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Environmental Policy Competition and Differential Tax Treatment

A Case for Tighter Coordination?

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Abstract in English

The Kyoto Protocol binds the level of greenhouse gas emissions in participating countries. It does not, however, dictate how the countries are to achieve this level. The economic costs of reaching emission targets are generally evaluated to be low. For example, evaluations with applied general-equilibrium models estimate the costs to be in the range of 0.2% to 0.5% of GDP, when international trade in emissions rights among governments is allowed for. We argue that important costs are overlooked since governments have an incentive to choose highly distorting tax schemes.
This paper shows that governments generally choose different energy tax rates for households and for internationally operating firms as the result of tax competition or pollution competition: in the first case, governments try to undercut other governments to attract firms to their country, whereas in the second, they try to push dirty industries across the border. In both cases, the incentive for firms and households to use or save energy is different at the margin. Both cases call for coordination of climate change policies that goes beyond a binding ceiling on greenhouse gas emissions and international trade in permit rights among governments alone.

Abstract in Dutch

Het Kyoto protocol legt het niveau van emissies van broeikasgassen in deelnemende landen vast. Het legt echter niet op *hoe* landen dit niveau dienen te bereiken. De economische kosten van het bereiken van de emissiedoelstellingen worden in het algemeen laag ingeschat. Evaluaties met toegepaste algemeen-evenwichtsmodellen schatten de kosten, bijvoorbeeld, op ongeveer 0,2 tot 0,5 % van het BBP, wanneer tussen overheden internationale handel in emissierechten wordt toegestaan. In dit artikel laten we zien dat in zulke analyses belangrijke kosten over het hoofd gezien worden omdat overheden geneigd zullen zijn voor verstorende belastingregimes te kiezen. Dit artikel toont aan dat overheden in het algemeen kiezen voor verschillende energiebelastingtarieven voor huishoudens en voor internationaal opererende bedrijven. De oorzaak hiervan is belasting- of vervuilingsconcurrentie. Bij belastingconcurrentie proberen overheden elkaar te onderbieden met het belastingtarief om hun land aantrekkelijk te maken als locatie voor vervuilende industrie. In het tweede geval trachten ze vervuilende industrie het land uit te werken. In beide gevallen zijn de prikkels voor bedrijven en huishoudens om energie te besparen verschillend aan de marge. In beide gevallen zou verdergaande coördinatie van milieubeleid wenselijk zijn; coördinatie die verder gaat dan de combinatie van het opleggen van een plafond aan broeikasgasemissies en internationale handel in emissierechten tussen overheden.

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Summary

The Kyoto Protocol binds the level of greenhouse gas emissions in participating countries. It does, however, not dictate how the countries are to achieve this level. The economic costs of reaching emission targets are generally evaluated to be low. For example, evaluations with applied general-equilibrium models estimate the costs to be in the range of 0.2% to 0.5% of GDP, when international trade in emissions rights among governments is allowed for. We argue that important costs are overlooked since governments are inclined to choose highly distorting tax schemes.

We employ a monopolistic competition model with direct consumption of energy and indirect consumption of the energy content of the tradeable varieties. In such a context, governments generally choose different energy tax rates for households and for internationally operating firms. We consider two different cases. First, if firms are (assumed to be) immobile, governments choose to tax firms more than households. The reason is that part of the firms' energy consumption is for production of foreign consumer goods and does not benefit domestic consumers. Second, if governments take into account relocation of firms and behave strategically, they set higher energy tax rates for households than for firms. This is the result of tax competition: governments try to undercut other governments to attract firms to their country.

Both cases call for co-ordination of climate change policies that goes beyond a binding ceiling on greenhouse gas emissions and international trade in permit rights among governments. The European Union has implemented a system of tradeable permits, in which also firms can buy and sell permits and thus internationally face the same incentive at the margin. This, however, will not avoid competition among governments completely. The paper shows that governments may allocate too much and too cheap permits to firms. The production decisions are then distorted and government revenues are wasted.

1 Introduction

Though systems of energy taxes are widely different across countries, they have one salient feature in common: the tax burden on firms is much lower than on households.[1] This is achieved in various ways. For example, the excise duty on diesel, which is more important for firms than for households, is lower than on petrol. Also, firms are often partially exempted from taxes or are refunded part of their tax payments.[2] Concerns for competitiveness usually motivate exemptions and refunds.

Table 1.1 shows for several West-European countries the burden of energy taxes on both firms and households (as a fraction of before-tax expenditure). In some cases, notably Germany, Italy and Spain, the tax rate on households is more than four times higher than that on firms. Even though these data on energy taxes are imperfect measures, they confirm the picture that emerges from a detailed analysis of the tax systems.

The economic literature provides a few attempts to rationalise the differential energy taxation of households and firms. Richter and Schneider (2003) consider domestic distortions as a motivation for a differential treatment. They find that distortionary taxes on labour or union power are a reason to discriminate in favour of the production sector. Hoel (1996), on the other hand, focuses on the international externality that arises from greenhouse gas emissions. If a large country or a group of countries wants to decrease emissions, it has to take into account that elsewhere emissions increase, i.e. carbon leakage. When the large country cannot rely on trade taxes and subsidies, optimal energy taxes for the different sectors depend on the scale of carbon leakage that is induced by reductions in these sectors. As household energy use and consumption is less prone to carbon leakage, the tax on households will exceed that on firms.

In this paper we provide a third rationale for differential taxation: policy competition. If one country raises its taxes on energy use in production, it will see part of the production relocate to other countries. Clearly, taxes on household energy consumption do not have this direct effect. This difference gives rise to differential energy taxation. On the one hand, a country may want to engineer a change in its sectoral structure, by imposing relatively high energy taxes on polluting industries. This case is characterized by the adage: not in my backyard (NIMBY). On the other hand, a country may want to keep and attract polluting industries, and choose for lower taxes on firms than on households. In this paper, building on 'new' trade theory, the reason for wanting to keep and attract polluting industries derives from the benefits of clustering. This case amounts to what is sometimes called 'reverse dumping.' More specifically, the smaller a country is, the larger the tax differential between households and firms. Indeed, Rietveld and Woudenberg

[1] We would like to thank Sjak Smulders, Paul Veenendaal and participants of seminar at the European University Institute in Florence for comments on earlier versions.

[2] OECD (2001) gives an overview of the different tax systems and provides numerous examples of the differential treatment.

(2005) find evidence that small countries tend to charge lower petrol prices than large countries. Whereas the case of 'reverse dumping' is probably more relevant than the case of 'not in my backyard,' the efficient solution, in which the marginal costs of energy reductions are the same throughout the economy, does not apply in either case.

Table 1.1 Energy taxes (fraction of expenditure[a])

	Firms	Households
Belgium	0.9	2.7
France	1.0	3.3
Germany	0.8	6.2
Italy	1.0	5.0
Netherlands	1.4	3.4
Spain	0.9	3.8
United Kingdom	0.8	2.2

[a] source: GTAP5 database: Dimaranan and McDougall (2002)

To tackle the problem of global warming energy taxes will have to rise much further and the problem of differential treatment will only worsen. The Kyoto Protocol commits countries to reduce their greenhouse gas emissions. It allows countries to reduce emissions at home but also abroad, through intergovernmental emission trade. This tends to equalise the marginal costs of emission reductions across countries. One of the main contributions of this paper is to show that marginal costs of emission reduction may become equal across countries but are not likely to become equal within countries. Generally, governments will set different energy tax rates for households and firms.

The implication of differential taxation within countries is that the macro-economic costs of implementing the Kyoto Protocol are underestimated. Evaluations with applied general-equilibrium models assess the costs to be in the range of 0.2% to 0.5% of GDP, when international trade in emissions rights among governments is allowed for. Typically, this is based on the assumption that within countries the marginal reduction costs are equal. When they are not, the macroeconomic costs may rise significantly. A related implication is that the initiative of the European Commission to install a system of emissions trade among firms, is very welcome, because it reduces the scope for governments to treat households and firms differently.

