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Unilateral climate policy and optimal containment in an open economy

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Abstract

In the absence of a broad international agreement, national climate policies are less efficient, due to carbon leakage, and more costly, due to causing unemployment and a loss of competitiveness on international markets. As, in many countries, a substantial fraction of emissions results from the production of intermediate goods, such as electricity or transportation services, we investigate whether the above negative side-effects can be addressed by a policy mix that (partially) contains the effects of climate policy to the intermediate goods sector. We use a four-sector general equilibrium model to study a policy mix that consists of taxing emissions and subsidizing the intermediate good. We show that such containment is a second-best approach to combat carbon leakage and to maintain a favorable international market position. Also, it can help to reduce climate-policy-induced unemployment.

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1 Introduction

Substantial reductions in global greenhouse gas emissions seem to be necessary to address the problem of climate change. The costs of these reductions can be minimized by a globally coordinated policy. But, so far, only few countries have committed to substantial reductions and, at the present stage of the negotiations, it seems unlikely that binding emission constraints will be accepted by the majority of emitters within the next years.

Nevertheless, some governments pursue an active climate policy, despite this lack of global action. For instance, the EU aims at reducing its greenhouse gas emissions by about 20% till 2020 and reduction targets have recently also been announced in the US. Such unilateral[1] policies are important, because they induce research in abatement technologies, which reduces abatement costs and thus helps to convince more countries to instate emission reduction measures. But governments that enact such unilateral policies are often subject to intense national pressure, being criticized as unreasonably sacrificing national welfare and allowing other countries to free-ride on national efforts.

Three arguments are frequently used to question the value of a unilateral climate policy. First, such a policy is seen as futile, because costly emission constraints will drive emission intensive industries to less active countries, so that national emission reductions are partially compensated by emission increases in other countries (carbon leakage). Second, national emission reductions in the presence of labor market imperfections can cause unemployment. Emission constraints will reduce the marginal productivity of labor, if these constraints are unilateral and thus not adequately reflected in international product prices. Under wage rigidities, this productivity reduction can induce unemployment. Finally, national industries could become less competitive, so that favorable trade positions could be lost. If a country has a strategic advantage on an international market, unilateral climate policy can reduce this advantage and thus be rather costly from a national perspective.

There is extensive literature that addresses these issues.[2] But while the main conclusion is that a global coordination of climate policy is important, only few studies investigate what should be done if international climate negotiations fail or become stalled for some time. Is it possible to reduce the negative side-effects of unilateral climate policy by using specifically designed policy measures?

In principle, combating these side-effects is simple. Supplementing climate

[1] To avoid awkward terminology, we refer to a national climate policy that is enacted outside the context of a global agreement with binding emission reductions for the major emitters as a "unilateral" policy. Of course, this term is not fully adequate, as some countries coordinate their policies, as in the EU.

[2] We briefly review this literature in the following section.

policy measures, such as emission taxes or permit trading, with tariffs or export subsidies could mitigate the negative effects of unilateral action. But, in practice, most countries that pursue active climate policies are bound by WTO rules that render such interventions in export and import markets impossible. Therefore the literature focuses on differentiating climate policy between sectors that are open to international trade and those that are not (see, for example, Hoel (1996) and Withagen et al. (2007)). These studies show that such policy differentiation is reasonable from a national perspective, although it induces inefficiencies.

However, policy differentiation is not always feasible. A substantial part of emissions are not directly caused by sectors that are open to international trade. Rather, they result from the production of intermediate goods and export industries are affected more by increasing prices for these goods than by direct compliance costs. An important example is energy. In 2006 around 30% of the CO_2-equivalent greenhouse gas emissions of the EU-27 were caused by the energy industries (UNFCCC, 2006), and almost 40% of US CO_2-emissions were generated by electricity production (EIA, 2008a). A large fraction of this energy is used as an input in export industries.

A policy differentiation fails in such cases, because several sectors use the same intermediate good and it is not possible to differentiate an emission tax levied in the intermediate goods sector according to where the intermediate good is used in final goods production. But, as markets for the relevant intermediate goods, such as electricity or transportation services, are often national and thus not subject to WTO rules, there is the possibility to intervene in these markets. For example, climate policy might lead to an increase in the price of electricity and thus to higher costs in final goods production, which can induce carbon leakage and unemployment as well as a loss of market power on international markets. To reduce these side-effects, it could be reasonable from a national perspective to tax the emissions caused by electricity generation (thereby setting abatement incentives, such as the use of natural gas fired power plants, wind and solar energy) but, at the same time, subsidize electricity to shield final goods production from increasing electricity prices (thereby reducing the negative side effects of unilateral climate policy).

Of course, such a policy induces inefficiencies and reduces the dynamic incentives of climate policy. But it can be a reasonable tool for a transitory climate policy until broad international agreements are reached. The idea is to contain the effects of climate policy to those sectors that are emission intensive and not subject to international competition. Intermediate goods, such as electricity or transportation services, are an ideal candidate for such an approach, because the production of these goods accounts for a large fraction of greenhouse gas emissions in most industrialized countries and these goods are rarely traded internationally.

The idea of this containment approach is similar to the policy differentiation of

Hoel (1996) and Withagen et al. (2007) in that this approach also aims at reducing the burden of those sectors that are open to international trade. The approaches differ in that they apply to different industries. Policy differentiation is possible, if the sectors that are open to international trade directly cause substantial emissions, as is the case in the cement industry or the iron and steel industry. Our approach applies to settings, where the sectors that are open to trade cause emissions mostly by using energy-intensive inputs, as in manufacturing, parts of the chemical industry, or the service sector. Thus our containment approach is complementary to the policy differentiation concept. Furthermore, both approaches have different economic implications. Policy differentiation is costly, because it allocates abatement inefficiently among sectors. Containment does not alter the allocation of abatement but leads to an inefficient use of energy-intensive inputs. Thus the consequences for factor allocation in the general equilibrium differ substantially.

In this paper, we use a simple model of unilateral climate policy in an open economy to investigate whether interventions in an intermediate good market are a reasonable way to combat the side-effects of unilateral climate policy. Our setup consists of a general equilibrium model of a four-sector economy, where one sector produces an intermediate good and is environmentally regulated, and where the three other sectors produce final goods. Two of these sectors use the intermediate good with one sector being open to international trade and one sector producing solely for the home country's internal market. The fourth sector engages in international trade but does not use the intermediate good and is therefore not directly affected by climate policy. To separate the strategic decision of whether a country will commit to a unilateral policy from the question of how such a commitment should be implemented, we assume that the policy target is already fixed. Indeed, this setup seems to be of high practical relevance, as policy targets are often set before the actual implementation is decided.

In this setup, we consider the above three arguments against a unilateral climate policy and show that each of these negative side-effects can be reduced by an intervention in the intermediate goods market. For each of these cases, we derive the optimal policy mix and discuss how it depends on general characteristics, such as the trade position of a country. Typically, the optimal policy mix consists of an emission tax and a subsidy on the intermediate good. But, in some cases, a taxation of the intermediate good can be optimal. Furthermore, except for the case of maintaining market power, the optimality of intervening in the intermediate goods market is not due to strategic behavior; it exists even in the case of a small open economy.

