THREE ESSAYS IN TRADE AND THE ENVIRONMENT

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Furthermore, I wish to thank all my colleagues at the WWZ Basel who provided an intellectually and personally stimulating environment.

This thesis is dedicated to my family.

Contents

List of Figures

Abbreviations

CGE	Computable General Equilibrium
EIA	Energy Information Administration
EPA	Environmental Protection Agency
EU	European Union
IEA	International Environmental Agreement
GATT	General Agreement on Trade and Tariffs
GHG	Greenhouse Gas
RHS	Right Hand Side
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
WTO	World Trade Organization

Introduction

The three papers comprising this thesis are distinct and independent studies; yet, they all explore interrelated facets of the broader field of environmental and climate policy, and international trade. They reflect my personal research interest that focuses on issues of climate change and international trade as well as the numerous and complex interdependencies that exist between the two fields. International trade can affect climate change by inducing economic growth, production and transport of goods, all of which can lead to an increase in greenhouse gas (GHG) emissions, which are the main cause of rising global temperatures. Also, climate change can affect international trade by altering comparative advantages, changing spatial patterns and productivity of agriculture, leading to the emergence of new products and industries, etc.

The relationship between climate change and international trade is clearly bidirectional. However, we still know very little about the scope and even the direction of many of the effects of the climate-trade relationship. A general rule in that respect is that there are no general rules. For instance, moderately rising average global temperatures will reduce agricultural output in some regions of the world (mainly in the developing countries in tropical and subtropical areas), but increase productivity and cultivation options in higher latitudes - both of which will affect trade patterns. Further examples include the ongoing and heated discussion on the effect of international trade on pollution, and the debate over the existence of an environmental Kuznets curve.

The three papers of this thesis tackle the environment-trade issue from an international environmental policy point of view. Hence, the underlying questions of this thesis are how environmental challenges such as climate change should and should not be addressed and how environmental policies and agreements interact with international trade. In doing this, we approach the issue from different directions, assuming that there is either partial cooperation between affected countries or that countries act unilaterally. The case of full global cooperation is of limited interest for an economist as it necessarily leads to the best possible outcome from a welfare point of view. For this reason, in this thesis we do not address mechanisms that facilitate international cooperation, but rather look at the welfare effects and optimal policies under limited or no cooperation.

While a more technical synopsis of the results of this thesis is given in the summary below, the relevance of the studies for real world policy making is outlined here in terms of intuitive reasoning.

The first paper of this thesis is on international environmental agreements (IEAs). Today there are hundreds of IEAs in force and almost every country in the world is part of at least one IEA. The need for international environmental cooperation is driven by the international dimension of environmental problems. Numerous pollutants are mobile across borders, traveling by air or water and thus causing damage in countries outside those of their origin. By way of cooperation, affected countries can internalize such external environmental effects. However, cooperation is not always easy to achieve because some countries will benefit more than others or even lose by cooperating. Free-riding incentives and the Prisoner's dilemma are typical phenomena in international environmental issues. Literature has focused a lot on how to design mechanisms that facilitate cooperation and break the Prisoner's dilemma, and this is certainly an important task. However, an IEA between some countries will, in general, not only affect the members of the IEA, but also non-members. Such effects have generally been ignored in the literature and are analyzed in the first paper of this thesis in the context of a model of strategic trade and environmental policy. We show that an IEA might be more than a simple tool to internalize externalities, but can implicitly be an exploitative trade contract that harms outsiders. The intuition behind this result is quite simple. If exporter countries fight for market shares on third country markets, the competition favors the third countries as it depresses prices. If, however, exporter countries cooperate, then they implicitly form a cartel to the disadvantage of third country consumers. Such a cartel would be illegal by WTO rules and thus cannot be implemented explicitly via a trade agreement; environmental agreements, however, that are generally viewed as beneficial or at least innocuous, might achieve the same task. Although such an IEA generally brings about improvements in terms of reduced pollution, its adverse effects on consumer surplus might outweigh all gains and lead to a welfare loss for the world as a whole. Hence, a direct and general notion that follows from this study is that, when IEAs are evaluated from a normative perspective, effects on third countries have to be taken into account. As a more indirect implication, the results rather suggest that regional or sub-global climate agreements are stumbling blocks and not building blocks towards a comprehensive global climate agreement, as members of such a partial agreement could gain at the expense of non-members making further expansion more difficult.

The second chapter of this thesis takes a public choice perspective on strategic trade and environmental policy. Here we investigate strategic interactions between governments when they follow objectives other than pure maximization of welfare. Arguably, in reality the behavior of bureaucrats and political decision makers can be and is influenced by lobbyists, political dogmata, religious beliefs and many other motivations that are not congruent with social welfare maximization. In these cases, outcomes of strategic interactions will have quite distinct positive and normative implications. We take the maximization of environmental tax revenue as an example of an objective that diverges from the textbook assumption of welfare maximization and analyze how such distorted incentives translate into different policy outcomes. One central and perhaps surprising result is that policy makers who do not have social welfare in mind can actually perform better in welfare terms than "good dictators" that aim exclusively at maximizing welfare.

This finding is quite intuitively explained by the facts that strategic rivalry between governments in general does not lead to the jointly optimal outcome, and that equilibria of such strategic interactions heavily depend on the set of credible threats of the governments. If governments can credibly commit to relatively high taxes, i.e., if their objective is to maximize tax revenue, this can lead to an equilibrium outcome in which social welfare is higher than under welfare maximizers. Starting from this insight, we investigate if welfare-maximizing governments could exploit this by delegating environmental tax policy to revenue-maximizing policy makers whenever this would be beneficial. We show that a commitment problem renders this strategy infeasible in most cases. The main policy insight from this paper is that standard economic intuitions are highly sensitive to the assumptions about governments' incentives. As the textbook assumption of countries being governed by good dictators that have nothing but the wellbeing of their citizens in their minds seems to be overly optimistic if one takes a look at (at least some) real world politicians, policy recommendations based on models that incorporate that assumption should be treated with caution.