Energy taxes serve different purposes, ranging from raising revenue to correcting local externalities. To what extent energy taxes are intended to correct for local externalities, ranging from noise and smog to congestion, is not clear (see Newbery (1992) and Rietveld and Woudenberg (2005)). Differential tax treatment is the outcome of a policy to achieve a given, national, target for greenhouse gas emissions (i.e. Kyoto) but is also the result of a policy to correct for local environmental externalities, where governments have the ability to set environmental standards. The objectives may differ but the problems are analytically isomorphic. This relates our paper to earlier work by Hoel (1997) and Pfluger (2001). They both consider policy competition when countries pursue environmental policies independently to correct for local externalities. When compared to a cooperative solution, policy competition leads to environmental standards that are either too strict (NIMBY) or too lenient (reverse dumping). This paper extends this literature by showing that governments set different standards for firms and households.[3]

We employ a monopolistic competition model with direct consumption of energy and indirect consumption of the energy content of the tradeable varieties. In such a context, governments generally choose different energy tax rates for households and for internationally operating firms. We consider two different cases. First, if firms are (assumed to be) immobile, governments choose to tax firms more than households. The reason is that part of the firms' energy consumption is for production of foreign consumer goods and does not benefit domestic consumers. Second, if governments take into account relocation of firms and behave strategically, they set higher energy tax rates for households than for firms. This is the result of tax competition: governments try to undercut other governments to attract firms to their country.

Both cases call for co-ordination of climate change policies that goes beyond a binding ceiling on greenhouse gas emissions and international trade in permit rights among governments. The European Union has implemented a system of tradeable permits, in which also firms can buy and sell permits and thus internationally face the same incentive at the margin. This, however, will not avoid competition among governments completely. The paper shows that governments may allocate too much and too cheap permits to firms. The production decisions are then distorted and government revenues are wasted.

The paper thus suggests that tighter coordination of national climate change policies is called for to reduce the economic costs of these policies. In the European case, the system of emission trade has to be extended to include more sectors and perhaps households.

The remainder of the paper is organised as follows. Section 2 sets up the model and derives the equilibrium. Section 3 discusses the two policy competition games. Section 4 discusses coordination. Section 5 provides a discussion of our assumptions and results. Section 6 concludes.

[3] Closely related is Florax and Withagen (2003), who address the issue of differential taxation in several different market structures with a given emission target. They analyze perfect competition, a large country and oligopoly. The set-up of their model is more complicated (three consumption commodities per country and two factors of production) which prevents them from deriving analytical solutions in the oligopoly case. Our paper differs, as the focus is on strategic interaction between governments and the market structure is monopolistic competition. Our set-up moreover allows for analytical results.

2 The model

2.1 Overview of the model

The model describes a world with one production factor, two countries and three (intermediate) goods. The supply of labour is exogenous. Labour is employed in the production of intermediate goods, that are combined in two (non-tradeable) bundles for final consumption, X and Z. The X-good is a composite good of different varieties. The production of each variety requires labour as well as energy as an intermediate input (the production of which also requires labour). Production of a variety is subject to increasing returns to scale, and the producers engage in monopolistic competition. The varieties are internationally tradeable and subject to transport costs. By assuming an identical and constant elasticity of substitution between all different varieties – the simplest version of the model in Dixit and Stiglitz (1977)– and identical technologies, we obtain symmetry across varieties within a country. This we take into account from the start. Z is a bundle of two homogenous goods of which one, the Y good, is tradeable without costs and the other, energy E, is not.[4] Both are produced under constant returns to scale in a sector with perfect competition. Production of both intermediate goods, Y and E, requires the employment of labour.

The analysis assumes incomplete specialisation throughout, which results in factor price equalisation (FPE). Incomplete specialization represents the situation that all countries harbour energy-intensive industries and want to impose taxes on energy use in these industries. Governments choose energy taxes given the energy taxes in the other country. This leads to a Nash-equilibrium for the tax-policy game. When the production of the X-good is concentrated in one country only, the nature of the policy game changes (see Baldwin and Krugman (2002) for an example of (capital) tax competition with complete specialisation).

The model in this paper is closer to 'new' trade theory (see for example Venables (1987)) than to 'new' economic geography. In the latter line of research, the tendency for firms to cluster in one region or country is magnified for example by considering intermediate deliveries among firms. The model in this paper does not incorporate these additional effects. The main reason is tractability. Nevertheless, the tendency to cluster (near the largest market) remains.

2.2 Consumers

The utility function of the representative consumer in the home country is $U = (1-\gamma)\log X + \gamma \log Z$. We use subscripts i and j to denote home and foreign country

[4] Davis (1998) argues that the usual and convenient assumption of zero transport costs is not harmless. For the home-market effect to prevail, trade costs for the homogenous good should be 'substantially' lower than for the composite good. This is what we assume throughout.

variables respectively. In many instances home and foreign are identical and we drop the index where it does not lead to confusion. Given that I is total income, straightforward optimisation yields that a constant fraction of income, $P_X X = (1-\gamma)I \equiv I_X$ is spent on the X good (P_X is the price of the composite X good). Similar, spending on Z is $P_Z Z = \gamma I \equiv I_Z$, and the price of Z is P_Z .

Given the expenditure on differentiated goods, consumers maximise:

$$X_i = \left[N_i x_i^{\frac{\varepsilon-1}{\varepsilon}} + N_j x_j^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}}, \varepsilon > 1, \tag{2.1}$$

subject to $N_i p_i^c x_i + N_j p_j^c x_j = I_{X_i}$. p^c denotes the consumer price of a variety, lowercase x consumption volume of a variety and N_i the number of varieties from country i. We introduce for later reference, N_W, to indicate the total number of varieties available in the world economy: $N_W \equiv N_i + N_j$. Optimisation gives country $i's$ demand for country $j's$ goods:

$$x_{ji} = \left(\frac{p_{ji}^c}{P_{X_i}} \right)^{-\varepsilon} X_i. \tag{2.2}$$

Demand for goods from j in i decreases with the price that $j's$ producers of varieties charge consumers in market i relative to the price index in that market. To obtain this price index, substitute (2.2) in (2.1):

$$P_{X_i} = \left[N_i \left(p_{ii}^c\right)^{1-\varepsilon} + N_j \left(p_{ji}^c\right)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}. \tag{2.3}$$

The homogenous consumption good Z is a bundle of energy E_Z and good Y. The price of the Z good is:

$$P_Z = C_Z \left(p_Y, p_E^z \right) \tag{2.4}$$

where C_Z is the indirect sub-utility function for the Z good, p_Y the price of the Y-good, $p_E^z \equiv P_E(1+t^Z)$ the after-tax price of energy and t^Z is the tax on energy consumption of households.[5]

2.3 Producers

Production of energy (E) and the good (Y)

Energy is produced with a linear production technology in labour only, $E = L_E$, where the unit labour requirement is set to unity. The market for energy is perfectly competitive, and international trade in energy is ruled out for simplicity.[6]

[5] We assume a convex and well-behaved function.

[6] In fact, making energy tradeable does not make a difference for the results. Only, the production pattern is undetermined since there are more goods than factors.

That energy is produced with labour only and constant returns to scale is perhaps somewhat unexpected. This specification gives, however, perfectly elastic supply of energy, ruling out the possibility that countries try to manipulate its terms of trade through environmental policy.[7]

The homogeneous consumption good is also produced with a linear production technology in labour only, $Y = L_Y$, where the unit labour requirement is again normalised to one. It is internationally tradeable at no cost. We assume that both countries produce Y and hence that the price of labour is identical across countries. Normalising wages to unity gives: $P_Y = P_E = w \equiv 1$.

Differentiated goods production

The production function for a specific variety is $Q = F(L_X, E_X)$. The corresponding cost function is:

$$C_X = C_X(w, p_E^x) \tag{2.5}$$

where C_X is the cost function for X-goods production and $p_E^x \equiv P_E(1 + t^X)$ the after-tax price of energy for firms. Firms have to incur variable costs as well as fixed costs of $\bar{Q}$ units of output. Thus, we can write profits as:

$$\begin{aligned} \Pi &= p^x\left(Q - \bar{Q}\right) - wL_X - P_E^x E_X, \\ &= \left(p^x - c_X\right)\left(Q - \bar{Q}\right) - c_X \bar{Q}, \end{aligned} \tag{2.6}$$

where p^x denotes the producer price of a variety and c_X is the cost-minimising cost level of C_X.[8] Since the elasticities of demand for a specific variety are identical across countries, firms price goods for different markets identically at the factory gate: so-called mill pricing. The firm, facing a downward sloping demand curve (equation 2.2), sets the price as a mark-up over unit costs:

$$p^x = \frac{\varepsilon}{\varepsilon - 1} c_X. \tag{2.7}$$

Substituting the price in the profit function and setting the latter equal to zero, gives the zero-profit firm size:

$$\left(Q - \bar{Q}\right)\frac{1}{\varepsilon - 1} = \bar{Q}, \tag{2.8}$$

which has an intuitive interpretation: in equilibrium the product of sales multiplied by the profit margin (the lhs of equation 2.8) should just cover the fixed costs (the rhs of equation 2.8). The fact that goods are differentiated makes that consumers demand all varieties. Firms thus supply to both the home and foreign market. Delivering goods to the latter market is subject to iceberg transport costs: only a fraction of the shipments arrives at the destination. τ_{ij} is the share of goods that is produced in i and arrives in j: $\tau_{ii} = 1$ and $0 < \tau_{ij} < 1 \forall i \neq j$. Hence, a higher τ indicates lower transport costs and better infrastructure. A different way of stating this is that the unit consumption price and the mill price differ: $p_{ij}^c = p_i^x / \tau_{ij}$.