In the following section, we briefly review the related literature. Then we set up our model. In Section 4, we derive the optimal policy response to each of the above arguments against unilateral climate policy, namely carbon leakage, unemployment due to market distortions, and the maintenance of market power. Section 5 concludes the paper.

2 Review of the Literature

Our analysis relates to three distinct strands of literature. The first of these is the early literature on optimal policies in the presence of distortions such as factor immobility, wage rigidity or fixed non-economic targets.

Bhagwati and Ramaswami (1963) have shown that if the distortion is domestic, that is, if, under laissez-faire, the domestic rates of substitution and transformation are not equal, the best policy is a domestic intervention. However, if the domestic and the foreign rates of transformation differ, for example, due to monopoly power, the optimal intervention is a trade tariff or subsidy.

Bhagwati and Srinivasan (1969) turn to the question of how to implement a given non-economic goal, such as a certain employment level or a minimum output of a given good, at the least possible social cost. The results of Bhagwati and Srinivasan (1969) relate intuitively to those of Bhagwati and Ramaswami (1963) and boil down to the principle that the optimal intervention takes place directly where the non-economic objective lies and does not include trade intervention. For example, to reach a given output level, the optimal policy is an output subsidy (and not an import tariff).

A collection and unification of results on distortions, policy interventions and welfare can be found in Bhagwati (1971).

Krishna and Panagariya (2000) add to the literature by clarifying some important issues of the theory of second-best interventions. In particular, they demonstrate that second-best policies crucially depend on whether the distortion takes the form of a restriction of choice variables or is a restriction on a first-order condition. In the former case, the first-order conditions of the first-best solution continue to characterize the optimum and there is no justification for intervention in undistorted sectors.

The second line of research which our paper relates to is the climate policy literature. While game theoretic methods, in particular coalition theory, have been widely applied to study the formation and stability of international climate agreements,[3] some research has also been done on unilateral climate policy in the absence of a global framework.

Hoel (1996) and Withagen et al. (2007) examine the question as to whether emission regulation should be differentiated across sectors if a country pursues climate policy unilaterally. Both Hoel (1996) and Withagen et al. (2007) find

[3] See Finus (2008) for a recent survey.

that there is no reason for a differentiated emission policy as long as trade policy instruments such as tariffs are available, but in case trade policy is ruled out, a differentiated regulation is second-best. This result is due to carbon leakage in Hoel (1996) and due to terms-of-trade effects in Withagen et al. (2007). In the absence of either carbon leakage or terms-of-trade effects, a uniform climate policy is always optimal.

Rauscher (1994) takes a positive rather than a normative approach and finds that strategic trade incentives, terms-of-trade arguments or political economy reasons might lead to sectoral differences in the stringency of emission policy.

Also, CGE modeling has been applied in order to analyze the effects of unilateral environmental and climate policies. Among these are Böhringer and Rutherford (2002), who study sectorally differentiated tax regimes and Dessus and O'Connor (2003) who estimate ancillary benefits from unilateral climate policy in Chile.

Finally, Copeland and Taylor (2005) explore a general equilibrium model with many countries and demonstrate that in fact, there might be negative carbon leakage, that is, unilateral emission cuts by some countries can lead to emission reductions by other countries. This somewhat surprising result is due to an income effect that counters the usual drivers of carbon leakage. Hence, the sign and magnitude of emission change in the rest of the world after a unilateral emission reduction by some countries is determined by a trade-off between free riding, substitution and income effects.

The third set of studies that our analysis is related to is the double dividend literature. A double dividend from environmental regulation arises if, independent of the reduction of environmental damage, a gain or a smaller loss in welfare is achieved by using the proceeds from environmental taxation to replace or reduce pre-existent distortionary taxes.[4] The weak double dividend hypothesis states that the welfare costs of environmental taxation is lower if such a "green tax reform" is carried out instead of returning tax revenue in a lump-sum fashion. If the green tax reform as a whole comes at zero or negative costs, a strong double dividend is reaped (Goulder, 1995). The theoretical soundness of particularly the strong double dividend hypothesis has been widely criticized due to the tax-interaction effect, which works against the welfare-increasing revenue-recycling effect (Bovenberg and de Mooij, 1994; Parry, 1995; Bovenberg and Goulder, 1996). Through the tax-interaction effect, environmental taxes raise the welfare costs of distortionary income taxation by increasing prices and thus further lowering the already suboptimal labor supply. However, Schwartz and Repetto (2000) show that if the assumption of separable utility functions is dropped, improvement of environmental quality can increase labor supply partially or entirely offsetting the tax-

[4]This argument was developed as early as in the 1980s, see, e.g., Terkla (1984) and Lee and Misiolek (1986). For a survey see Schoeb (2003).

interaction effect. Various other aspects of environmental revenue recycling, such as distributional concerns (Mayeres and Proost, 2001) or the interplay of environmental taxes with trade taxes (Smulders, 2001) have been studied. However, all of these concepts of additional dividends rely on the assumption of pre-existing distortions. Hence, in the absence of distortions, no second dividend exists, and optimal revenue recycling consists of lump-sum transfers.

3 The Model

We consider a small open economy that consists of four sectors. One sector provides intermediate goods, like electricity or transportation services, that are used for production in two final goods sectors. One of the final goods is traded internationally, whereas the other is a domestic good. The fourth sector is also a final goods sector and is open to international trade but does not use the intermediate good. This sector depicts the part of the economy that is not affected by climate policy. Accounting for this sector is necessary for being able to study both the case where the country imports the traded final good and the case where it exports this good. In order to simplify the distinction between the three final goods sectors, we will refer to those sectors that use the intermediate good as an input as "dirty", while the final goods sector that does not use the intermediate good will be referred to as "clean". Figure 1 shows a graphic representation of the model structure.

In our basic setup, all factors can move freely between sectors and all markets are perfectly competitive. There is international trade for the two final goods already mentioned and national and foreign products are perfect substitutes. Furthermore, the resources needed to produce the intermediate goods (such as fossil fuels) are imported. All other markets are national.

In our model, greenhouse gas emissions arise only in the intermediate goods sector, which is consequently the subject of environmental regulation. Of course, this is a substantial simplification. But additional emitting sectors can be added to our model without changes to the main implications of our results.[5] Furthermore, in industrialized countries, a large fraction of greenhouse gas emissions result from the production of intermediate goods like electricity generation and transportation services.[6] For instance, trucks, that are mainly used for commercial

[5] If such additional sectors are open to international trade, the optimal policy will consist of a mix of policy differentiation (i.e., different emission taxes for these sectors and the intermediate goods sector) and the containment studied here.

[6] Often, these "intermediate" goods are also used as final goods in consumption. For simplicity, we neglect this point. But it can be introduced into our model without substantial changes to our results.