The third paper of this thesis, which is a joint study with Prof. Frank Krysiak, is concerned with unilateral climate policy, i.e., with climate policy that takes place outside of an international agreement. If global efforts to reduce GHG emissions are not coordinated between the emitting countries, additional costs can arise that go beyond the direct abatement costs. First, emission-intensive industries might be driven out of the country that implements climate regulation and continue to produce and to emit GHG emissions in other countries that have no or less stringent regulations. This effect is known as "carbon leakage". Second, climate policy can lead to unemployment if labor markets are imperfect, particularly if wages are rigid, which, at least in the short run, is the case for many industries. Finally, unilateral climate policy can lead to worsening terms of trade. All of these effects are potential ammunition for opponents of unilateral climate policy and can lead to considerable domestic political pressure against unilateral action. This paper turns to the question of how unilateral climate policy should be designed to reduce welfare losses stemming from the factors mentioned above. Additionally, we take into consideration, that national political decision makers are bound by the WTO agreements that prohibit direct trade intervention. For the case of emitting final goods sectors, it has been shown in the literature that differentiating emission regulation between sectors that are open to international trade and such that are purely national is optimal. If, however, GHG emissions are caused by the production of an intermediate good, such an approach is infeasible. In this chapter we show that an intervention in the intermediate good sector can be an optimal strategy to reduce the costs of unilateral climate policy. The results of this study have direct implications for policy design, as they suggest feasible climate policy regimes that can be part of unilateral strategies to cut emissions for countries that wish to be frontrunners.

Summary

This thesis comprises of three papers on various aspects of trade and the environment.

The first paper takes a closer look at the interplay of international environmental agreements (IEAs), trade and welfare. It is well known from the literature of strategic environmental policy that governments bound by WTO-rules that preclude direct trade intervention may use environmental policy as a substitute for trade policy. Studying a third-market model with imperfect competition and global emissions, we first show that the strategic rivalry between exporter countries causes a welfare loss for both countries. Such a loss represents a motivation for the countries involved to conclude an IEA that internalizes the external effects. Welfare of the exporter countries increases as a consequence of such an IEA. However, we show that, taking into account the accompanying loss of consumer surplus in third countries, the overall welfare effect might be negative, so that the world as a whole is worse off with than without the IEA. The main conclusions drawn from the first paper are that IEAs are a useful tool to internalize environmental externalities, but that (i) malign welfare effects can arise in the presence of pre-existing distortions such as imperfect competition; (ii) an evaluation of the recent proliferation of regional IEAs has to take into account impacts on non-members; and (iii) regional IEAs may not be a fruitful way of addressing global environmental challenges such as climate change.

The second paper analyzes the impact of decisions made by governments that are not strict welfare maximizers on strategic and cooperative environmental pol-

icy making. Again we analyze a version of the third-country model of strategic trade policy including pollution and, inspired by the public choice view on governments and bureaucrats, we show that decisions made by policy makers that have incentives diverging from pure welfare maximization can lead to quite distinct outcomes both from a positive as well as from a normative point of view. In particular, we show that even a fully cooperative IEA between governments that maximize tax revenue rather than welfare may lead to a welfare loss for the signatory countries. Furthermore, we demonstrate that tax revenue-maximizing governments may lead to a higher welfare than welfare-maximizing governments, because the former can credibly commit to higher emission tax levels. Finally, a delegation game between governments is used as an illustration to show that the strategic situation between the two exporter countries does not always correspond to the Prisoner's Dilemma but might be of several other game-theoretic types. These results expose the sensitivity of many of the conclusions from the strategic trade and environmental policy literature to variations of the arguably optimistic assumption that governments are strictly welfare-maximizing.

The third paper, which was written jointly with Prof. Frank Krysiak, is an attempt to find strategies of reducing the costs and increasing the effectiveness of unilateral climate policy. As a global climate agreement encompassing all major emitters of GHGs is unlikely to be forthcoming in the near future, but nonetheless some countries such as the EU and Switzerland have decided to pursue reduction targets independently, the question arises as to how such unilateral policies should be optimally designed. For the case of emitting intermediate goods sectors, this question has not been thoroughly addressed in the literature. Using a three-sector general equilibrium model it is shown that, if the production of an intermediate good, such as electricity or transportation services, causes GHG emissions, it can be optimal to (partially) contain the effects of climate policy to that sector. Containment consists of a subsidy or tax on the intermediate good and is a second-best policy in the presence of WTO rules for the cases of carbon leakage and market power; through containment, also climate policy-induced unemployment can be reduced. The results of this paper suggest ways in which countries that wish to be frontrunners could design climate policies that achieve reduction cuts at lower costs and thus also reduce domestic political pressure against unilateral action.

Chapter 1

The global welfare effects of international environmental cooperation

Abstract

This study explores the global welfare effects of international environmental agreements (IEAs) that coordinate emission policies between exporter countries. We show that, when export markets are imperfectly competitive, IEAs might cause a global welfare loss even if non-signatories benefit from lower emission levels. This result is due to a loss of consumer surplus in importer countries. From a global welfare perspective, the desirability of IEAs depends on the size of the signatories and the harmfulness of emissions.

1.1 Introduction

In the last decades, governments all over the world have signed a large number of international environmental agreements (IEAs). There are more than 270 IEAs in force today according to UNEP (2005); more than 120 of them were signed after 1990.

Economic research on IEAs has largely focussed on issues of stability and compliance.[1] In contrast, the global welfare effects of IEAs have not received much attention.

An IEA that implements jointly optimal environmental policies necessarily improves the total welfare of signatories. If such an agreement leads to less pollution, one is tempted to believe that, if any, the welfare effects on non-signatories are positive, and the world as a whole is better off with than without the IEA.