[7] We want to focus our analysis on policy competition that runs via other channels than the terms of trade.

[8] The function is assumed to be convex and well-behaved.

Budget constraints

Households earn a wage and receive a government transfer. The government taxes energy consumption of households and energy use of firms in the X-sector. It spends money on tradeable permits and gives a lump-sum subsidy, S, to consumers (or imposes a lump-sum tax) to keep the budget balanced. Substituting the government budget in the household budget gives:

$$I = wL + S + t^Z P_E E_Z + t^X P_E E_X - t^E \tilde{E} \tag{2.9}$$

where $\tilde{E}$ is the amount of tradeable permits the government has bought at price t^E (from the government in the other country).

Labour markets clear instantaneously and the resource constraints are always obeyed:

$$L = L_Y + L_E + NL_X \tag{2.10}$$

2.4 Equilibrium prices

The prices of the different goods follow from the wage and energy taxes (recall that $P_Y = P_E = w \equiv 1$ and see equation 2.7 for the price of differentiated goods). To complete the characterization of equilibrium we need to determine for each country the number of firms or, similarly, the price index for the composite X-good. These follow from the zero-profit conditions.

For each firm in the X-sector net supply has to equal demand: $Q_i - \bar{Q} = x_{ii} + x_{ij}/\tau_{ij}$. Substitute the demand functions (2.2) in this expression to get:

$$Q_i - \bar{Q} = \left[\left(\frac{p_i^x}{P_{X_i}} \right)^{-\varepsilon} I_{X_i} + \left(\frac{p_i^x/\tau_{ij}}{P_{X_j}} \right)^{-\varepsilon} I_{X_j} \frac{1}{\tau_{ij}} \right]. \tag{2.11}$$

To save on notation we introduce a slightly different measure for transport costs $T_{ij} \equiv \tau_{ij}^{\varepsilon-1}$ Furthermore, we introduce short-hand notation for the effective market size: $W_i = I_{X_i} P_{X_i}^{\varepsilon-1}$.[9] Using these definitions and the expression of producer prices (2.7) we can write equation (2.11) as:

$$Q_i - \bar{Q} = \left(\frac{\varepsilon}{\varepsilon - 1} c_{X_i} \right)^{-\varepsilon} [W_i + T_{ij} W_j]. \tag{2.12}$$

From the zero-profit condition (equation 2.8) we know the equilibrium firm size. Using this and rewriting gives:

$$c_{X_i}{}^{\varepsilon} F = [W_i + T_{ij} W_j], \quad F = \bar{Q}(\varepsilon - 1)^{(\varepsilon-1)} \varepsilon^{\varepsilon}. \tag{2.13}$$

[9] The effective market size combines two factors that are important for locational choice: local expenditures and the local price index (measuring the degree of competition).

Using equation (2.13) for both countries and solving for the effective market size gives:

$$W_i = \frac{F}{1 - T_{ij}T_{ji}} \left[{c_{X_i}}^{\varepsilon} - T_{ij}{c_{X_j}}^{\varepsilon} \right], \tag{2.14}$$

$$W_j = \frac{F}{1 - T_{ij}T_{ji}} \left[-T_{ji}{c_{X_i}}^{\varepsilon} + {c_{X_j}}^{\varepsilon} \right]. \tag{2.15}$$

These two equations determine the effective market sizes (recall that c_X is determined by the price of labour and energy tax rates). Combining the expression for disposable income (2.9) with the Cobb-Douglas spending share gives expenditure on the X-goods, equation (2.14) and (2.15) then determine the equilibrium price indices for the X-goods.

The zero-profit conditions determine indirectly, through the price indices for the X-good, the number of varieties that each country produces. Given the price indices, the number of firms in each country follows from the definition of these indices:

$$P_{X_i} = \left[N_i \left(p^c_{ii} \right)^{1-\varepsilon} + N_i \left(p^c_{ji} \right)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}. \tag{2.16}$$

Consumer prices are a function of (given) wage costs, transport costs and energy tax rates. Then the two (country) versions of equation (2.16) determine the allocation of firms across countries.

3 Policy game with energy taxes

The Kyoto Protocol binds countries, that ratified the treaty, to reduce their energy use to a given level. Governments are assumed to buy or sell emission permits and set energy tax rates on households and firms to minimize the welfare costs of energy reductions. This section discusses policy for two different settings. In the first, firms are assumed to be immobile; in the second governments take into account firm mobility and engage in competition to keep and attract firms. In the second setting policy competition is strategic in the sense that governments use energy taxes to redistribute profits in their favour. First, however, we explain the general solution procedure.

3.1 The general solution

Governments are committed to keep energy use, and thus its related emissions, below a permitted level:

$$\bar{E} + \tilde{E} - E_Z - E_X \geq 0, \tag{3.1}$$

i.e. the total of energy consumption by households (E_Z) and firms (E_X) should be equal or less than the permitted level, which is sum of a national target ($\bar{E}$) and bought emission rights ($\tilde{E}$). Given this constraint, the government sets taxes by maximising the following indirect utility function:

$$V = -(1-\gamma)\ln P_X - \gamma \ln P_Z + \ln I, \tag{3.2}$$

where disposable income is defined by equation (2.9).[10] The government simultaneously chooses its three instruments $(\tilde{E}, t^Z, t^X)$.

Irrespective of the policy setting, the optimal tax differential between the Z-composite and X-composite takes the following form (the derivations are in the appendix):

$$t^Z - t^X = \frac{1}{\Delta^a}\left[-\left(\frac{\partial E_X}{\partial t^X} + \frac{\partial E_Z}{\partial t^X}\right) E_Z A_Z^a - \left(\frac{\partial E_Z}{\partial t^Z} + \frac{\partial E_X}{\partial t^Z}\right) E_X A_X^a\right], \tag{3.3}$$

where the determinant Δ is positive and defined as: $\Delta^a = \frac{\partial E_X}{\partial t^X}\frac{\partial E_Z}{\partial t^Z} - \frac{\partial E_X}{\partial t^Z}\frac{\partial E_Z}{\partial t^X} > 0$. Between parenthesis are the marginal effects of taxes on energy use, and A is an outcome of the optimisation (with subscripts indicating sectors and superscripts indicating different cases).

Usually, a first-best, efficient solution (fb) does not entail a wedge between marginal reduction costs for households and for firms $(A_X^{fb} = A_Z^{fb} = 0)$ and the two energy tax rates are the same and equal to the price of tradeable permits: $t^X = t^Z = t^E$.

[10] The welfare function does not show disutility from the global level of energy use or related emissions. This is not necessary since under the Kyoto agreement the level is predetermined and constant.

Assumption A

We assume that

$\frac{\partial E_X}{\partial t^X} + \frac{\partial E_Z}{\partial t^X} \equiv \frac{\partial E}{\partial t^X} < 0, \frac{\partial E_Z}{\partial t^Z} + \frac{\partial E_X}{\partial t^Z} \equiv \frac{\partial E}{\partial t^Z} < 0,$

which says that the direct effect of an energy tax exceeds the indirect effect. Hence, the instruments are effective.

This allows us to write equation (3.3) more concise:

$$t^Z - t^X = \frac{1}{\Delta}\left[-\left(\frac{\partial E}{\partial t^X}\right) E_Z A_Z^a - \left(\frac{\partial E}{\partial t^Z}\right) E_X A_X^a\right]. \tag{3.4}$$

With effective instruments, taxes on households are larger than on firms if $A_Z^a > 0$ and/or $A_X^a > 0$.