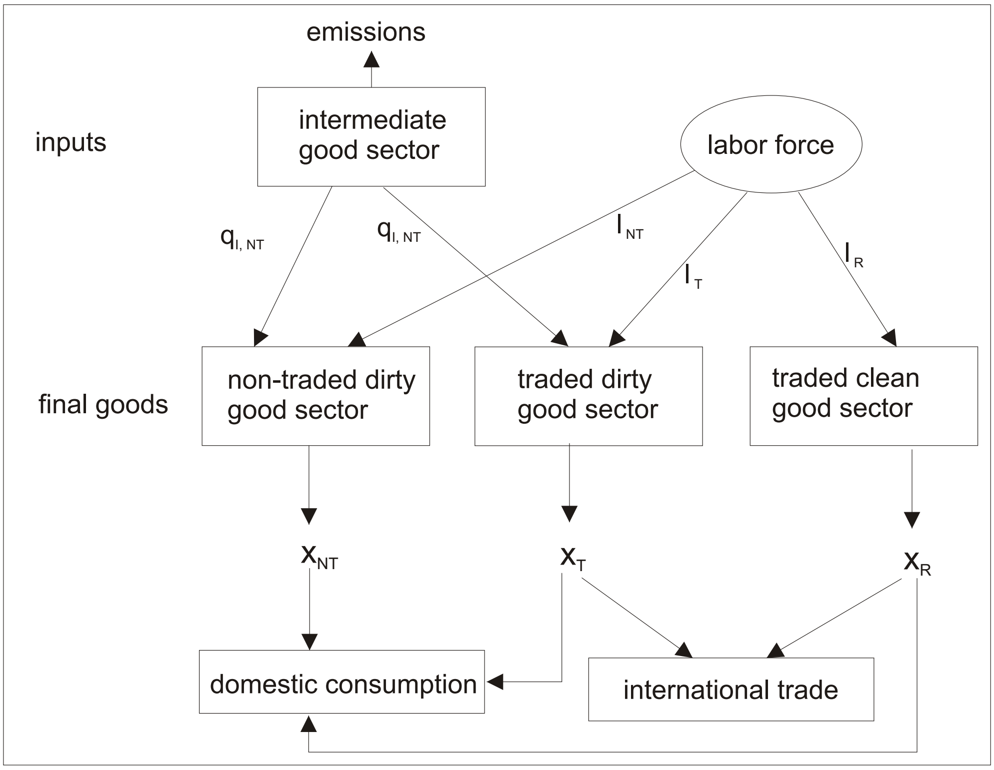

Figure 1: The Model structure

purposes, accounted for more than 40% of gasoline and more than 80% of diesel consumption in the USA in 2006 (EPA, 2008). The energy industries caused more than 25% of CO_2-equivalent greenhouse gas emissions of Annex I countries in 2006 (UNFCCC, 2006). These intermediate goods are usually traded only on internal markets. For example, both the UK and the USA imported less than 1% of their total electricity consumption in 2007 (EIA, 2008b; BERR, 2008). Thus, although the case that we consider is a special case, it is a quantitatively important one.

In this setup, we consider a unilateral climate policy where only the country under consideration implements a regulation to reduce greenhouse gas emissions.[7] For simplicity, we constrain our investigation to a regulation based on an emission tax. But our results easily transfer to tradable permit schemes or to standards. As mentioned above, this policy aims at implementing a fixed national emission target, such as the 20% target of the EU.

[7]Again, this is a reasonable albeit somewhat stylized assumption; currently, several countries have enacted policies to reduce greenhouse gas emissions, but the majority of emitters have only suggested that they may do at some point in the future.

The emission tax leads to a higher price of intermediate goods (such as electricity) and thus to higher factor costs in final goods production. As the policy is unilaterally enacted, the prices on international markets do not increase likewise, implying that production is shifted to countries without climate policy. The purpose of our study is to investigate whether it is reasonable from a national perspective to counter this effect by accompanying measures. As WTO rules preclude tariffs or export subsidies, we consider an accompanying intervention in the intermediate good market. This is also reasonable, because climate policy affects the production costs of this good most strongly.

We assume that production possibilities in the intermediate goods sector are represented by the following cost function.

$$c_I(q_I, a_I) = c_P(q_I) + q_I c_A(a_I), \tag{1}$$

where q_I denotes output, a_I is abatement, and $c_P, c_A : \mathbb{R}_+ \to \mathbb{R}_+$ are twice differentiable, strictly convex, and increasing cost functions with $c_P(0) = c_A(0) = 0$. Emissions are given by $e = q_I(\bar{e} - a_I)$. Thus $c_A(a_I)$ are the costs of reducing emissions per unit of production from their baseline level $\bar{e}$, whereas $c_P(q_I)$ are the production costs in the absence of abatement.

To keep the analysis tractable, we assume that these costs arise solely due to the use of imported factors, such as fossil fuels or machinery, and that the amount of labor employed in the production of the intermediate good is negligible on a national scale. Indeed, for the examples given above, this is a reasonable assumption. Although electricity generation and transportation services account for a large part of the emissions of industrialized countries, the fraction of labor employed in these sectors is rather small.

We depict the production possibilities in the final good sectors by production functions that depend on the quantity of the intermediate good and the quantity of other factors of production. For the latter, we use labor as an example. The production functions are given by $f_{NT}(l_{NT}, q_{I,NT}) : \mathbb{R}^2_+ \to \mathbb{R}_+$, for the non-trading dirty sector, by $f_T(l_T, q_{I,T}) : \mathbb{R}^2_+ \to \mathbb{R}_+$ for the trading dirty sector and by $f_R(l_R) : \mathbb{R}_+ \to \mathbb{R}_+$ for the trading clean sector. The variables l_T, l_{NT}, l_R denote the labor inputs of the final good sectors and $q_{I,T}, q_{I,NT}$ are the quantities of the intermediate good used there. We assume that the production functions f_{NT}, f_T exhibit constant returns to scale, and that all production functions are twice differentiable, strictly increasing in their arguments and strictly concave. There is a fixed supply of labor $\bar{L}$, so that full employment implies

$$l_{NT} + l_T + l_R = \bar{L}. \tag{2}$$

The climate policy is given by an emission tax τ and a subsidy σ. The former is levied on the emissions of the intermediate goods sector, the latter is paid for the output of this sector. The aim of the policy is to reduce emissions to an exogenously given level $\tilde{e}$. We assume that the subsidy is not differentiated, that is, both dirty final good sectors benefit from it. This is likely to be suboptimal. But a differentiated subsidy would cause substantial problems in implementation and might be seen as a trade-distorting measure. Furthermore, if an undifferentiated subsidy is welfare increasing, the same also holds for an optimally differentiated subsidy. Thus our conclusions can be transferred easily.

The firms in the intermediate goods sector maximize their profit

$$\pi_I = (p_I + \sigma)q_I - c_P(q_I) - q_I c_A(a_I) - \tau q_I(\bar{e} - a_I), \tag{3}$$

leading to

$$p_I = c'_P(q_I^*) - \sigma + c_A(a_I^*) + \tau(\bar{e} - a_I^*), \tag{4}$$
$$\tau = c'_A(a_I^*). \tag{5}$$

Total emissions are given by $e = q_I^*(\bar{e} - a_I^*)$. With Eqs. (3)–(5), we get

$$\tau = c'_A\left(\bar{e} - \frac{\tilde{e}}{q_I^*}\right), \tag{6}$$

as the necessary tax τ to reduce emissions to $\tilde{e}$. Market clearing for the intermediate good implies that

$$q_I^* = q_{I,T}^* + q_{I,NT}^*, \tag{7}$$

where $q_{I,T}^*$ and $q_{I,NT}^*$ denote the profit-maximizing intermediate good demand of the dirty final goods sectors.

