necessarily lead to a lower exporter fuel price; and does not necessarily benefit the fringe. There are two opposing effect on the fuel export price: the policy bloc being more monopolistic reduces the export price; but ex post fuel demand being less sensitive to price increases it. The monopoly power of the exporter is greater when the policy bloc is larger, since a larger fraction of overall fuel demand does not respond to changes in the fuel import price. This may translate into a higher export price when the policy bloc makes up a larger fraction of total fuel demand, which in turn hurts the fringe.

The other major issue in model 2 is how an optimal offset market then functions. With a unified market for quotas, within and outside of the policy bloc, there must be a single trading price since the policy bloc quota price,  $t_2$ , must equal the offset price in the fringe,  $q_2$ . This has two effects which separate this offset solution from the carbon tax solution. First, tradability of quotas makes it no longer feasible for the policy bloc to under-price offsets relative to the price of internally traded quotas. Offsets are then less attractive than under model 1. The direct



equilibrium relationship between  $t_2$  and  $q_2$  makes trading less attractive, with an optimal offset trading price that is unambiguously *lower* in model 2 than in model 1 in many cases (when the policy bloc is small and the fringe is large, and/or there is a small carbon externality). Opposite, the offset price itself is always *higher* when the policy bloc is large and the fringe small, and the carbon externality is great. The offset policy in this way acts as a “drag” on carbon pricing in the policy bloc under model 2. When  $h$  is large, the fringe is small, and the presence of the offset market then has a relatively small effect on the pricing policy for carbon within the policy bloc.  $t_1$  is then only slightly higher than  $t_2$ . When  $h$  is small (and the fringe and thus the required volume of offsets is high), by contrast, this “drag” is great. The use of optimal offsets then tends to reduce the carbon price in the policy bloc a lot. Note then also that when  $h$  becomes small, fringe offsets becomes the overriding policy for mitigation for the policy bloc. Mitigation in the policy bloc is small for two reasons: a small policy bloc has little incentive to implement any climate policy whatsoever; and most mitigation happens in the fringe.

The result derived here, that the policy bloc finds it optimal to utilize a maximal volume of offsets under c-a-t (for a given offset price), is not immediately nor intuitively obvious. It follows from the saddle point solution of the problem of the joint maximization problem with respect to price and volume of offsets. The robustness of this result requires scrutiny in future work. One question here is what sorts of constraints follow from the, less than fully general, linear-quadratic structure of the model as currently set up.

One overall conclusion from comparing the two models is that a tax policy is, rather generally preferred to a cap policy by all fuel consuming countries, both by those that establish a climate policy, and those that do not. Fundamentally, this is because a monopolistic exporter sets a higher fuel export price when a cap policy implemented by one group of fuel demanders (the

“policy bloc”), than when this group instead uses a tax policy; and this higher price hurts all consumer countries.

A novel feature of this paper is to include an offset market in a model of optimal mitigation. This is done in a highly idealized way by assuming that offset markets are fully efficient. In particular, I assume that when the fringe faces an offset price equal to  $q$ , the potential amount of mitigation implemented in the fringe is the same as when it faces a carbon tax of  $q$ . This may be a useful benchmark against which to compare more realistic solutions; by itself it is not realistic, as I have argued elsewhere (Rosendahl and Strand (2009); Strand and Rosendahl (2010)). Much more likely, less mitigation would take place in the offsetting region; and it would be more expensive to carry out. The wider implications of such alternatives on the functioning of offset markets remains to be studied. But it is straightforward to predict that, in more “realistic” cases (with a less than perfectly functioning offset market), offsets will be less attractive, and their optimal volume smaller.

It can perhaps also be argued that an offset market can be arranged differently than assumed here; potentially, one might separate the “domestic” and “foreign” markets under c-a-t, allowing different prices to rule in the two sub-markets. It can also be questioned whether a totally separate sub-market for offsets (managed e.g. by the public sector) can provide the same degree of efficiency as an integrated, private, domestic and foreign c-a-t market. These are issues I will need to come back to in future research.

My model is also in other respects based on highly simplifying assumptions which could be relaxed. I here only briefly mention a few of these; work to rectify these problems is, in some cases, already carried out or under way.

A) There is no fuel production in consuming countries, and no fuel consumption in fuel-producing countries.

B) There is only one, homogeneous, fuel. Strand (2011) deals with the two-fuel case but in a model of two blocks only (exporters and importers). This is shown to change conclusions slightly; in particular by making the ex post fuel demand function potentially more elastic under c-a-t, thus making that solution less attractive.

C) Dynamic considerations are ignored. First, fossil fuels are viewed as a regular commodity with a stable short-run supply function. Secondly, there are no dynamic effects via the accumulation of GHGs over time. Work is currently under way (joint with Larry Karp) to compare tax and c-a-t solutions in a dynamic version of the current model.

D) A monolithic, and monopolistic, fuel exporter dictates the fuel export price; and there is no fringe of competitive fuel suppliers. A start of a competitive fringe analysis is found in Keutiben (2010).