3.2 Taxation without firm mobility

Governments may choose their taxes while taking the number of firms as given. In this setting they overlook the effect of their taxes on location choices. With a fixed number of firms, governments expect relocation of polluting activities to occur through the usual channel of imperfect substitution between domestic and foreign varieties: a higher energy tax for firms raises the price of domestic varieties and demand shifts to foreign varieties.[11]

The case without (assumed) firm mobility is relevant for two reasons. First, changing the assumption about firm mobility - a case with firm mobility is discussed later - helps to show how important this assumption is for the results of policy competition with energy taxes. Second, nearly every AGE-model assumes imperfect substitution between varieties of different origin (the Armington assumption) and does not incorporate location decisions. The case without firm mobility indicates what model-consistent government behaviour is in these AGE-models.[12]

Here we discuss informally the different sides of the optimisation problem for the governments when setting the tax rates (and trading emission permits), and we present their optimal response. The formal analysis is relegated to the appendix.

Raising the tax rate on firms above the tax rate for households has a distortionary effect: the marginal costs of energy reductions becomes higher for firms than for households. Creating a tax differential at the expense of firms has, on the other hand, the effect that the tax burden partly falls on foreigners. The government balances these negative and positive effects of a tax differential. Formally, we show that:

$$A_X^n = -1 + \frac{x_{ii}}{Q_i - \overline{Q}}, \qquad A_Z^n = 0. \tag{3.5}$$

The term $x_{ii}/(Q - \overline{Q})$ is the share of domestic deliveries in net output; the right-hand side thus represents the export share. Since the share is between zero and one, the sign of A_X^n is negative.

[11] The governments do have a correct perception of the energy-tax elasticity.

[12] Acemoglu and Ventura (2002) discuss in more detail the similarities between the Armington assumption of imperfect substitution and the Dixit-Stiglitz formulation.

The government chooses to tax firms more than households (see the expression for the tax differential 3.4). Only when a country does not export, it will choose the first-best solution in which the marginal costs of energy savings are the same throughout the economy. Without exports a country cannot shift the burden abroad.

When the cross-effects of the energy taxes are ignored, $\frac{\partial E_Z}{\partial t^X} = \frac{\partial E_X}{\partial t^Z} = 0$, we get a convenient expression for the tax differential:

$$e^{E_X}_{t^X}\left(t^Z - t^X\right) = -\left(1 - \frac{x_{ii}}{Q_i - Q}\right) t^X, \tag{3.6}$$

where $e^{E_X}_{t^X}$ is the elasticity of energy use with respect to the energy tax on firms. This shows not only that the tax for firms is higher than for households, but also that the differential diminishes with the tax elasticity of energy demand: a familiar result. The fact that the tax incidence falls partly upon foreigners leads to the following proposition.

Proposition 1 NIMBY without strategic interaction

Without strategic interaction between the two governments (thus where firm mobility is assumed to be absent) the energy tax on the manufactured composite X is higher than the energy tax on the consumption composite Z , $t^X > t^Z$, as long as a part of the manufactured goods is exported, $\frac{x_{ii}}{Q_i - Q} < 1$. The proof consists of solving the government's optimisation

problem and solving for the tax differential. Details of the proofs / derivations of the results summarised in the propositions are in the appendix. This proposition says that a country uses energy taxes on firms to shift the tax burden onto the other country. Or, saying the same from a different perspective, governments try to shift polluting industries abroad (Not In My Back Yard).

3.3 Strategic tax competition

The case without (assumed) firm mobility is not particularly realistic. Governments overlook the direct effect of energy taxes on location choices and are as a result unconcerned with 'competitiveness', i.e. the fact that energy taxes erode the position of industrial firms on the international markets and lead to a relocation of industrial activities. In fact, in this case governments impose higher energy taxes on firms than on households. This is in clear contradiction with the stylized fact that the burden of energy taxes is lower for firms than it is for households.

The case with firm mobility is more convincing. In this case, governments do take into account that the energy taxes are relevant for location choices. They are concerned about relocation: a decrease in the number of domestic firms (and an increase in the number of foreign firms) tends to raise the consumption price index of the X-goods, since consumers incur transport costs when importing foreign varieties.

The effect on location choices runs via two channels. First, by raising tax rates the government raises the production costs of domestic firms that thereby become less competitive relative to foreign firms and less profitable. The cost differential forces some domestic firms to leave business or to relocate their production abroad. Second, by raising tax rates, of which the burden partly falls on foreign consumers, the government increases national income and spending. This is a benefit in itself, but also has the effect that it raises the (effective) size of the domestic market and profits for domestic firms.

There are, however, more considerations than the location of firms. Of course, creating a tax differential between households and firms leads to a difference in the marginal costs of energy reduction. Besides, in this full-fledged case governments are also concerned with a static distortion between the Z-good and the X-good, that follows from monopolistic competition in the production of the latter good. This distortion is mitigated when the energy tax for firms is higher than for households, leading to a smaller price differential between the Z-good and X-good. Since the distortion is domestic in origin and has little or nothing to do with policy competition, we choose to introduce an ad-valorem constant consumption tax on the Z-good t^C. The tax rate is such that the price of the Z-good is a factor $\frac{\varepsilon}{\varepsilon-1}$ higher than its production costs, $t^C = \frac{1}{\varepsilon-1}$.[13] In first-best equilibrium this would just correct the consequences of mark-up pricing in the X-sector:

Assumption B

In the remainder we assume that governments in both countries impose a constant ad-valorem consumption tax on the Z-good in order to correct for the price distortion that results from mark-up pricing in the X-sector: $t^C = \frac{1}{\varepsilon-1}$.

Using Assumption B, we can derive that:

$$A_X^s = -1 + \frac{{c_{X_i}}^{\varepsilon}}{{c_{X_i}}^{\varepsilon} - T{c_{X_j}}^{\varepsilon}} \frac{P_{X_i} X_i}{N_i p_i (Q_i - Q)}, \qquad A_Z^s = 0. \tag{3.7}$$

An alternative expression is

$$A_X^s = -1 + \frac{1}{1-T^2}\frac{1}{s_{ii}}, \qquad s_{ii} = \frac{N_i p_i^{1-\varepsilon}}{N_i p_i^{1-\varepsilon} + N_j T p_j^{1-\varepsilon}}, \tag{3.8}$$

where s_{ii} is again the market share of firms in country i on their home market.

We can evaluate the tax differential by evaluating A_X^s. Two effects play a role. The first is related to the position of home firms in the international market and is captured by the first factor (cf. equations 2.14 and 2.15). Governments tax mobile firms less if the cost advantage of home firms over foreign firms, including transport, becomes smaller. The second effect is related to tax

[13] Rather than keeping the tax rate constant, it could be included in the set of instruments for the governments. This does not have consequences for the subsequent analysis and its results.

revenue and is captured by the second factor in equation (3.7) which is the ratio of total consumption to total production of the X-good. If the tax base is small, because most goods are imported, raising the tax does not generate substantial revenues (nor does it reduce energy use substantially).

In a symmetric equilibrium the production costs in the X-sector are the same in each country and the net exports and imports are zero, so that the second factor is unity. In this equilibrium it is clear from equation 3.7 that $A_X^s = T/(1-T) > 0$. This implies that the tax differential between households and firms is positive. In other words, energy consumption of households is taxed more heavily than energy use by firms. This is in clear contrast with the previous case without assumed firm mobility, summarized in Proposition 1. The difference between the two cases results from the assumption about firm mobility and location choices. Governments take into account that energy taxes on firms push them abroad and that importing their products is costly, as a result of transport costs. The following proposition summarises this result.

Proposition 2 Strategic competition and reverse dumping in a symmetric equilibrium With strategic policy competition, and a symmetric equilibrium, the energy tax on consumption goods Z is unambiguously higher than the energy tax on the manufactured composite X. The tax differential is decreasing in the elasticity of firms' energy use with respect to their energy tax.

The proof consists of solving the government's optimisation problem, while taking into account firm relocation and solving for the Nash tax differential. The intuition for the result is as follows. In a first-best world, governments prefer to equal tax rates so as to prevent a distortion in energy consumption. However, being aware that a tax on energy-intensive, manufactured goods shifts the production of these goods abroad makes that governments set a lower tax on energy use in the production of these goods.