The demand for the intermediate good results from production in the dirty final goods sectors. In the non-trading dirty sector, profit maximization implies

$$p_I = p_{NT}\frac{\partial f_{NT}(l_{NT}, q_{I,NT})}{\partial q_{I,NT}}, \tag{8}$$
$$w = p_{NT}\frac{\partial f_{NT}(l_{NT}, q_{I,NT})}{\partial l_{NT}}, \tag{9}$$

where w denotes the wage and where p_{NT} is the price of the non-traded dirty good. In the trading dirty sector, we get

$$p_I = p_T\frac{\partial f_T(l_T, q_{I,T})}{\partial q_{I,T}}, \tag{10}$$
$$w = p_T\frac{\partial f_T(l_T, q_{I,T})}{\partial l_T}. \tag{11}$$

Finally, profit maximization in the trading clean sector leads to

$$w = p_R \frac{\partial f_R(l_R)}{\partial l_R}, \tag{12}$$

where p_R is the output price aggregate for this part of the economy.

To measure the national welfare effects of the policy, we use the welfare of a representative consumer. We depict this welfare by a utility function $U(y_T, y_{NT}, y_R)$ that depends on the consumption of the final goods. Consumption expenditures are restricted by national income:

$$\begin{aligned} p_T y_T + p_{NT} y_{NT} + p_R y_R \leq & p_T f_T(l_T, q_{I,T}) + p_{NT} f_{NT}(l_{NT}, q_{I,NT}) \\ & + p_R f_R(l_R) - c_P(q_I) - q_I c_A(a_I). \end{aligned} \tag{13}$$

To gain a reference point, we first consider the base case in which there are no market imperfections, no strategic behavior, and in which carbon leakage effects are not taken into account. In this case, the optimal policy consists of an emission tax without a subsidy, as the following lemma shows.

Lemma 1. *In the case of a small open economy without market imperfections and without carbon leakage, the optimal policy to implement the emissions target $\tilde{e}$ is the emission tax* (6) *without an accompanying measure (i.e., $\sigma = 0$).*

Proof. Maximizing $U(y_T, y_{NT}, y_R)$ under the budget constraint (13), the market clearing constraints (2), (7), and $y_{NT} = f_{NT}(l_{NT}, q_{NT})$ with regard to y_T, y_{NT}, y_R, l_T, $q_{I,T}$, l_{NT}, $q_{I,NT}$, l_R, q_I and a_I yields first order conditions that equal Eqs. (4)–(5), (8)–(12) for $\sigma = 0$. The necessary tax to meet the target $\tilde{e}$ follows from (6). □

4 Designing a Unilateral Climate Policy

As shown above, an optimal climate policy in an ideal world would consist only of a uniform emission tax or an emission trading scheme encompassing all emitting sectors; additional measures, such as subsidies, or a policy differentiation would only lead to distortions and reduce social welfare.

However, climate policy often has to be designed under less benign conditions. The main problem is that not all emitting countries have instated policy measures to reduce their emissions. Thus a country that enforces substantial emissions reductions faces several problems that arise from this lack of global action.

First, its emission reductions may be partially countered by emission increases in countries with no climate policies in place, that is, there may carbon leakage. This reduces the benefits the country reaps from its climate policy. Second, there can be internal constraints, like factor immobility between sectors or wage rigidities. If a country that is open to international trade pursues unilateral emission reductions, this will result in a reallocation of production and, consequently, factor employment among sectors. Such constraints can hamper this adjustment and thereby increase the costs incurred by the policy. Finally, a country that is a major producer of some goods may lose a strategic advantage on these markets if it cuts emissions while its main competitors do not.

In the following sections, we inquire whether these problems can be reduced by additional policy measures, particularly by a (partial) containment of the effects of climate policy to the intermediate goods sector.

4.1 Reducing Carbon Leakage

If a country unilaterally restricts emissions in a sector that is open to international trade, production in this sector will decrease and will be compensated by increased foreign production. Thus emissions in the home country decrease but foreign emissions can increase. This effect is referred to as “carbon leakage.” For perfectly mobile pollutants, such as greenhouse gas emissions, the benefit of the domestic emission reduction is reduced.

The causes and the magnitude of carbon leakage have been extensively discussed in the literature, see, for example, Hoel (1991), Golombek et al. (1995), or Copeland and Taylor (2005). We investigate whether carbon leakage can be reduced by supplementing climate policy with additional policy measures and to what extent it is in the interest of a country to do so.

We assume that the home country is a small open economy in the sense that the country’s exports or imports of the traded goods do not alter the prices on the international markets and do not change foreign demand. This is the case, if changes in domestic imports or exports are so small compared to the total trade volume that foreign production adjusts at constant marginal costs to the amount necessary for market clearing. Decreasing exports or increasing imports of the home country are thus fully compensated by an increase in foreign production. Of course, these assumptions are highly stylized and exclude several effects, especially income effects in the foreign countries, that are often discussed in the context of carbon leakage. But they facilitate a clear separation of the incentives for intervening in the intermediate good market that are attributable to an increasing damage due to a shift of production to countries with less strict environmental regulation from incentives related to terms-of-trade effects.

If the intermediate goods sector is subject to climate policy, the price of the intermediate good increases, leading to a smaller use of this good in final goods production. Usually, this effect is desired, because an optimal emission reduction typically consists of a combination of more abatement and less production.

However, if the climate policy is unilateral, it can cause carbon leakage.

To depict this effect, we assume that foreign firms use $\bar{q}_T$ units of the intermediate good to produce one unit of output of the traded dirty good and that the intermediate good in these countries is produced without abatement, that is, producing one unit of the intermediate good causes $\bar{e}$ units of emissions. With our above assumptions, global emissions E can be written as

$$E = (Y_T + y_T - f_T(l_T, q_{I,T}))\, \bar{q}_T \bar{e} + \tilde{e} + E^{NT,F}. \tag{14}$$

Here, Y_T denotes global demand for the traded dirty good and $E^{NT,F}$ are the foreign emissions due to production of the dirty non-traded good.

To assess the costs caused by carbon leakage, we assume that the home country benefits from the decreasing global emissions by a reduction of national environmental damage, which we depict by a damage function $d(E)$. We assume that $d(E)$ is strictly increasing and convex in E for all $E \geq 0$ and that it is a differentiable function of $E \in \mathbb{R}_+$. We include this damage additively in our measure of national welfare. But we assume, as is standard, that consumer behavior is unchanged by carbon leakage, that is, there are so many consumers that individual incentives to reduce the environmental damage by adjusting consumption are negligible.

With these settings, we get the following result.

Proposition 1. *Assume that*[8] $\frac{\partial U(y_T, y_{NT}, y_R)}{\partial y_T} > d'(E^*)\bar{q}_T\bar{e}$*. Then, from a national perspective, it is always optimal to subsidize the intermediate good. The optimal subsidy is given by*

$$\sigma^* = \frac{d'(E^*)\, \bar{q}_T\, \bar{e}\, p_T}{\frac{\partial U(y_T, y_{NT}, y_R)}{\partial y_T} - d'(E^*)\, \bar{q}_T\, \bar{e}} \cdot \frac{\partial f_T(l_T, q_T)}{\partial q_T}. \tag{15}$$

The necessary tax τ to constrain total national emissions to $\tilde{e}$ is given by Eq. (6).