In this study we explore the global welfare effects of IEAs between governments that have strategic trade policy incentives, and come to a more nuanced conclusion.

Our analysis departs from the following simple setting: The production of an export good causes internationally mobile emissions. Governments of polluter countries can regulate emissions cooperatively or non-cooperatively. If firms compete on imperfectly competitive export markets, this changes the nature and effects of both cooperative and non-cooperative environmental policy setting as compared to perfect competition. From the literature on strategic environmental policy, it is well known that governments might use environmental policy as a proxy for strategic trade policy if the latter is not feasible. In such a situation, governments of exporting/polluting countries choose weak environmental regulation in order to shift rents from foreign firms to home firms. Signing an IEA on jointly optimal environmental policies eliminates this strategic conflict between exporting countries and thus unambiguously improves their welfare. However, the *global* welfare effects of such an IEA are less clear cut.

[1] See e.g. Carraro and Siniscalco (1993) and Barrett (1994a).

In this paper, we show that, even if non-signatories benefit from lower emission levels, an IEA might reduce global welfare as the associated loss of consumer surplus in importing countries might outweigh all welfare gains. In particular, we demonstrate that from a global perspective, the desirability of an IEA depends on the size of the signatory countries and the degree of harmfulness of emissions. Furthermore, we show that an IEA between exporter countries might implement environmental regulation that is either too lax or too strict as compared to the global optimum.

The remainder of this paper is structured as follows: Section 2 contains a literature review; in section 3 a simple model is developed; section 4 explains the main findings, and in section 5 the conclusions are presented.

1.2 Literature Review

The seminal contribution by Brander and Spencer (1985) has laid the ground for a rich body of literature on trade policy under imperfect competition. Brander and Spencer (1985) have shown that if export markets are imperfectly competitive, interventionist policies become attractive. The reason for this is the presence of rents that creates incentives for beggar-thy-neighbour trade policy (Brander, 1986). Through strategic policy setting, governments can shift rents from a foreign firm to a home firm. If competition is à la Cournot, it is in the individual interest of exporting countries to subsidize, whereas they would do better as a group without subsidies.[2][3] Thus, governments find themselves in a Prisoner's Dilemma that leads to a Pareto-suboptimal outcome.

A notable extension of the Brander and Spencer (1985) model emerged parallel to advancing international trade liberalization beginning in the 1990s. With direct export subsidies becoming largely illegal under GATT/WTO rules, secondary trade policies have gained increasing attention. Several authors have extended the

[2] In fact, exporters' joint welfare-maximizing policy would be a negative export subsidy, i.e. an export tax (Brander and Spencer, 1985).

[3] Eaton and Grossman (1986) have shown that the opposite is true if firms compete in prices.

Brander and Spencer (1985) framework to the case of polluting industries. Research in the area of strategic environmental policy has been spearheaded, among others, by Barrett (1994b), Rauscher (1994) and Ulph (1996). One general conclusion emerging from these studies is that if the production costs of firms are positively related to the stringency of domestic environmental regulation, environmental policies will be laxer than first-best. However, Greaker (2003a) showed that the opposite is the case if emissions are an inferior input. Conrad (2001) uses a reversed timing version of Brander and Spencer (1985) in order to explain why firms engage in voluntary environmental agreements. Investigating this issue in a model where firms are footloose, Greaker (2003b) comes to the somewhat surprising result that the threat of plant relocation can lead to stricter environmental policy. Burguet and Sempere (2003) analyze the effects of trade liberalization on environmental policies and welfare.

To our knowledge, Walz and Wellisch (1997) are the only authors who include world welfare considerations in a model of strategic trade and environmental policy. In this sense, it is the paper most closely related to ours. However, our analysis differs in two fundamental ways from that of Walz and Wellisch (1997). First, while Walz and Wellisch (1997) take pollution as being purely local, we consider globally mobile emissions. This adds an additional dimension to the model, as pollution constitutes a negative externality which has to be taken into account. Second, Walz and Wellisch (1997) study a move towards free trade, *i.e.* direct export subsidies are allowed, and the welfare implications of a ban on such subsidies are analyzed. We start our analysis at a point where export subsidies are already banned, which we believe comes closer to today's reality. We then take the case of international environmental cooperation, and analyze its global welfare effects. In this sense, our study takes a new approach and arrives at results absent so far in the literature on strategic environmental policy.

1.3 The model

For our analysis, we develop a version of the Brander and Spencer (1985) 2-stage game, where, in the first stage, governments of polluter countries set environmental policies, and, in the second stage, firms play Cournot-Nash. We then make a welfare comparison between international environmental cooperation and non-cooperation by considering two different ways of policy setting in the first stage.

The model consists of three countries A, B and C (rest of the world). In countries A and B there is one firm each, producing a normal homogeneous good. The total production is exported to country C. The two firms compete in quantities.

Production is accompanied by emission of a global pollutant for which governments set a standard.

In the first subgame, governments A and B simultaneously set emission standards.[4] In the second subgame, firms simultaneously decide on output levels, taking emission standards as given. We solve the model by backwards induction, considering the second stage of the game first.