E) All countries are assumed to be equally averse to climate change; and have equal loss (relative to their size) per unit of carbon emissions. With different loss parameters, countries' incentives to join the policy bloc will generally vary among countries. The climate impact factor for the policy bloc, here  $h_c$ , will then also be a more complex function of  $h$ .

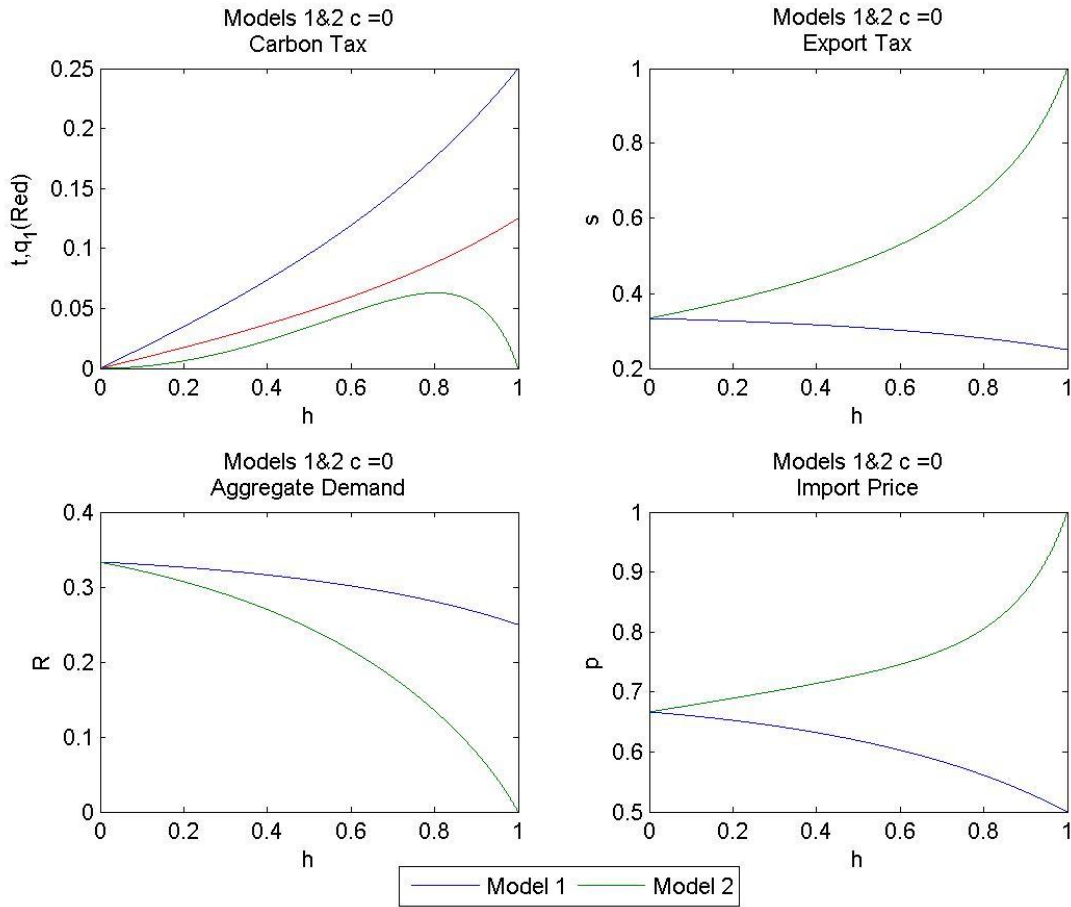
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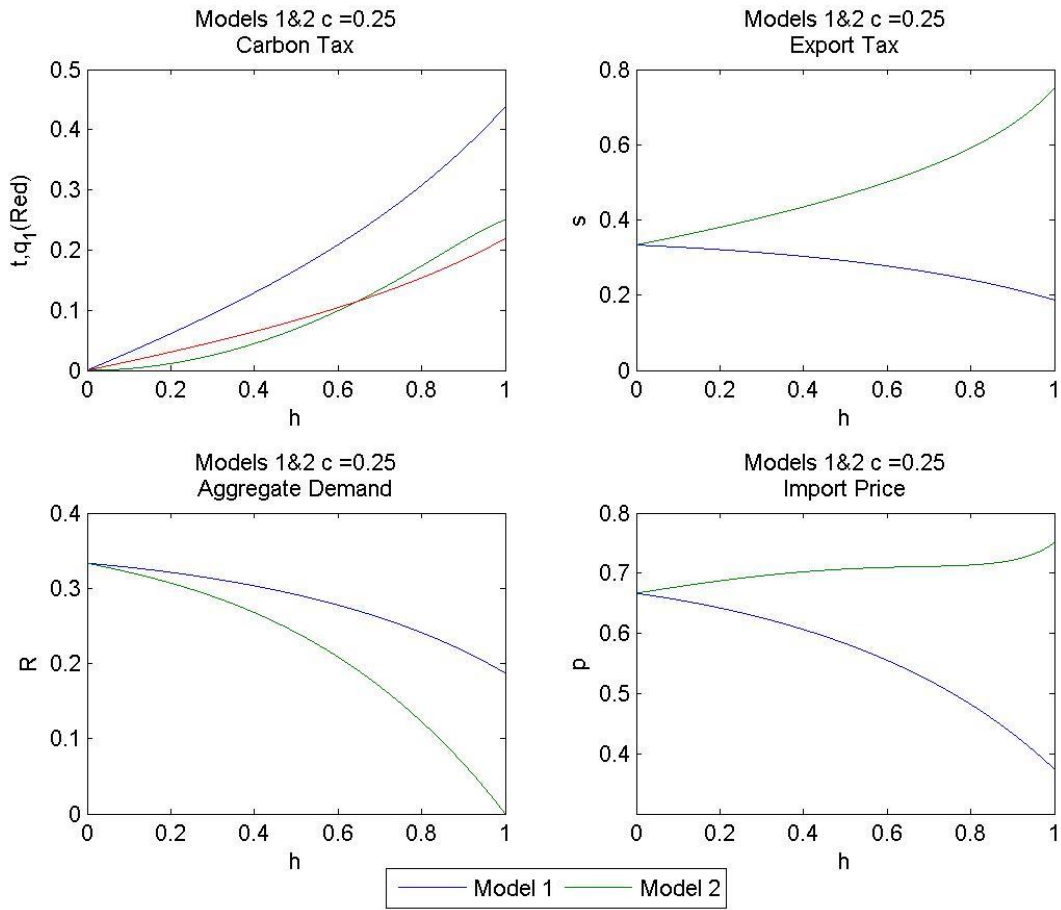
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## Appendix: Figures