Proof. As the policy is a second-best policy, we calculate the optimal tax τ and the optimal subsidy σ by assuming that all endogenous variables (i.e., $q_{I,NT}$, $q_{I,T}$, l_{NT}, l_T, l_R, a_I, p_I, p_{NT}, p_R, w) are functions of these policy measures and by optimizing the utility of the representative individual minus the damage caused by global emissions with regard to (τ, σ) under the constraints that (i) total consumption expenditures do not exceed national income; that (ii) consumption of the non-traded dirty good equals production of this good; that (iii) national emissions do not exceed $\tilde{e}$; and that (iv) total labor supply matches total labor demand. This

[8]This condition assures that it is optimal to consume the traded good at all.

leads to

$$
\begin{aligned}
\frac{\partial U(y_T, y_{NT}, y_R)}{\partial y_T} & \left((\tau(a_I - \bar{e}) + \sigma) \left(\frac{\partial q_{I,T}}{\partial \sigma} + \frac{\partial q_{I,NT}}{\partial \sigma} \right) + (q_{I,T} + q_{I,NT}) \frac{\partial a_I}{\partial \sigma} \right. \\
& \left. - w \left(\frac{\partial l_T}{\partial \sigma} + \frac{\partial l_{NT}}{\partial \sigma} + \frac{\partial l_R}{\partial \sigma} \right) \right) - D'(E) \bar{e} \bar{q}_{I,T} \left(p_I \frac{\partial q_{I,T}}{\partial \sigma} + w \frac{\partial l_T}{\partial \sigma} \right) \\
& = \mu \left((q_{I,T} + q_{I,NT}) \frac{\partial a_I}{\partial \sigma} - p_T(\tilde{e} - a_I) \left(\frac{\partial q_{I,T}}{\partial \sigma} + \frac{\partial q_{I,NT}}{\partial \sigma} \right) \right) \\
& - \nu p_T \left(\frac{\partial l_T}{\partial \sigma} + \frac{\partial l_{NT}}{\partial \sigma} + \frac{\partial l_R}{\partial \sigma} \right),
\end{aligned} \tag{16}
$$

$$
\begin{aligned}
\frac{\partial U(y_T, y_{NT}, y_R)}{\partial y_T} & \left((\tau(a_I - \bar{e}) + \sigma) \left(\frac{\partial q_{I,T}}{\partial \tau} + \frac{\partial q_{I,NT}}{\partial \tau} \right) + (q_{I,T} + q_{I,NT}) \frac{\partial a_I}{\partial \tau} \right. \\
& \left. - w \left(\frac{\partial l_T}{\partial \tau} + \frac{\partial l_{NT}}{\partial \tau} + \frac{\partial l_R}{\partial \tau} \right) \right) - D'(E) \bar{e} \bar{q}_{I,T} \left(p_I \frac{\partial q_{I,T}}{\partial \tau} + w \frac{\partial l_T}{\partial \tau} \right) \\
& = \mu \left((q_{I,T} + q_{I,NT}) \frac{\partial a_I}{\partial \tau} - p_T(\tilde{e} - a_I) \left(\frac{\partial q_{I,T}}{\partial \tau} + \frac{\partial q_{I,NT}}{\partial \tau} \right) \right) \\
& - \nu p_T \left(\frac{\partial l_T}{\partial \tau} + \frac{\partial l_{NT}}{\partial \tau} + \frac{\partial l_R}{\partial \tau} \right),
\end{aligned} \tag{17}
$$

where μ and ν are the Lagrange coefficients of condition (iii) and (iv) above.

To simplify these expressions, we differentiate Eqs. (4)–(5) and Eqs. (8)–(12) with regard to (τ, σ) and substitute the resulting expressions in (16)–(17). This directly yields Eqs. (6) and (15). As can be easily verified, the second order conditions for a maximum are met. □

So, in the case of unilateral climate policy, it is optimal to subsidize the intermediate good. This is intuitive, because there are two distinct market failures. First, the producers do not account for the costs of climate change, resulting in overproduction and a lack of abatement efforts. Second, the consumers (national and abroad) do not consider these costs in their consumption decisions, so that an increase in domestic production costs due to policy-induced abatement efforts leads to a higher share of unregulated foreign producers in total production. An emission tax (or permit trading) can correct the first market failure. But if a unilateral climate policy is pursued in an open economy, the tax cannot correct the second market failure as well; consumers can avoid the increased costs of cleaner products by choosing goods produced in an unregulated country, resulting in carbon leakage. Thus a second intervention is necessary.

A first-best solution would consist of correcting the consumer's incentives. But this would require a change of the price of the traded good and thus either tariffs or export subsidies, which are not conform with WTO rules. The above discussed solution of intervening in the intermediate goods market is only second-best but feasible.

The optimal subsidy is easily interpretable. The numerator depicts the reduction in damage, if an additional unit of the traded dirty good is exported, times the marginal productivity of the intermediate good in this sector. Thus it describes the benefit, in terms of reduced damage, of supplying an additional unit of the intermediate good to the traded dirty-good sector. The denominator equals the social value of consuming an additional unit of the traded dirty good. This value, normalized by the price of the traded dirty good, consists of the marginal utility of consumption minus the marginal damage caused by higher foreign production.[9]

Calculating the marginal reduction of the domestic excess demand (i.e., domestic production minus consumption) due to subsidizing the intermediate good shows that this is given by

$$\frac{\partial(x_T - y_T)}{\partial\sigma} = \frac{c_A(a_I) + c'_P(q_{I,T} + q_{I,NT})}{p_I c''_P(q_{I,T} + q_{I,NT})}. \tag{18}$$

The marginal reduction in national income B due to the subsidy is

$$\frac{\partial B}{\partial\sigma} = -\frac{\sigma - \tau(\bar{e} - a_I)}{c''_P(q_{I,T} + q_{I,NT})}. \tag{19}$$

With the optimal tax and subsidy, we get

$$\frac{\partial B}{\partial\sigma} = -\frac{d'(E^*)\bar{e}\bar{q}_T\left(c_A(a_I) + c'_P(q_{I,T} + q_{I,NT})\right)}{\frac{\partial U(y_T,y_{NT},y_R)}{\partial y_T} c''_P(q_{I,T} + q_{I,NT})}. \tag{20}$$

Thus with the optimal tax and subsidy, we have

$$d'(E^*)\bar{e}\bar{q}_T \frac{\partial(x_T - y_T)}{\partial\sigma} + \frac{\partial U(y_T, y_{NT}, y_R)}{\partial y_T}\frac{\partial B}{\partial\sigma} = 0. \tag{21}$$

So the optimal subsidy balances its positive effects on the damage with its negative effect on utility through reduced national income. The reduction in national income stems from the inefficient factor allocation that the subsidy induces in production. Due to the subsidy, the traded dirty-good and the non-traded dirty-good sector calculate with a price of the intermediate good that does not reflect the

[9]It is necessary to reduce the individual utility of consumption by the marginal damage of production, because the policy results only in a second-best allocation. The price of the traded dirty good is not influenced, so that consumers do not take the damage caused by increased consumption of this good into account.

marginal costs of supplying this good. Consequently, these sectors use a socially suboptimal factor combination, which reduces national income.