1.3.1 Firms' behavior

We will assume that the two firms are symmetric and neither has means to influence its government's decision on the emission standard, so that each firm faces the following profit maximization problem:

$$\max_{x_i} \Pi_i = R_i(x_i, x_j) - C_i(x_i, e_i) \tag{1.1}$$

with the subscript denoting the country ($i = A, B;\ i \neq j$), x being output, Π being profit, R being revenue, C being costs and e being the emission standard. We assume that costs depend on the quantity of output produced and on the emission standard in the following manner:

[4] As there is only one firm per country, taxes and standards are equivalent. Hence, all results obtained in our analysis also hold for the case of emission taxes.

$$\frac{\partial C_i}{\partial x_i} > 0, \frac{\partial C_i}{\partial e_i} < 0, \frac{\partial^2 C_i}{\partial x_i^2} > 0, \frac{\partial^2 C_i}{\partial e_i^2} > 0 \text{ and } \frac{\partial^2 C_i}{\partial x_i \partial e_i} < 0 \tag{1.2}$$

A first-order condition for a profit maximum obtains from taking the partial derivative of (1.1) with respect to x_i:

$$\frac{\partial \Pi_i}{\partial x_i} = \frac{\partial R_i}{\partial x_i} - \frac{\partial C_i}{\partial x_i} = 0 \tag{1.3}$$

We assume that the second-order condition and the Routh-Hurwitz stability conditions are satisfied so that the Cournot-Nash equilibrium is unique and stable.[5] Furthermore, the firms' output choices are strategic substitutes:

$$\frac{\partial^2 \Pi_i}{\partial x_i^2} < 0 \tag{1.4}$$

$$\left|\frac{\partial^2 \Pi_i}{\partial x_i^2}\right| > \left|\frac{\partial^2 \Pi_i}{\partial x_i \partial x_j}\right| \tag{1.5}$$

$$\frac{\partial^2 \Pi_i}{\partial x_i \partial x_j} < 0 \tag{1.6}$$

Lemma 1. *Equilibrium output of firm i increases (decreases) in the emission standard of country i (j).*

Proof. See Appendix. □

As the two firms are symmetric and the equilibrium is unique, the firms' output choices will be symmetric functions of the emission standards in both countries.

1.3.2 Strategic government behavior

In the first stage of the game, the emission standard of country i is determined by government i that maximizes welfare, given the Cournot-Nash game of the firms and the strategic choice of e_j by government j.

[5]See Tirole (1988) chapter 5.7.

Welfare consists of firm profits, consumer surplus from domestic consumption and environmental damage from emissions.

We normalize the world population size to 1 and assume that all consumers are identical. A fraction $\frac{\phi}{2}$ of the world population lives in each exporter country and a fraction $1-\phi$ in the rest of the world. The world market for the traded good is fully integrated, so that there is only one price. Global net consumer surplus is an increasing function of total consumption:[6]

$CS(X) \equiv \int\limits_0^X P(X)dX - P(X)X$, with $CS'(X) > 0$ and $X = x_i + x_j$.

Furthermore, we assume that emissions cause environmental damage in each country. This damage is measured by a convex function of global emissions:

$\gamma D(E)$, with $\gamma D'(E) > 0$, $\gamma D''(E) > 0$ where $E = e_i + e_j$ and $\gamma \geq 0$.

The parameter γ is a measure of the harmfulness of emissions.

Government i hence solves the following maximization problem:

$$\max_{e_i} W_i = \Pi_i(x_i, x_j, e_i) + \frac{\phi}{2}CS(X) - \gamma D(E) \tag{1.7}$$

Differentiating (1.7) with respect to e_i and substituting in (1.1) and (1.3) yields the following first-order condition for a welfare maximum:

$$\gamma D'(E) = \frac{\partial R_i}{\partial x_j}\frac{dx_j}{de_i} - \frac{\partial C_i}{\partial e_i} + \frac{\phi}{2}CS'(X)\frac{dX}{de_i} \tag{1.8}$$

where $\frac{dX}{de_i} = \frac{dx_i}{de_i} + \frac{dx_j}{de_i} > 0$.

Equations (1.8) are the usual conditions that equate marginal damage with marginal benefit for both exporter countries.

Again we assume that the second-order conditions and the Routh-Hurwitz conditions are satisfied.

Considering the firms' behavior in the second stage and the government behavior in the first stage, equilibrium emission standards and output levels can be

[6]We assume the existence of a well-behaved demand function X(P) that is continuous and strictly decreasing wherever X(P)>0; P(X) is the implied inverse demand function.

calculated. As country A and country B are identical, a unique symmetric equilibrium obtains, which we call the Nash-Cournot-Nash equilibrium (NCN):

$$e_i^{NCN} = e_j^{NCN} = e^{NCN} \tag{1.9}$$

$$x_i^{NCN} = x_j^{NCN} = x^{NCN} \tag{1.10}$$

From the point of view of exporter countries, these NCN emission standards are not jointly optimal.

Lemma 2. *In NCN, a decrease in emission standards leads to an increase in exporters' joint welfare.*

Proof. See Appendix. □

This result is analogous to the result obtained by Brander and Spencer (1985) on export subsidies and highlights the Prisoner's Dilemma faced by exporter countries. The choice of exporter countries that is individually rational leads to a jointly suboptimal outcome. Brander and Spencer (1985) do not analyze the cooperative case correctly pointing out that countries could not credibly commit to cooperation. However, in repeated Prisoner's Dilemmas, cooperation can be sustained as equilibrium. While our model is not explicitly dynamic, one could imagine that governments face the decision whether or not to honor an IEA every period, rather than once and for all (which corresponds to the one-shot Prisoner's Dilemma), and thus cooperation is a relevant and important case to be considered.

1.3.3 Government cooperation

Let us now take the case of an IEA. If the governments cooperate in setting emission standards, they solve the following joint optimization problem in the first stage of the game:

$$\max_{e_i, e_j} W_{i+j} = \Pi_i(x_i, x_j, e_i) + \Pi_j(x_i, x_j, e_j) + \phi CS(X) - 2\gamma D(E) \tag{1.11}$$

The first-order conditions yield:

$$2\gamma D'(E) = \frac{\partial R_i}{\partial x_j}\frac{dx_j}{de_i} - \frac{\partial C_i}{\partial e_i} + \frac{\partial R_j}{\partial x_i}\frac{dx_i}{de_i} + \phi CS'(X)\frac{dX}{de_i} \tag{1.12}$$

Equations (1.12) differ from (1.8) in three ways reflecting that the governments now take into account the effects the emission standard in one exporter country has on environmental damage, revenues and net consumer surplus in the other exporter country. These additional terms reduce emission standards in the resulting symmetric equilibrium which we designate as Cooperation-Cournot-Nash equilibrium (CCN):

Proposition 1. *In the CCN case, emission standards and output levels are strictly lower than under NCN.*

Proof. See Appendix. □

The rationale behind Proposition 1 is explained by the absence of rent-*shifting* and the presence of rent-*extracting* under CCN. If governments cooperate, they individually have no longer any incentives to increase the home firm's market share at the foreign firm's expense by subsidizing exports through lax environmental regulation. Moreover, governments jointly have incentives to tax exports by setting strict emission standards in order to extract rents from the rest of the world. However, by doing so they also hurt the consumers within the exporter countries, which in turn attenuates the rent-extracting incentives.