The last part of the proposition – that the tax differential is decreasing in the tax elasticity of firms' energy use – is a corollary of the standard result that the dead-weight loss of taxes (or a tax difference) is larger, the more elastic demand is.

Suppose that starting in a symmetric equilibrium country i gains a comparative advantage in the production of the X-goods. This advantage could arise in two ways. First, country i could become larger through population growth or overall technical change, leaving the unit production costs in the X-sector unaltered. Firms will relocate towards the larger market. Country i wants a smaller tax differential, since it becomes a net exporter (see equation 3.7) and increases its market share at home and abroad (see equation 3.8). Second, the production costs in the X-sector may fall as a result of technical change in this sector. With a cost differential in favour of country i, its market share will increase. Relocation of firms towards country i only reinforces this. It is thus inclined to choose for a lower tax differential than country j (see equation 3.8). Irrespective of the reason for the comparative advantage, the country that specializes in the production of the X-good and becomes a net exporter, is inclined to have a smaller tax differential than the net importer.

Whether the net exporter does indeed opt for a smaller tax differential than a net importer, also depends on the derivatives of energy demand to energy taxes. In an asymmetric equilibrium these can be different for the different countries. Only near a symmetric equilibrium and for a small cost differential, it is certain that the net exporter will have a smaller tax differential than the net importer.

Proposition 3 Strategic competition between asymmetric countries

When, starting from a symmetric equilibrium, country i specializes in the production of the energy-intensive X-good and becomes a net exporter, country i will choose a smaller tax differential between households and firms than the other country j, that is a net importer: ${A_{X_i}}^s > {A_{X_j}}^s$. Hence, larger countries tend to have a smaller tax differential.

4 Tax coordination

In the two cases of tax competition (section 3.2 and 3.3) governments choose a differential treatment of households and firms. In both cases a tax differential follows from attempts to 'beggar thy neighbour'. Without (assumed) firm mobility governments attempt to let the tax burden fall partly on foreign consumers, while pushing polluting-activities abroad. With firm mobility and strategic considerations, they try to lure firms into their country by undercutting the other country's energy tax on internationally competing and mobile firms. Both cases suggest opportunities for coordination.

This section derives the tax structure that emerges when governments are able to commit to a tax scheme that maximises joint welfare. With coordination, they take into account two cross-border effects in particular. First, an energy tax in one country affects energy demand in the other country. Second, and more importantly, they incorporate that a relocation of firm to one country may hurt the other. This goes to the heart of the problem with tax competition.

With coordination, the expression for the tax differential is not as simple with competition (see equation 3.3). However, the outcome of joint optimisation is still adequately characterized by the terms A^c_X and A^c_Z :

$$A^c_{X_i} = -1 + \left[\frac{c^\varepsilon_{X_i}}{c^\varepsilon_{X_i} - T c^\varepsilon_{X_j}} - \frac{T c^\varepsilon_{X_i}}{c^\varepsilon_{X_j} - T c^\varepsilon_{X_i}} \right] \frac{P_{X_i} X_i}{N_i p_i (Q_i - \overline{Q})}, \qquad A^c_Z = 0, \tag{4.1}$$

when Assumption B applies. Again, an alternative expression is

$$A^c_{X_i} = -1 + \frac{1}{1-T^2} \frac{1}{s_{ii}} \left(1 - T \frac{c^\varepsilon_{X_i} - T c^\varepsilon_{X_j}}{c^\varepsilon_{X_j} - T c^\varepsilon_{X_i}} \right). \tag{4.2}$$

In a symmetric equilibrium the term in square brackets in equation 4.1 is equal to one. Countries take into account that – through the entry conditions and the allocation of firms – they affect the price index of the X-good in both countries. Besides, in a symmetric equilibrium, the consumption value equals the production value of output, so that $A^c_X = 0$. Hence, with policy coordination there is no tax differential.

Proposition 4 Coordination and taxation

With tax coordination and in a symmetric equilibrium, governments agree to avoid a tax differential between the consumption composite (Z) and the manufactured composite (X). A

small perturbation of the symmetric equilibrium provides insight in the outcome of policy coordination between two asymmetric countries. Suppose that production costs in the X-sector are the same but that country i becomes slightly larger than j. The familiar home-market effect will pull production of the X-good more than proportionally towards country i. It will see its share on both markets increase. In other words, country i becomes a net exporter and country j a net importer. This results in $A^c_{X_i} < 0$ and $A^c_{X_j} > 0$, implying a higher energy tax for firms in country i and a lower energy tax in country j. The tax differential between the two countries corrects the excessive agglomeration that prevails in the larger country with free trade. Ottaviano and Van Ypersele (2002) end up with comparable results when considering policy coordination of capital taxes.[14] The intuition for excessive agglomeration is the business stealing effect: firms entering the market do no take into account that they reduce the demand for other firms (Mankiw and Whinston (1986)).

Now, assume instead that countries remain equal in size but that country i attains slightly lower costs than country j. Then again, by inspection of equation 4.2, follows: $A^c_{X_i} < 0$ and $A^c_{X_j} > 0$. This implies higher taxation of the X-good in the low-cost country and vice versa. Inspection of equation 4.2 learns that this occurs even for a given allocation of firms. This points at another reason than excessive agglomeration for different tax structures in the two countries. Given the allocation of firms, country i benefits more from the cost decrease than country j. The home bias in consumption is responsible for that. The relocation as a result of the cost differential will only worsen the distribution of the welfare gain. Through different energy taxes on firms, the welfare gain is partly taken from the low-cost country and redistributed to the high-cost country. We summarise the results on the asymmetric case by formulating the following proposition:

Proposition 5 Coordination between asymmetric countries
When starting from a symmetric equilibrium, country i gains a slight comparative advantage in the production of the energy-intensive X-good and becomes a net exporter of that good, countries i and j will partly offset this advantage by higher energy taxes on firms in country i and lower taxes in country j.

Countries use energy tax rates to affect agglomeration. The underlying reason is that they lack instruments to affect the allocation of firms directly. For example, they are not allowed to discriminate between domestic and foreign firms, for example through import tariffs or through state subsidies (cf.Hoel (1996), and Rauscher (1995)).

[14] Their analysis starts however with a quasi-linear utility function, whereas ours starts with a Dixit and Stiglitz (1977) model. They analyse tax competition without environmental problems.

5 Discussion of assumptions and results

Every case that has been discussed so far, led to the result that $A_Z = 0$. This changes when assumption B is dropped and the static, domestic distortion as the result of mark-up pricing in the X-sector is reintroduced. Energy taxes will then be set such that the static distortion is mitigated: with $A_Z > 0$ government will choose to tax energy-use in the production of the Z-good more than that in the production of the X-good, thereby reducing the price difference between the two goods. This holds for both the case of strategic policy competition and for the case of policy coordination.

In contrast, the assumption of intergovernmental trade in emission rights does not effect the results as summarized in the expressions for A_X. International trade in permits eliminates any difference in the average tax rate between countries (more precisely, the difference in the social marginal costs of energy reductions) but does not essentially affect the tax structure within countries.

With policy competition, governments choose to tax different sectors differently. In the case without firm mobility, the energy tax rate in the X-sector is higher than that in the Z-sector, whereas it is the other way around in the more realistic case with firm mobility. Either way, the assumption that the tax differential within a country is not affected does not hold. Typically, the model simulations to assess the costs of the Kyoto Protocol are based on this assumption; the costs are thus underestimated.

Corollary 6 The cost of the Kyoto protocol
Energy reductions are more costly with tax differentials across the sectors than with a uniform energy tax. Since the Kyoto Protocol does not prevent policy competition that leads to these tax differentials, a cost assessment should take them into account.

This corollary follows directly from Propositions (1 or) 2 and 4.

Normally, the costs of the Kyoto Protocol are underestimated, but so are the benefits of a system with inter-firm trade in emission rights, such as the European Commission has installed. It goes to the heart of the problem with policy competition: with such a system governments lose the ability to set the (marginal) energy tax rate for internationally mobile firms and no longer compete with each other. Indeed, we can show that

Proposition 7 Partial coordination in a symmetric equilibrium
In a symmetric equilibrium, coordination of just the energy taxes on firms is enough to ensure that (after-tax) energy prices are the same across countries as well as for firms and households.