Note that the optimality of intervening in the intermediate goods market is not attributable to strategic behavior of the home country, because strategic incentives cannot exist in the small open economy case considered here. Indeed, as (15) shows, the optimality of subsidizing the intermediate good is solely due to the damage caused by carbon leakage; for $d'(E) = 0$, that is, whenever carbon leakage does not result in higher damage, it is always optimal not to intervene in the intermediate goods market.

Interestingly, the optimal subsidy does not depend directly on the stringency of the national climate target ($\tilde{e}$).[10] The reason is that the intervention aims at decreasing total emissions by shifting production from abroad to the home country. Thus it balances the benefit of reducing the damage with the costs of this intervention, which consist of the inefficiency induced by the intervention. Both the benefit and the costs do not directly depend on the national climate target.

This implies that it remains optimal to intervene even if the national emission target is optimized taking into account carbon leakage. Thus the optimality of taxing or subsidizing the intermediate good is not due to our setup, where the national emission target is exogenous. In fact, optimizing national welfare (including the environmental damage) with regard to t and σ without a fixed emission target leads to $\tau = d'(E^*)p_T/((\partial U(y_T, y_{NT}, y_R)/\partial y_T) - d'(E^*)\bar{q}_T\bar{e})$ and an optimal subsidy again given by Eq. (15). Thus the emission tax induces the intermediate goods sector to take the social damage caused by emissions into account and the market intervention is used to reduce the negative effect of carbon leakage.

Finally, it is important to note that the type of intervention studied here results in only a second-best outcome. A first-best result would be achievable by a tariff or export subsidy on the traded final good.[11] Such an intervention would increase domestic production of the traded dirty good and decrease its domestic consumption without interfering with the optimal factor combination. Thus it results in the best attainable allocation. However, such a policy is infeasible under WTO rules.

4.2 Market Distortions and Policy-Induced Unemployment

Another reason for using a policy-mix might be given by market imperfections, such as price rigidities, factor immobility, or pre-existing market interventions. For climate policy, the case of wage rigidities seems to be of highest importance,

[10] Of course, it depends indirectly on the policy target, that is, via the factor allocation, the total production in the traded dirty-good sector, and the marginal damage of emissions.

[11] The optimal subsidy would be $\sigma_T = \frac{d'(E^*)\bar{q}_T\bar{e}p_T}{\frac{\partial U(y_T, y_{NT}, y_R)}{\partial y_T} - d'(E^*)\bar{q}_T\bar{e}}$.

as a common argument against unilateral climate policy is that it might lead to unemployment.[12]

In this section, we consider a simple case of wage rigidities, where the wage cannot adjust downward in response to climate policy. Instead, there will be unemployment. For simplicity, and to avoid incentives for strategic behavior, we analyze this case in the context of a small open economy.

Initiated by Bhagwati and Ramaswami (1963), there is substantial literature that analyzes market interventions in an open economy with distortions, that is, with factor price rigidities and factor immobility. As discussed in Section 2, the optimal policy consists of an intervention (usually a subsidy) in the distorted market. In addition, there is extensive literature on designing environmental policy under pre-existing market interventions, see, for example, Bovenberg and de Mooij (1994) or Bovenberg and Goulder (1996). Our setup deviates from this literature in that there are no pre-existing interventions; the economy is in an efficient equilibrium before the introduction of the climate policy. Our setup deviates from the distortions literature in that we do not consider a change in the terms of trade that renders the distortions relevant but rather a change in national policy that reduces the supply of a factor (allowable emissions). Also, we do not assume factor immobility and use a model that differentiates between intermediate and final goods production.

If an emission tax is introduced, the price of the intermediate good increases, reducing the use of this good in the dirty final goods sectors. This induces a decline of the marginal productivity of labor in these sectors; for a given wage, less labor is employed there. As the clean final good sector cannot absorb the released amount of labor at constant marginal productivity, there is either unemployment or the wage has to decline. With a wage rigidity, the former consequence ensues. A subsidy on the intermediate good might be helpful to partially reverse this effect and thereby reduce the unemployment attributable to climate policy.

The following proposition characterizes the optimal choice of (τ, σ).

Proposition 2. *Assume that there is a lower boundary $\bar{w}$ of the wage that equals the wage before the introduction of the climate policy. Then the optimal policy (τ, σ) consists of the tax* (6) *and the following subsidy*

$$\sigma = \min\{\frac{l_T}{q_T}\bar{w}, c_A(a_I) + \tau(\bar{e} - a_I)\}. \tag{22}$$

Proof. Again, the policy is only second-best, so that we calculate the optimal tax τ and the optimal subsidy σ by assuming that all endogenous variables (i.e., $q_{I,NT}, q_{I,T}, l_{NT}, l_T, l_R, a_I, p_I, p_{NT}, p_R$) are functions of these policy measures and

[12]In our setup, climate policy causes unemployment only if wages do not fully adjust to marginal productivity.

by optimizing the utility of the representative individual with regard to (τ, σ) under $w \geq \bar{w}$ and the constraints that (i) total consumption expenditures do not exceed national income; that (ii) consumption of the non-traded dirty good equals production of this good; that (iii) national emissions do not exceed $\tilde{e}$; and that (iv) total labor demand is less or equal than total labor supply. To simplify the resulting first-order conditions, we again differentiate Eqs. (4)–(5) and Eqs. (8)–(12) with regard to (τ, σ) and substitute the resulting expressions. This leads to Eqs. (6) and

$$\sigma = \frac{l_T \left(\frac{\partial U(y_T, y_{NT}, y_R)}{\partial y_T} \bar{w} - p_T \nu \right)}{q_T \frac{\partial U(y_T, y_{NT}, y_R)}{\partial y_T}}, \tag{23}$$

where ν denotes the Lagrange multiplier associated with the total labor-force constraint. For $l_T + l_{NT} + l_R < \bar{L}$, the constraint is not binding, so that we have $\nu = 0$. Otherwise, we have $\nu = \frac{\partial U(y_T, y_{NT}, y_R)}{\partial y_T} \frac{\bar{w}}{p_T}$, so that the optimal subsidy is zero. By assumption, $\bar{w}$ equals the marginal productivity of labor if there is no emission constraint. With any binding emission constraint and without the subsidy, the marginal productivity of labor is smaller than in this base case, because less of the intermediate good is used in final goods production and, by our assumptions on the technology, the intermediate good raises the productivity of labor. Thus we cannot have full employment without a subsidy. The largest subsidy that is compatible with $\nu = 0$, is $\sigma = c_A(a_I) + \tau(\bar{e} - a_I)$, as this subsidy reduces the price of the intermediate good to its level without climate policy. Consequently, the optimal subsidy is either given by (23) with $\nu = 0$ or by this upper bound. Again, the second-order conditions for a maximum of national welfare are met. $\square$

So if, in our context, climate policy induces unemployment due to wage rigidities, subsidizing the intermediate good is a feasible strategy to reduce unemployment. Two cases can emerge. First, it may be optimal to subsidize the intermediate good so that the price of this good is not affected by climate policy. This assures that climate policy induces no unemployment. This is the relevant case, if the traded dirty good is labor intensive, that is, if l_T/q_T is large. Second, it can be optimal to reduce the effect of the emission tax on the price of the intermediate good somewhat but to keep this price higher than in the case without climate policy, which implies some unemployment. This case is relevant, if the traded dirty good sector is not too labor intensive.