1.4 World welfare

What are the effects of international environmental cooperation on global welfare? Let us define global welfare as the sum of welfare in the three countries:

$$W_G = 2W_E + W_I \tag{1.13}$$

with W_E being welfare of an exporting country in equilibrium and W_I being welfare of the importing country corresponding to:

$$W_I = (1 - \phi)CS(X) - \gamma D(E) \tag{1.14}$$

Clearly, the net welfare effect of an IEA between exporting countries on the rest of the world is *a priori* ambiguous.

On the one hand, consumer surplus in the CCN setting is lower than the NCN level ('supply effect'). On the other hand, less production also causes fewer emissions and thus, less environmental damage ('pollution effect'). In general, either effect could dominate.

If the supply effect is outweighed by the pollution effect, the net global welfare effect of an IEA is positive. However, if the opposite is true, one has to weigh the welfare loss in the rest of the world against the welfare gains of exporters in order to determine the sign of the net global effect. This sign depends crucially on the population size of the exporting countries and the harmfulness of emissions.

In order to illustrate this point, let us consider the effect of each factor separately.

1.4.1 No domestic consumption: $\phi = 0$

This case corresponds to the "third market" model frequently studied in the literature on strategic trade policy.

The more harmful the emissions, the higher weighs the pollution effect against the supply effect. This can be seen most clearly by looking at equations (1.7) and (1.11). It is apparent that the weight of environmental damage relative to firm profits in the government's welfare maximization problem is determined by γ. We can establish that the global welfare effect of an IEA is negative (positive) if γ lies below (above) a certain threshold.

Proposition 2. *There exists a value* $\gamma_0^* \in]0, \gamma_c^{CCN}]$ *for which*

$$\gamma < \gamma_0^* \Leftrightarrow \Delta W_G < 0 \text{ and } \gamma > \gamma_0^* \Leftrightarrow \Delta W_G > 0$$

with $\Delta W_G \equiv W_G^{CCN} - W_G^{NCN}$

Proof. See Appendix. □

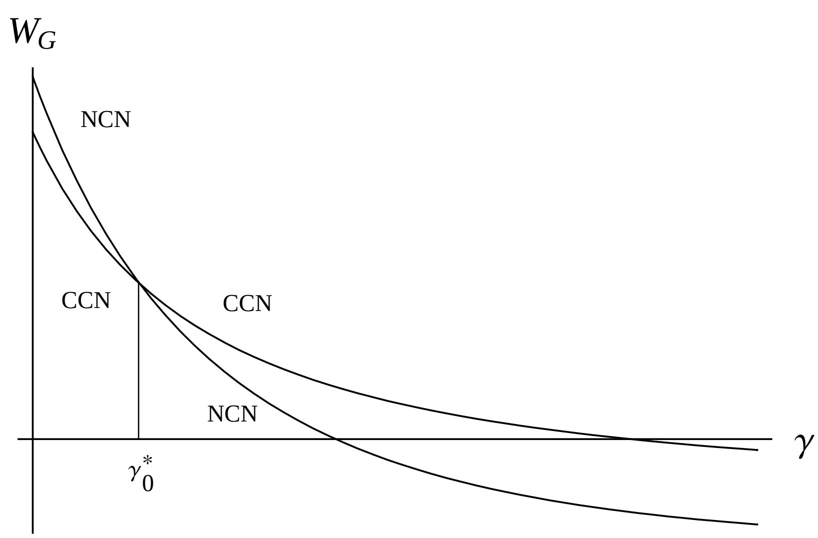

Figure 1.1: The critical damage parameter γ_0^*

Proposition 2 contains the main insight of the analysis and is illustrated in Figure 1.1. The governments of the exporting countries have two policy objectives. First, there is the environmental policy goal, namely minimizing damage from emissions. Second, there is the trade policy goal, namely securing maximal rents.

If exporting countries act strategically, governments seek to increase the home country's market share by implicitly subsidizing exports through lax environmental regulation. This beggar-thy-neighbour policy favors the rest of the world in terms of consumer surplus as output is higher than in the cooperative case. However, higher production also leads to higher emissions which harm the rest of the world.

If exporting countries cooperate, the strategic conflict between the governments is broken and exporters can implement their jointly optimal environmental regulation, which will lead to lower output. The rest of the world thus loses in terms of consumer surplus, but benefits from lower emissions.

If γ is relatively low, the trade policy goal outweighs the environmental policy goal in the exporters' welfare function. As the objectives of the exporters and the rest of the world are congruent concerning environmental policy but diametrically opposed concerning trade policy, the rest of the world prefers that no IEA is signed. This is due to the fact that when exporter countries act strategically, their ability to pursue the trade policy objective (extracting rents) is lower than in the cooperative case.

If γ is relatively high, emissions are relatively harmful so that the rest of the world prefers that an IEA is signed. If exporter countries act cooperatively, they will extract more rents from the rest of the world, but lower emission levels more than outweigh this negative welfare effect.

From a world welfare point of view, an IEA is only preferred if γ lies above some critical value, *i.e.* that emissions are "harmful enough" so that the global environmental effect dominates the loss in total surplus.