Policy competition makes the case for a system of inter-firm trade strong, but may also undermine such a system. Suppose that a government cannot affect the emission price but is allowed to grant internationally mobile firms emission rights. That is similar to a situation in which the government cannot set the marginal tax rate on energy use but is still allowed to choose the average tax rate. For example, part of the energy use is exempted from energy taxes. We can show that in the case of strategic policy competition governments have a positive incentive to let the average energy tax rate (for firms in the X-sector) fall below the marginal tax rate.

Proposition 8 Emission trade among firms in a symmetric equilibrium
Within a system of emission trade among firms governments cannot directly manipulate the marginal energy tax rate for firms, i.e. the emission price. However, they will continue to compete strategically through the allocation of emission rights to firms, driving a wedge between the tax rates on firms and households in a symmetric equilibrium.

6 Conclusions

If environmental policy is not coordinated across countries, policy will not be set socially optimal. As the marginal costs of emission reductions will generally be set differently between sectors of a country, the first-best is achieved. We derive this result in a monopolistic competition model where governments optimally set taxes, and trade in emission permits. Hence, permit trade is not a sufficient means of coordination in order to minimise the costs of implementing the Kyoto protocol. As the costs of differential taxation within countries are overlooked in the evaluation of the costs of Kyoto, these costs tend to be underestimated.

We considered two different cases of policy competition. First, when firms are assumed to be immobile, governments choose to tax firms more than households. The reason is that part of the firms' energy consumption is for production of foreign consumer goods and does not benefit domestic consumers. Second, if governments take into account relocation of firms and behave strategically, they set higher energy tax rates for households than for firms. This is the result of tax competition: governments try to undercut other governments to attract firms to their country.

Both cases call for co-ordination of climate change policies that goes beyond a binding ceiling on greenhouse gas emissions and international trade in permit rights among governments. The European Union has implemented a system of tradeable permits, in which firms can buy and sell permits and thus internationally face the same incentive at the margin. This, however, will not avoid competition among governments completely. The paper shows that governments have an incentive to favour firms in the allocation of permits. The production decisions are then distorted and government revenues are wasted.

The paper thus suggests that tighter coordination of national climate change policies is called for to reduce the economic costs of these policies. In the European case, the system of emission trade has to be extended to include more sectors and perhaps households.

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Appendix

Deriving Nash taxes without strategic considerations (proof of proposition 1)

The government maximises:

$$\text{MAX} \quad V = -(1-\gamma)\ln P_X - \gamma \ln P_Z + \ln I + \lambda\left(\bar{E} + \tilde{E} - E_Z - E_X\right), \tag{6.1}$$

where

$$I = wL + S + t^Z P_E E_Z + t^X P_E E_X - t^E \tilde{E} \tag{6.2}$$

This gives the following first-order conditions:

$$\frac{\partial V}{\partial t^Z} = -\frac{\gamma}{P_Z}\frac{\partial P_Z}{\partial P_E^z}\frac{\partial P_E^z}{\partial t^Z} + \frac{1}{I}\left(E_Z + t^Z\frac{\partial E_Z}{\partial t^Z} + t^x\frac{\partial E_X}{\partial t^Z}\right) - \lambda\left(\frac{\partial E_Z}{\partial t^Z} - \frac{\partial E_X}{\partial t^Z}\right) = 0, \tag{6.3}$$

$$\frac{\partial V}{\partial t^X} = -\frac{1-\gamma}{P_X}\frac{\partial P_X}{\partial P_{ii}}\frac{\partial P_{ii}}{\partial c_X}\frac{\partial c_X}{\partial P_E^x}\frac{\partial P_E^x}{\partial t^X} + \frac{1}{I}\left(E_X + t^Z\frac{\partial E_Z}{\partial t^X} + t^X\frac{\partial E_X}{\partial t^X}\right) - \lambda\left(\frac{\partial E_Z}{\partial t^X} - \frac{\partial E_X}{\partial t^X}\right) = 0, \tag{6.4}$$

$$\frac{\partial V}{\partial \tilde{E}} = -\frac{t^E}{I} + \lambda = 0. \tag{6.5}$$

Using that the price energy-tax elasticities are equal to the production cost share of energy, the first two expression can subsequently be simplified to:

$$\left(t^Z\frac{\partial E_Z}{\partial t^Z} + t^X\frac{\partial E_X}{\partial t^Z}\right) = \lambda I\left(\frac{\partial E_Z}{\partial t^Z} - \frac{\partial E_X}{\partial t^Z}\right), \tag{6.6}$$

and:

$$(1-s_{ii})E_X + \left(t^Z\frac{\partial E_Z}{\partial t^X} + t^X\frac{\partial E_X}{\partial t^X}\right) = \lambda I\left(\frac{\partial E_Z}{\partial t^X} - \frac{\partial E_X}{\partial t^X}\right). \tag{6.7}$$

The first term on the right-hand side of this expression the share of X-goods that is exported: $s_{ii} = \frac{x_{ii}}{Q_i}\frac{\varepsilon}{\varepsilon-1}$. Substituting the third first order condition we can rewrite this as a system of two equations and two unknowns:

$$\begin{bmatrix} \frac{\partial E_Z}{\partial t^Z} & \frac{\partial E_X}{\partial t^Z} \\ \frac{\partial E_Z}{\partial t^X} & \frac{\partial E_X}{\partial t^X} \end{bmatrix} \begin{bmatrix} t^Z - t^E \\ t^X - t^E \end{bmatrix} = \begin{bmatrix} 0 \\ -(1-s_{ii})E_X \end{bmatrix}, \tag{6.8}$$

solving the expression for the two tax-permit-price differentials allows to calculate:

$$t^Z - t^X = \frac{(1-s_{ii})E_X}{\Delta}\left(\frac{\partial E_Z}{\partial t^Z} + \frac{\partial E_X}{\partial t^Z}\right). \tag{6.9}$$

where $\Delta = \frac{\partial E_X}{\partial t^X}\frac{\partial E_Z}{\partial t^Z} - \frac{\partial E_X}{\partial t^Z}\frac{\partial E_Z}{\partial t^X} > 0$ as the direct effects of the energy taxes exceed the indirect effects. This implies that the tax on firms exceeds that on consumers (if $s_{ii}>0$) ■

Deriving Nash taxes with strategic considerations (proof of proposition 2 and 3)

The set-up is analogous to that discussed above. Strategic considerations, however, are taken into account. That is, governments take into account that by raising tax rates they raise the cost of domestically producing firms that thereby become less competitive to firms producing abroad. This has the consequence that firms may relocate to the other country. Technically speaking, this effect can be divided in two parts. First, governments do not only take into account the direct effect of a tax on the price level but also the indirect effect of the tax on the price level that runs via relocation of firms. That is the fact that some goods, first produced at home (and consumed without bearing transport costs), need to be imported after that raising taxes 'pushed' them out of the country. Taking this effect into account means that the indirect effect of prices, running via the change in the effective market size is to be taken into account. Second, any policy measure that changes income levels has an effect on the effective market size via the spending level on X goods that is directly affect by income. Thus we use the definition of the effective market size $W_j = I_{X_i} P_{X_i}^{\varepsilon-1}$ to get the price effect of changing the effective market size:

$$W_i = \frac{1}{1-T_{ij}T_{ji}} \left[F_i {c_{X_i}}^{\varepsilon} - T_{ij} F_j {c_{X_j}}^{\varepsilon} \right], \tag{6.10}$$

Now the first-order conditions can be derived as:

$$\begin{aligned} \frac{\partial V}{\partial t^Z} = & \quad -\tfrac{\gamma}{P_Z} \tfrac{\partial P_Z}{\partial P_E^z} \tfrac{\partial P_E^z}{\partial t^Z} + \tfrac{1}{I} \left(E_Z + t^Z \tfrac{\partial E_Z}{\partial t^Z} + t^X \tfrac{\partial E_X}{\partial t^Z} \right) \\ & - \tfrac{1-\gamma}{P_X} \tfrac{\partial P_X}{\partial I} \left(E_Z + t^Z \tfrac{\partial E_Z}{\partial t^Z} + t^x \tfrac{\partial E_X}{\partial t^Z} \right) - \lambda \left(\tfrac{\partial E_Z}{\partial t^Z} - \tfrac{\partial E_X}{\partial t^Z} \right) = 0 \end{aligned} \tag{6.11}$$

$$\begin{aligned} \frac{\partial V}{\partial t^X} = & \quad -\tfrac{1-\gamma}{P_X} \left(\tfrac{\partial P_X}{\partial W} \tfrac{\partial W}{\partial c_X} \tfrac{\partial c_X}{\partial P_E^x} \tfrac{\partial P_E^x}{\partial t^X} + \tfrac{\partial P_X}{\partial I} \tfrac{\partial I}{\partial t^X} \right) \\ & + \tfrac{1}{I} \left(E_X + t^Z \tfrac{\partial E_Z}{\partial t^X} + t^X \tfrac{\partial E_X}{\partial t^X} \right) - \lambda \left(\tfrac{\partial E_Z}{\partial t^X} - \tfrac{\partial E_X}{\partial t^X} \right) = 0, \end{aligned} \tag{6.12}$$

$$\frac{\partial V}{\partial \tilde{E}} = -\frac{t^E}{I} - \frac{1-\gamma}{P_X} + \frac{\partial P_X}{\partial I} \frac{\partial I}{\partial \tilde{E}} + \lambda = 0. \tag{6.13}$$