The optimal subsidy balances the gain of higher labor productivity, and thus less unemployment, with the costs of an inefficient combination of abatement and output reduction in the intermediate goods sector.

However, in contrast to the preceding and the following section, there is a better way to reduce the costs of unemployment induced by climate policy. This approach uses a subsidy on labor to bridge the gap between the wage and labor productivity at full employment. It is easily shown (see, e.g., Bhagwati and Srinivasan (1969)) that this is the best possible solution.

Thus our argument is not that a subsidy on the intermediate good should be used to overcome climate-policy-induced unemployment.[13] Rather, our analysis shows that if such a subsidy is used for other reasons, such as reducing carbon leakage or maintaining a favorable trade position, there is the additional benefit that it reduces unemployment.

4.3 Maintaining Market Power

If the country committed to a reduction of greenhouse gas emissions is a large supplier or demander of the traded dirty good, then changes of the net excess demand for that good influence world prices. In the context of our model this means that unilateral climate policy, by causing a reallocation of factors between the non-traded and the traded sectors and thus leading to changes in production, indirectly changes the terms of trade. In such a case, an additional intervention exploiting the country's monopoly (monopsony) power in trade can increase national income and thus welfare. If an optimal intervention already had been in place before the implementation of the emission target, this intervention will no longer be optimal and will need to be updated. For simplicity we will assume that the country is a large supplier or demander of the traded dirty good, but that the traded clean-good sector is small compared to the world market. Thus the price of the clean final good is taken as given.

For analyzing the large country case, we need to slightly modify the model developed in Section 3 by altering the budget constraint (13) to

$$\begin{aligned} p_T(m_T)y_T + p_{NT}y_{NT} + p_R y_R \leq & p_T(m_T)f_T(l_T, q_{I,T}) + p_{NT}f_{NT}(l_{NT}, q_{I,NT}) \\ & + p_R f_R(l_R) - c_P(q_I) - q_I c_A(a_I). \end{aligned} \tag{24}$$

where $m_T \equiv x_T - y_T$ is the country's net excess demand for the traded dirty good.

In principle, "optimization" of the terms of trade should take the form of direct trade measures such as export or import tariffs. Hence, in the presence of an emission limit and market power, the first-best policy is a combination of the optimum trade tariff and an emission tax. However, as we rule out direct trade intervention due to WTO rules, the government has an incentive to use an intervention in the

[13]There can be situations, where a subsidy on labor is not politically feasible. For instance, subsidizing labor can be very costly, because, for being efficient, the subsidy has to be the same in all sectors, so that the total labor force needs to be subsidized. If the expenditures for the subsidy have to be covered by taxes that cause distortions, it can be better to use a subsidy on the intermediate good, which will often require substantially smaller expenditures.

intermediate good sector as a secondary trade policy instrument. This is shown in the following Proposition.

Proposition 3. *In case of a large country that has monopoly power in the trading dirty sector but cannot use direct trade intervention, it is always optimal to intervene in the intermediate good sector. The optimal intervention is given by*

$$\sigma^* = \frac{p_I \, m_T \, p_T'(m_T)}{p_T(m_T)}. \tag{25}$$

The necessary tax to constrain total national emissions to $\tilde{e}$ is given by Eq. (6).

Proof. To derive the second-best optimal tax t and intervention σ, we assume that all endogenous variables (i.e., $q_{I,NT}, q_{I,T}, l_{NT}, l_T, l_R, a_I, p_I, p_{NT}, p_R$) are functions of these policy measures and maximize the utility of the representative individual with regard to (τ, σ) under the constraints that (i) total consumption expenditures do not exceed national income; that (ii) consumption of the non-traded dirty good equals production of this good; that (iii) national emissions do not exceed $\tilde{e}$; and that (iv) total labor demand is less or equal than total labor supply. Imposing the first order conditions of the intermediate goods sector (4)-(5) and the final goods sectors (8)-(12), and exploiting constant returns to scale in the final goods sectors yields (6) and (25). $\square$

Proposition 3 shows that the sign of the optimal intervention in the intermediate good sector depends on the sign of m_T, that is, on whether the country is a net importer or exporter of the dirty final good. If the country is an importer, a subsidy is in place; if the country exports the traded dirty good, a tax on the intermediate good is optimal.

These results are intuitive in the light of the first-best trade policies. A classic result from trade theory says that the first-best policy for a country with monopoly (monopsony) power in trade is an export tax (import tariff).[14] As the intervention on the intermediate good sector is used as a substitute for these direct measures, the optimal intervention analogously contracts supply (demand) in case the country is a net exporter (importer).

Note that the optimal intervention does not directly depend on the emission target $\tilde{e}$. This is because the main driving force behind the intervention is its effect on the terms of trade. This effect is present in a large economy independent of an emission target. However, as the implementation of the emission target leads to a change of the price of the intermediate good and thus to factor reallocation, the magnitude of the optimal intervention is indirectly dependent on the emission tax. Hence, setting an emission ceiling on the intermediate good sector renders

[14] This argument originally goes back to Bickerdike (1906).

a previously optimal intervention suboptimal. Whether the optimal intervention after imposing an emission tax is quantitatively smaller or bigger than before, depends on whether the increase in the price of the intermediate good works in the same or in the opposite direction as the intervention. For instance, if the country is an exporter of the traded dirty good, the optimal intervention is a tax on the intermediate good. The introduction of an emission tax in this case will lead to a decrease of the size of the optimal intervention. This is because the emission tax is a substitute for the tax on the intermediate good. However, if the country imports the traded dirty good, then the emission tax will lead to an increase of the magnitude of the optimal intervention, i.e. an increase in the subsidy rate, because it counteracts the effect of the intervention.

The optimal intervention is neither equal nor equivalent to the optimal trade tariff, that is, to the inverse of the export demand or import supply elasticity,[15] due to two reasons. First, the output of the intermediate sector is an input in both dirty sectors. Hence, the intervention affects not only the production of the traded dirty good as would be the case for a trade tax, but also changes output of the non-traded dirty good. The reallocation of factors that leads to this change of output is inefficient, and thus comes at the cost of a decrease in national income. However, this loss of welfare is outweighed by an increase in national income due to the favorable change of the terms of trade. Second, a subsidy on an input of the trading dirty sector is an indirect measure in the sense of the policy targeting literature (see, e.g., Bhagwati and Ramaswami (1963) and Bhagwati and Srinivasan (1969)) and thus is an inefficient instrument for the exploitation of monopoly (monopsony) power. Therefore, the optimal intervention goes beyond balancing the terms-of-trade effect with the quantity-of-trade effect; it also accounts for the inefficiencies that it produces as an indirect instrument.