1.4.2 The case with domestic consumption: $\phi \in]0,1]$

If the exported good is also consumed domestically, there is a welfare cost attached to contracting production under an IEA. This welfare cost increases in the population size of the exporting countries.

By similar reasoning as in the above section we can show that:

Proposition 3. *For every $\gamma < \gamma_0^*$, there exists a $\phi^* \in\ ]0,1]$ for which*

$$\phi < \phi^* \Leftrightarrow \Delta W_G < 0 \text{ and } \phi > \phi^* \Leftrightarrow \Delta W_G > 0$$

with $\Delta W_G \equiv W_G^{CCN} - W_G^{NCN}$

Proof. See Appendix. □

Corollary 1. *If γ lies above γ_0^*, the sign of the global welfare effect of an IEA is positive and independent of ϕ:*

$$\gamma > \gamma_0^* \Leftrightarrow \Delta W_G > 0 \, \forall \, \phi \in [0, 1]$$

Proof. See Appendix. □

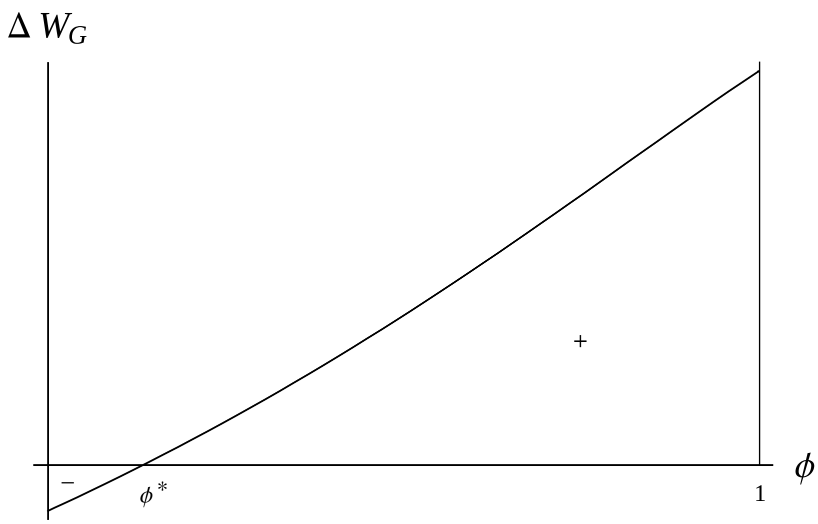

Figure 1.2: The critical population fraction ϕ^*

Proposition 3 shows that the global welfare effect of an IEA between polluter countries is positively related to their size (see Figure 1.2). This result is quite intuitive. The higher the fraction of the welfare of consumers included in the decision of the governments, the higher are the benefits to be reaped by cooperation. Thus we can conclude that IEAs encompassing large fractions of the world are preferred over smaller IEAs. Our conclusion somewhat contrasts studies by Asheim et al. (2006) and Osmani and Tol (2007) who find that two smaller IEAs might lead to globally better outcomes than a single global treaty. Of course, in these studies, stability rather than the effects of strategic trade policy incentives on the formulation of treaties is the issue. However, our results show that if governments can use IEAs to extract rents from non-signatories, smaller (non-global) agreements impose an additional welfare cost that is potentially high.

Figure 1.3 below finally shows the interdependence of the critical values of the harmfulness of emissions and the size of the exporting countries. The grey area corresponds to combinations of γ and ϕ that imply a negative global welfare effect of an IEA between exporter countries. As can be seen, the higher ϕ, the lower is the critical γ (and *vice versa*).

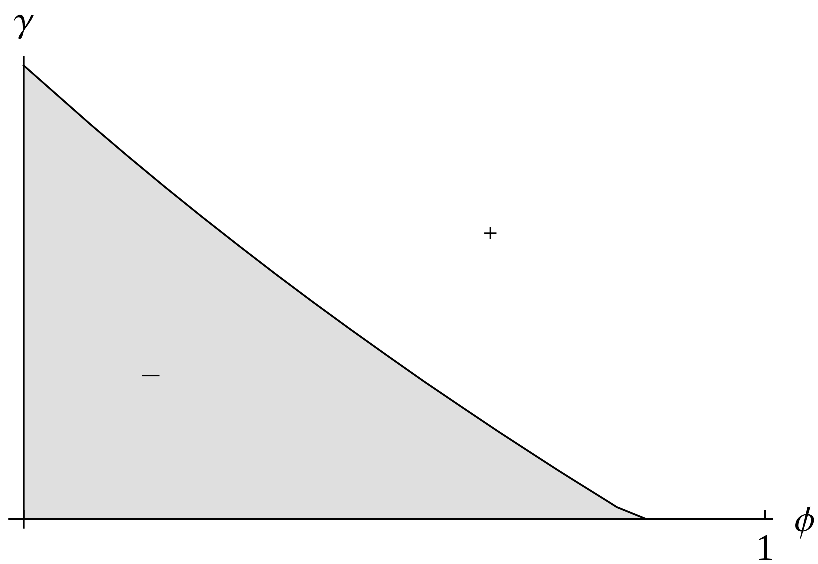

Figure 1.3: The sign of the global welfare effect of an IEA depends on γ and ϕ

1.4.3 The global optimum

Let us finally describe the globally optimal IEA. If the polluter countries take the welfare of the rest of the world into account when formulating an IEA, that is, if there is full global cooperation, the welfare optimization problem becomes:

$$\max_{e_i,e_j} W_G = \Pi_i(x_i, x_j, e_i) + \Pi_j(x_i, x_j, e_j) + CS(X) - 3\gamma D(E) \tag{1.15}$$

The first order conditions yield:

$$3\gamma D'(E) = \frac{\partial R_i}{\partial x_j}\frac{dx_j}{de_i} - \frac{\partial C_i}{\partial e_i} + \frac{\partial R_j}{\partial x_i}\frac{dx_i}{de_i} + CS'(X)\frac{dX}{de_i} \tag{1.16}$$

which corresponds to the equalization of marginal (global) environmental damage with net marginal (global) benefits from production and consumption of the good at the optimal emission level.