Simplifying the first-order conditions again leads to a system of two equations and two unknowns:

$$\begin{bmatrix} \frac{\partial E_Z}{\partial t^Z} & \frac{\partial E_X}{\partial t^Z} \\ \frac{\partial E_Z}{\partial t^X} & \frac{\partial E_X}{\partial t^X} \end{bmatrix} \begin{bmatrix} t^Z - t^E \\ t^X - t^E \end{bmatrix} = \begin{bmatrix} -\frac{1-\gamma}{\varepsilon-\gamma} E_Z \\ -\left(1 - \frac{\varepsilon}{\varepsilon-\gamma} \frac{c_X^{\varepsilon}}{c_X^{\varepsilon} - T c_{X_j}^{\varepsilon}} \frac{P_X X}{Np(Q-\bar{Q})} \right) E_X \end{bmatrix}, \tag{6.14}$$

We introduce notation:

$$M^S \equiv -\left(1 - \frac{\varepsilon}{\varepsilon-\gamma} \frac{c_{X_i}^{\varepsilon}}{c_{X_i}^{\varepsilon} - T c_{X_j}^{\varepsilon}} \frac{P_X X}{Np(Q-\bar{Q})} \right) > 0. \tag{6.15}$$

where M is to be read as the import quote or $1/M$ as an indication of the size of the country. Solving for the tax-differential gives:

$$t^Z - t^X = \frac{1}{\Delta} \left[\left(\frac{\partial E_X}{\partial t^X} + \frac{\partial E_Z}{\partial t^X} \right) \left(-\frac{1-\gamma}{\varepsilon-\gamma} E_Z \right) - \left(\frac{\partial E_Z}{\partial t^Z} + \frac{\partial E_X}{\partial t^Z} \right) M^S E_X \right]. \tag{6.16}$$

We use the following assumptions:

$$dE = \left(\frac{\partial E_Z}{\partial t^Z} + \frac{\partial E_X}{\partial t^Z} \right) dt^Z < 0. \tag{6.17}$$

and the analog for the tax on manufacturing firms. These conditions say that for marginal changes the direct negative effect on energy use of a tax exceeds the indirect positive effect.

Using these assumptions and the fact that the three terms in parenthesis in equation (6.16) all exceed one, we obtain the result that the taxation on households exceeds that on firms. ■

Expression (6.16) is more insightful if we set the indirect effects of energy taxes on energy use equal to zero:

$$t^Z - t^X = \left[\left(\frac{1}{e^{ZZ}} \right) \left(-\frac{1-\gamma}{\varepsilon - \gamma} \right) t^Z - \left(\frac{1}{e^{XX}} \right) M^S t^X \right]. \tag{6.18}$$

Deriving coordinated taxes (proof of proposition 4 and 5)

With coordination the governments maximise a utilitarian joint welfare function:

$$\text{MAX} \quad V = \frac{1}{2} \sum_i \left[-(1-\gamma) \ln P_{X_i} - \gamma \ln P_{Z_i} + \ln I_i \right], \tag{6.19}$$

subject to

$$I_i = w_i - T_i + t_i^Z E_{Z_i} + t_i^X E_{X_i} - t^E \tilde{E}_i, \forall i, j, \tag{6.20}$$

$$\bar{E_i} + \tilde{E}_i - E_{Z_i} - E_{X_i} = 0, \forall i, j \tag{6.21}$$

and use $W_j = I_{X_i} P_{X_i}^{\varepsilon - 1}$ and $W_i = \frac{1}{1 - T_{ij} T_{ji}} \left[F_i c_{X_i}{}^{\varepsilon} - T_{ij} F_j c_{X_j}{}^{\varepsilon} \right]$.

The derivation of the first-order conditions for $t_1^Z, t_2^Z, t_1^X, t_2^X, \tilde{E}_1 (= -\tilde{E}_2)$ is straightforward:

$$\begin{aligned} \frac{\partial V}{\partial t_i^Z} = & -\tfrac{\gamma}{P_{Z_i}} \tfrac{\partial P_{Z_i}}{\partial P_{E_i}{}^z} \tfrac{\partial P_{E_i}{}^z}{\partial t_i^Z} + \tfrac{E_{Z_i}}{I_i} + \tfrac{1}{2} \textstyle\sum_j^{1,2} \tfrac{1}{I_j} \left(t_j^Z \tfrac{\partial E_{Z_j}}{\partial t_i^Z} + t_j^X \tfrac{\partial E_{X_j}}{\partial t_i^Z} \right) - \\ & (1-\gamma) \tfrac{1}{2} \textstyle\sum_j^{1,2} \tfrac{1}{P_{X_j}} \tfrac{\partial P_{X_j}}{\partial I_j} \left(E_{Z_j} + t_j^Z \tfrac{\partial E_{Z_j}}{\partial t_i^Z} + t_j^X \tfrac{\partial E_{X_j}}{\partial t_i^Z} \right) - \\ & \tfrac{1}{2} \textstyle\sum_j^{1,2} \lambda_j \left(\tfrac{\partial E_{Z_j}}{\partial t_i^Z} - \tfrac{\partial E_{X_j}}{\partial t_i^Z} \right) = 0, \ \text{ for } \ i \in \{1,2\}. \end{aligned} \tag{6.22}$$

$$\begin{aligned} \frac{\partial V}{\partial t_i^X} = & -(1-\gamma) \tfrac{1}{2} \textstyle\sum_j^{1,2} \tfrac{1}{P_{X_j}} \left(\tfrac{\partial P_{X_j}}{\partial W_j} \tfrac{\partial W_j}{\partial c_{X_j}} \tfrac{\partial c_{X_j}}{\partial P_{E_j}{}^x} \tfrac{\partial P_{E_j}{}^x}{\partial t_i^X} + \tfrac{\partial P_{X_j}}{\partial I_j} \tfrac{\partial I_j}{\partial t_i^X} \right) + \\ & \tfrac{E_{X_i}}{I_i} + \tfrac{1}{2} \textstyle\sum_j^{1,2} \tfrac{1}{I_j} \left(t_j^Z \tfrac{\partial E_{Z_j}}{\partial t_i^X} + t_j^X \tfrac{\partial E_{X_j}}{\partial t_i^X} \right) - \\ & \tfrac{1}{2} \textstyle\sum_j^{1,2} \lambda_j \left(\tfrac{\partial E_{Z_j}}{\partial t_i^X} - \tfrac{\partial E_{X_j}}{\partial t_i^X} \right) = 0, \ \text{ for } \ i \in \{1,2\}. \end{aligned} \tag{6.23}$$

$$\frac{\partial V}{\partial \tilde{E}_1} = \frac{t^{E_2}}{I_2} - \frac{t^{E_1}}{I_1} + \frac{1-\gamma}{P_{X_2}} - \frac{1-\gamma}{P_{X_1}} + \frac{\partial P_{X_1}}{\partial I_1} \frac{\partial I_1}{\partial \tilde{E}_1} - \frac{\partial P_{X_2}}{\partial I_2} \frac{\partial I_2}{\partial \tilde{E}_1} + \lambda_1 - \lambda_2 = 0. \tag{6.24}$$