Finally, let us put Lemma 1 and Proposition 3 into relation. For a small economy, the emission target per se does not call for a subsidy on the intermediate good (or any other additional interventions) in order to alleviate the effects of the increase in factor prices. This is because a restriction on emissions does not constitute a distortion in the Lipsey and Lancaster sense (Lipsey and Lancaster, 1956; Krishna and Panagariya, 2000). Even for a large economy, an intervention in the intermediate good sector is not first-best. However, an intervention is second-best for a large economy if first-best trade intervention is infeasible due to WTO regulations. The strategic incentive for intervening in the intermediate good sector exists independently of any emission regulation. However, the magnitude of the intervention that optimally exploits the terms-of-trade effect depends on the

[15] Of course, the optimal intervention is not independent of the price elasticity of export demand or import supply. To see this divide nominator and denominator of (25) by $p_T(m_T)$ to get $\sigma^* = p_I \frac{1}{\epsilon}$ where ϵ corresponds to the elasticity. For $\epsilon \to -\infty$, the optimal intervention becomes zero, as the terms-of-trade effect of the intervention vanishes.

stringency of the emission target. Therefore, an optimal combination of emission policy and trade policy takes this relationship into account.

5 Conclusions

Theoretically, climate policy should be globally coordinated. But, in practice, such coordination is still lacking. In this paper, we have analyzed a concept of implementing a unilateral climate policy in a way that reduces the national costs of the policy while being compatible with international trade rules. This concept consists of containing the effects of climate policy to the production of an intermediate good that is emission intensive but not open to international trade. In practice, such a good could be electricity or transportation services, both of which account for a substantial fraction of national greenhouse gas emissions in most industrialized countries but serve mainly an internal market. The policy uses an emission tax to set abatement efforts and a product subsidy to reduce the effects on other sectors. We have shown that such a policy might help to counter the most important objections against unilateral greenhouse gas reductions, by attenuating carbon leakage, allaying policy-induced unemployment, and helping to maintain a country's favorable position on international markets.

Our analysis complements the literature on policy differentiation, like Hoel (1996) and Withagen et al. (2007), by considering the case of industries that are only indirectly accountable for greenhouse gas emissions by using an emission-intensive intermediate good. In this often relevant case, a policy differentiation is not easily possible but an intervention in the intermediate goods market can help to constrain the effects of the climate policy to the intermediate good sector. Our approach differs from the literature on trade policy with market distortions and that on strategic environmental policy in that we distinguish between intermediate and final goods production and consider an intervention in the intermediate goods market. As intermediate goods prices, such as electricity prices, are often referred to in the discussion on climate policy and international competitiveness, this seems to be a relevant extension.

As we have pointed out, our analysis refers to a special case, where emissions are due to intermediate goods production. In this case, the negative side-effects of unilateral climate policy result solely from cost increases in final goods production caused by higher production costs in the intermediate goods sector. The distinction between intermediate and final goods is essential to our analysis, as it facilitates an intervention in an internal market, which conforms to WTO rules. Thus, obviously, our analysis applies only to a special case. However, this special case is quantitatively important in most industrialized countries; there, intermediate goods production usually accounts for significant portions of national greenhouse gas emissions and industries that use this intermediate good, such as manufacturing or parts of the chemical industry, are often subject to intense international competition.

In general, emissions are caused both by intermediate good production and by some final goods sectors. It can be easily shown that in this general case, the optimal policy consists of a mix of containment and policy differentiation; the emissions of intermediate goods and those of final goods production are regulated by differing taxes and the intermediate good is subsidized (or taxed, as in Section 4.3).[16]

Like Hoel (1991) and Withagen et al. (2007), our analysis shows that the costs of being a frontrunner in climate policy can be reduced by using a policy mix. In our case, it is reasonable from a national perspective to contain the effects of climate policy to the intermediate goods sector. For example, a policy mix would induce abatement efforts in electricity generation, such as the use of natural gas fired power plants, wind and solar energy, by using an emission tax or permit trading but shield the final goods sectors from the cost increase by subsidizing electricity. Of course, this entails inefficiencies, because the emission reduction is not achieved by an optimal combination of abatement efforts and output reduction. But as output reductions are costly in the case of unilateral climate policy, due to carbon leakage, unemployment, or the loss of market power, this containment is reasonable from a national perspective. Indeed, losing competitiveness on international markets due to rising energy prices is one of the most important objectives against active climate policy in many European countries.

As in the distortions literature, an important objection to intervening in the intermediate goods market is that such interventions reduce the incentives for adjustments in final goods production. Subsidizing electricity reduces the incentives to use more energy-efficient production equipment and hampers adjustments in the labor allocation, that is, a reallocation of labor from sectors that are more affected by climate policy to those that are less affected.

However, for the case of unilateral climate policy, this objection is only partially valid. It seems likely that climate policy will be coordinated among the major emitters at some time in the future.[17] Therefore, unilateral climate policy can be expected to be transitory. But once all major emitting countries commit to substantial emission reductions, international prices change and thus new adjustment processes are induced. As these later adjustments are likely to partially reverse adjustments that would seem necessary in the case of unilateral climate policy, it seems reasonable to defer substantial adjustments until a broad interna-

[16]If, in our model, the trading "clean" sector directly causes emissions, that is, if we have $f_R(l_R, e_R)$ with $\partial f_R(l_R, e_R)/\partial e_R > 0$, then the optimal policy consists of a differentiated tax and the subsidy/tax on the intermediate good derived in Prop. 1-3.

[17]Otherwise, few countries would continue to pursue an active climate policy.

tional consensus is reached. Our approach will assure this. Furthermore, as our approach consists of a policy mix, it is easily possible to meet the same emission target while reducing the subsidy to the intermediate good over time. In this way, moderate adjustment incentives in the final goods sectors can be set.

A point that we have not considered in our analysis are the implications of our national policy mix on international negotiations. Our approach increases the effectiveness and decreases the costs of implementing a national climate policy in the absence of a broad international agreement. Thus it is likely to induce more countries to adopt unilateral emission reductions and to lead to the setting of stricter targets. So in the short run, an increased reduction of global emissions can be expected. However, whether this will facilitate or complicate international negotiations is not clear. Trade economists have extensively analyzed the question whether unilateral trade liberalization and regional trade agreements are building blocks or stumbling blocks for global free trade.[18] The issue is still being actively studied and both views have numerous advocates. To our knowledge, the question whether unilateral or sub-global efforts to reduce greenhouse gas emissions constitute building or stumbling blocks on the road towards a viable global climate agreement has not yet been investigated, and thus remains an open and interesting field for research.

Finally, as noted in the preceding sections, there are better ways (at least, in theory) to reduce the negative side-effects of unilateral climate policy. We have chosen the intervention in the intermediate goods market, because it conforms with WTO rules, is easily implementable, and is able to address several such side-effects simultaneously. Of course, a policy that differentiates the subsidy among sectors according to their exposure to international competition would be better. But such a differentiated policy would be hard to implement and would, most likely, be challenged as being an inappropriate intervention in export and import markets. Furthermore, from a theoretical point of view, it is more important to show that the use of a simple instrument is welfare increasing; naturally this conclusion extends to all more sophisticated instruments, as these grant more degrees of freedom.

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