We denote the resulting global emission level with E^{FC} (full cooperation) and note the following:

Proposition 4. *An IEA between polluter countries can lead to emission levels below or above the global optimum:*

$$E^{FC} \lesseqqgtr E^{CCN}$$

Proof. See Appendix. □

This result shows that, perhaps against conventional wisdom, an IEA that does not internalize environmental damage in non-signatory countries does not necessarily lead to an emission level that is too high from a global perspective. The reason for this is that we are in a second best world with more than one distortion. The presence of market distortion due to imperfect competition can lead to a situation where the rest of the world is better off if the polluter countries set less stringent environmental regulations, even if this aggravates the pollution externality.

1.5 Conclusions

In this paper we have shown that IEAs in imperfectly competitive market environments carry various implications for the welfare of signatories and the rest of the world. Alongside the obvious positive welfare effect of the internalization of an environmental externality, negative welfare effects accrue due to a loss of consumer surplus. While signatories of IEAs are always better off with than without such an agreement, non-signatories might suffer a net loss in welfare even if they benefit from reduced global emission levels. This welfare loss potentially outweighs all positive welfare effects stemming from the IEA, so that the world as a whole is worse off if polluter countries cooperate in setting emission policies. We find that the global welfare effect of an IEA depends on the harmfulness of emissions and on the population size of the signatory countries.

To keep the analysis as clear as possible, we made a number of simplifying assumptions. First, in line with most of the literature on strategic trade and environmental policy we consider a symmetric setting. This allows us to abstract from effects due to idiosyncratic differences of governments and firms, and concentrate fully on the effects of strategic incentives on the nature of IEAs between exporter countries, which is the main focus of this paper. While we allow for differences in size between exporters and importers, preferences are taken as identical. Incorporating North-South type differences in preferences for consumption or environmental quality would be an interesting extension that is left for further research. Second, we implicitly assume that damage from emissions is independent of population size. This is to avoid *ad-hoc* assumptions on a systematic relationship between the number of inhabitants of a country and the damage it suffers from emissions. At least for the case of damage from greenhouse gas emissions, this seems to be a reasonable approximation, as population size is a rather negligible factor compared to geographical location and ability to adapt to rising temperatures. For other pollutants, this simplification might not be innocuous.

Brander and Spencer (1985) have explained the source and mechanism of strategic incentives that induce governments to subsidize exports when there is Cournot competition on the export market. Barrett (1994b) has shown that these strategic incentives translate into distorted environmental policies when direct trade policies are infeasible and environmental policy is used as a proxy. We find that exporters might profit from their strategic advantage vis-à-vis the rest of the world by signing an IEA that serves as a tool not only for internalizing external effects, but also for extracting rents. Such an IEA is *de facto* also a trade policy contract as it implicitly provides for export taxation by putting in place strict environmental regulation.

Apart from their theoretical contribution, the results of this study inform the policy debate surrounding IEAs and the world trade system. We show that IEAs can cause distortions of international trade flows that lead to a welfare loss for the world as a whole. Furthermore, we establish that regional environmental agreements, today part of numerous regional trade agreements, can secure rents for signatories at the expense of non-signatories. This makes enlargement of such agreements difficult, as existing members could lose by further accession and thus prefer to keep the agreement exclusive. Therefore, our results suggest that regional environmental agreements are rather stumbling blocks than building blocks for the solution of global environmental challenges.

There are a large number of IEAs and their number is steadily increasing, and advancing global trade liberalization makes environmental policy a more and more attractive vehicle for the exertion of market power and the exploitation of strategic advantages. This paper is a first attempt to understand the global welfare effects of IEAs by studying their interplay with international trade in an imperfectly competitive market environment. However, we believe that further theoretical and empirical research is needed to fully comprehend the implications of the ongoing proliferation of IEAs for the world trade system and global climate policy.

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Appendix

Proof of Lemma 1

It follows directly from the total differential of equations (1.3) and rearranging that:

$$\frac{dx_i}{de_i} = \frac{\frac{\partial^2 C_i}{\partial x_i \partial e_i}[\frac{\partial^2 R_i}{\partial x_i^2} - \frac{\partial^2 C_i}{\partial x_i^2}]}{[\frac{\partial^2 R_i}{\partial x_i^2} - \frac{\partial^2 C_i}{\partial x_i^2}][\frac{\partial^2 R_j}{\partial x_j^2} - \frac{\partial^2 C_j}{\partial x_j^2}] - \frac{\partial^2 R_j}{\partial x_j \partial x_i}\frac{\partial^2 R_i}{\partial x_i \partial x_j}} \tag{1.17}$$

By assumptions (1.2), (1.4) and (1.5), both nominator and denominator are positive so that $\frac{dx_i}{de_i} > 0$.

An analogous calculation yields:

$$\frac{dx_i}{de_j} = -\frac{\frac{\partial^2 C_j}{\partial x_j \partial e_j}\frac{\partial^2 R_i}{\partial x_i \partial x_j}}{[\frac{\partial^2 R_i}{\partial x_i^2} - \frac{\partial^2 C_i}{\partial x_i^2}][\frac{\partial^2 R_j}{\partial x_j^2} - \frac{\partial^2 C_j}{\partial x_j^2}] - \frac{\partial^2 R_j}{\partial x_j \partial x_i}\frac{\partial^2 R_i}{\partial x_i \partial x_j}} \tag{1.18}$$

Both terms of the nominator are negative by assumptions (1.2) and (1.6), respectively, while it follows from (1.5) that the denominator is positive. Hence, $\frac{dx_i}{de_j} < 0$. $\square$