Solving the tax-differential gives:

$$t_i^Z - t_i^X = \frac{1}{\Delta i}\left[\left(\frac{\partial E_{X_1}}{\partial t_i^X}+\frac{\partial E_{Z_i}}{\partial t_i^X}\right)\left(-\frac{1-\gamma}{\varepsilon-\gamma}E_{Z_i}\right)\right] - \frac{1}{\Delta i}\left[\left(\frac{\partial E_{Z_i}}{\partial t_i^Z}+\frac{\partial E_{X_i}}{\partial t_i^Z}\right)\left(1-\frac{\varepsilon}{\varepsilon-\gamma}\left[\frac{c_{X_i}^{\varepsilon}}{c_{X_i}^{\varepsilon}-Tc_{X_j}^{\varepsilon}}-\frac{Tc_{X_i}^{\varepsilon}}{c_{X_j}^{\varepsilon}-Tc_{X_i}^{\varepsilon}}\right]\frac{P_{X_i}X_i}{N_i p_i(Q_i-Q)}\right)E_{X_i}\right]. \tag{6.25}$$

Introducing Assumption B in this expression gives:

$$t_i^Z - t_i^X = -\frac{1}{\Delta i}\left[\left(\frac{\partial E_{Z_i}}{\partial t_i^Z}+\frac{\partial E_{X_i}}{\partial t_i^Z}\right)\left(1-\left[\frac{c_{X_i}^{\varepsilon}}{c_{X_i}^{\varepsilon}-Tc_{X_j}^{\varepsilon}}-\frac{Tc_{X_i}^{\varepsilon}}{c_{X_j}^{\varepsilon}-Tc_{X_i}^{\varepsilon}}\right]\frac{P_{X_i}X_i}{N_i p_i(Q_i-Q)}\right)E_{X_i}\right]. \tag{6.26}$$

This completes the proof. ■

The EC proposal (proof of proposition 7 and 8)

The EC proposal allows inter-firm trade in emission rights. To analyse this, we use the following set up. Suppose that the total level of emissions by X-firms is fixed (E_F^T) and that each country receives a fixed part of the total emission rights. In other words, the revenues from selling emission rights is divided between the two countries: $t^E E_F^T = t^E E_{F_1}^* + t^E E_{F_2}^*$. Suppose furthermore that the total level of emissions is set such that the coordinated symmetric equilibrium is reproduced if $t^F = t^{Z_1} = t^{Z_2}$. Within this set up, governments do not try to influence emissions by firms in the X-sector in their country. The key element, however, is that governments can give firms, located in their country, emission rights for free. These we denote by $\bar{E_F}$. This boils down to a production subsidy, such that equation (2.8) in the main text is changed into

$$\left(Q-\bar{Q}\right)\frac{1}{\varepsilon-1} = \bar{Q} - \frac{t^E \bar{E_F}}{c_X}, \tag{6.27}$$

The optimisation problem for the government can than be written as

$$\text{MAX} \quad V = -(1-\gamma)\ln P_X - \gamma \ln P_Z + \ln I, \tag{6.28}$$

subject to

$$E_z + \tilde{E} - E_z^* = 0 \tag{6.29}$$

$$P_X = \left[\frac{W}{(1-\gamma)I}\right]^{\frac{1}{\varepsilon-1}} \tag{6.30}$$

$$I = \frac{\tilde{I}}{1-\frac{\gamma r}{1+r}} \quad r = \frac{1}{\varepsilon-1} \tag{6.31}$$

$$\tilde{I} = wL + t^Z E_Z - t^E \tilde{E} + t^F E_F^* - t^F N \bar{E_F} \tag{6.32}$$

The goverment has three instruments: the amount of emission rights ($\tilde{E}$), the tax on energy use by consumers (t^Z) and the amount of permits donated to X-firms ($\bar{E_F}$). Now the first-order conditions can be derived as:

$$\frac{\partial V}{\partial \tilde{E}} = -\frac{t^E}{I} - \frac{1-\gamma}{P_X} + \frac{\partial P_X}{\partial \tilde{I}}\frac{\partial \tilde{I}}{\partial \tilde{E}} + \lambda = 0$$
$$\Leftrightarrow \left(1+\frac{1-\gamma}{\varepsilon-1}\right)t^E = \lambda \tilde{I} \tag{6.33}$$

$$\frac{\partial V}{\partial t^Z} = \qquad -\frac{\gamma}{P_Z}\frac{\partial P_Z}{\partial P_E^z}\frac{\partial P_E^z}{\partial t^Z} + \frac{1}{\tilde{I}}\left(E_Z + t^Z\frac{\partial E_Z}{\partial t^Z}\right)$$

$$-\frac{1-\gamma}{P_X}\frac{\partial P_X}{\partial \tilde{I}}\left(E_Z + t^Z\frac{\partial E_Z}{\partial t^Z}\right) - \lambda\left(\frac{\partial E_Z}{\partial t^Z}\right) = 0$$

$$\Leftrightarrow -\frac{\gamma E_Z}{P_Z Z} + \left(1+\frac{1-\gamma}{\varepsilon-1}\right)\frac{E_Z}{\tilde{I}} + \frac{\partial E_Z}{\partial t^Z}\left(\left(1+\frac{1-\gamma}{\varepsilon-1}\right)\frac{t^Z}{\tilde{I}} + \lambda\right) = 0 \tag{6.34}$$

$$\frac{\partial V}{\partial \bar{E}_F} = -\frac{t^F N}{\tilde{I}} - \frac{1-\gamma}{P_X}\left(\frac{\partial P_X}{\partial W}\frac{\partial W}{\partial \bar{E}_F} + \frac{\partial P_X}{\partial \tilde{I}}\frac{\partial \tilde{I}}{\partial \bar{E}_F}\right) - \frac{t^F \bar{E}_F N}{\tilde{I}}\frac{\partial N}{\partial \bar{E}_F} \tag{6.35}$$

The first two terms in equation 6.34 ad up to zero as $(1+t^Z)P_Z Z = \gamma I$ and $I = \frac{\varepsilon}{\varepsilon-\gamma}\tilde{I}$. Then combining 6.33 with 6.34 gives that $t^Z = t^E$. This completes the prove of proposition 7. ■

To prove prosition 8 we need to analyse equation 6.35 somewhat further. We can rewrite 6.35 as

$$\frac{\partial V}{\partial \bar{E}_F} = -\frac{t^F}{\tilde{I}}\left(N + \bar{E}_F\frac{\partial N}{\partial \bar{E}_F}\right) - \frac{1-\gamma}{P_X}\left(\frac{1}{\varepsilon-1}\frac{P_X}{W} - \frac{1}{1-T^2}\varepsilon^{\varepsilon}(\varepsilon-1)^{\varepsilon-1}c_X^{\varepsilon}\frac{t^F}{c_X} - \frac{1}{\varepsilon-1}\frac{P_X}{\tilde{I}}\right) \tag{6.36}$$

Defining the permit-number of firms elasticity as $\sigma_{\bar{E}_F}^N = \frac{\bar{E}_F}{N}\frac{\partial N}{\partial \bar{E}_F}$ and use the definition of the effective market size $W_j = I_{X_i}P_{X_i}^{\varepsilon-1}$ and the expession for the effective market size 6.10, to rewrite 6.36 as

$$-\frac{N}{\tilde{I}}\left(1+\sigma_{\bar{E}_F}^N\right)\left(1+-\frac{1-\gamma}{\varepsilon-1}\right) + \frac{1-\gamma}{\varepsilon-1}\left(\frac{c_{X_i}^{\varepsilon}}{c_{X_i}^{\varepsilon}F_i - T_i j c_{X_j}^{\varepsilon}F_j}\frac{1}{c_{X_i}}\right) = 0 \tag{6.37}$$

Use $I = \frac{\varepsilon}{\varepsilon-\gamma}\tilde{I}$ and the fact that $(1-\gamma)I = P_X(Q-\bar{Q})N$ and the symmetry assumption to see that

$$\frac{(1-\gamma)N}{(\varepsilon-1)c_X F N(1-T)} = \frac{\varepsilon(1-\gamma)N}{(\varepsilon-1)P_X(Q-Q)N(1-T)} \tag{6.38}$$

Then 6.38 simplyfies to

$$-\left(1+\sigma_{\bar{E}_F}^N\right) + \frac{1}{1-T} \tag{6.39}$$

finally, if $\bar{E}_F$ goes to zero, $\sigma_{\bar{E}_F}^N$ goes to zero and the expression is positive. This implies that for this first-order condition to hold governments tend to subsidise their firms by donating emission rights. This completes the proof ■