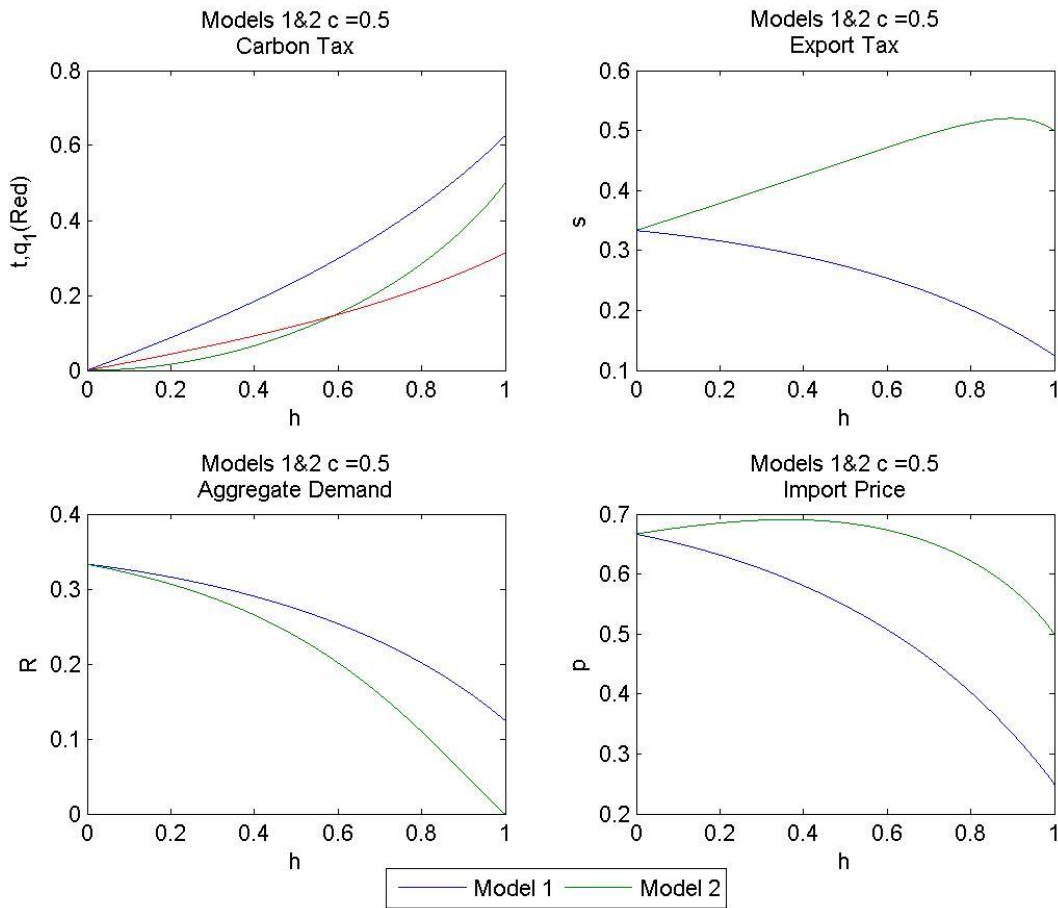
**Figures 1-4: Carbon prices, export tax, import price and fuel demand, as functions of  $h$  for  $c = 0$**



**Figures 5-8: Carbon prices, export tax, import price and fuel demand, as functions of  $h$  for  $c = 0.25$**



**Figures 9-12: Carbon prices, export tax, import price and fuel demand, as functions of  $h$  for  $c = 0.5$**





**Figures 13-15: Size of “cap quota” under carbon tax and c-a-t scheme, for different values of  $h$  and  $c$**