Proof of Lemma 2

In NCN, a unilateral change in the emission standard of country i has the following effect on exporters' joint welfare (W_{i+j}):

$$\frac{\partial W_{i+j}(e_i, e_j)}{\partial e_i} = \frac{\partial W_i(e_i, e_j)}{\partial e_i} + \frac{\partial W_j(e_i, e_j)}{\partial e_i}. \tag{1.19}$$

The first term of the RHS of (1.19) equals zero by the first-order condition of government i. The second term equals:

$$\frac{\partial R_j}{\partial x_i}\frac{dx_i}{de_i} + \frac{\phi}{2}CS'(X)\frac{dX}{de_i} - \gamma D'(E) \tag{1.20}$$

The first term of (1.20) is negative by Lemma 1. The second term is smaller than the third term by (1.8). Hence it follows that $\frac{\partial W_{i+j}(e_i,e_j)}{\partial e_i} < 0$ □

Proof of Proposition 1

The proof follows straightforwardly from Lemma 2. At NCN, lowering the emission standard in either country increases the exporter's joint welfare. Therefore, the joint welfare maximizing emission standard must lie below the NCN level. It follows that $e^{CCN} < e^{NCN}$. As the firms' equilibrium output levels are strictly increasing in the emission level by Lemma 1, $e^{CCN} < e^{NCN} \iff x^{CCN} < x^{NCN}$. □

Proof of Proposition 2

Claim 1: If emissions cause no damage, the global welfare effect of an IEA is strictly negative:

$$\lim_{\gamma \to 0} \Delta W_G < 0$$

with $\Delta W_G \equiv W_G^{CCN} - W_G^{NCN}$

Proof. Consider once again equations (1.7) and (1.11), which characterize the government's problem in the Nash and the cooperative case, respectively. If $\phi = 0$ and $\gamma = 0$, the last terms disappear, which means that the government's objective becomes identical to the firm's problem of profit maximization, and global welfare equals total surplus. It follows that, in the Nash case, the outcome is a Cournot-duopoly, whereas in the cooperative case, the resulting equilibrium is a collusive duopoly, *i.e.* a two firm monopoly. Hence, the world as a whole suffers a deadweight welfare loss if an IEA is signed. □

Let us next define γ_c^{NCN} as the value at which global welfare under NCN becomes zero.

Claim 2: $W_G^{NCN}(\gamma_c^{NCN}) < W_G^{CCN}(\gamma_c^{NCN})$.

Proof. By construction, at γ_c^{NCN}, total surplus equals global environmental damage under NCN, which means that the emission level lies above the global optimum. Hence, a decrease in emissions leads to an increase in global welfare. As emissions under CCN are lower than under NCN the result follows. □

Proposition 2 now follows from Claim 1 through 2 and the intermediate value theorem. □

Proof of Proposition 3 and Corollary 1

Claim 1: If there is no consumption in the rest of the world (*i.e.* no trade), the global welfare effect of an IEA is always positive:

$$\lim_{\phi \to 1} \Delta W_G > 0$$

with $\Delta W_G \equiv W_G^{CCN} - W_G^{NCN}$

Proof. It follows by inspection of (1.14) and by Proposition 1 that if $\phi = 1$, the rest of the world suffers no loss in consumer surplus but benefits from lower emissions under CCN. Therefore, the world as a whole is better off if polluter countries cooperate. □

By definition, for any $\gamma < \gamma_0^*$, ΔW_G is negative at $\phi = 0$; and for any $\gamma > \gamma_0^*$, ΔW_G is positive at $\phi = 0$.

Hence, the results follow from Claim 1 and the intermediate value theorem. □

Proof of Proposition 4

At $\gamma = 0$ (and $\phi \in [0, 1[$), E^{FC} clearly lies above E^{CCN} as there is no environmental damage and the world as a whole suffers a pure deadweight loss from too little production under CCN. As γ increases, both E^{FC} and E^{CCN} decrease, but the former at a higher rate than the latter as, under full cooperation, global environmental damage rather than environmental damage only in exporter countries is taken into account. Therefore, above a certain value of γ, $E^{FC} < E^{CCN}$. □

Chapter 2

A public choice approach to strategic and non-strategic environmental policy

Abstract

In this paper we take a public choice perspective on strategic environmental policy and international environmental agreements. We examine cooperative and non-cooperative environmental policies under governments that are either welfare maximizers ("good dictators") or tax revenue maximizers ("Leviathans"). We show that Leviathans can perform better in terms of welfare and that good dictators can set higher taxes. We then analyze international environmental agreements and show that the breakdown of environmental cooperation can indeed lead to a welfare gain for all signatory countries. Considering a delegation game between governments, we find that a Pareto-superior Leviathan outcome can be the unique Nash-equilibrium.

2.1 Introduction

In his seminal work, Niskanen (1971) has shown how governments that are not maximizing welfare but rather budgets, power or influence can lead to inefficiency. The notion that public officials ("bureaucrats") are driven by such distorted incentives is part of a school of thought that is known as public choice.

In this paper we take a public choice perspective on strategic environmental policy and on international environmental agreements (IEAs). Instead of "good dictators" we let countries be governed by "Leviathans". In other words, governments maximize revenue from emission taxation instead of welfare. This, of course, is but one possible interpretation of government incentives from the rich public choice school. We choose the somewhat extreme assumption of pure revenue maximization not because we believe that governments actually behave this way but rather use the approach as a vehicle to highlight some important features of strategic and non-strategic environmental policy making in the absence of the arguably equally extreme assumption of purely welfare-maximizing governments. Furthermore, revenue-maximizing governments have been studied in the literature before and therefore allow explicit comparison with existing results. Additionally, our modeling approach has tractability and clarity, which enables a lucid presentation of our results.

Our interpretation of the Leviathan should be treated with caution and should be understood as illustrative. However, all our results could be qualitatively reproduced for a Leviathan that maximizes a convex combination of public welfare and tax revenue and for many other incentive systems that diverge from strict welfare maximization.

The purpose of this study is to demonstrate how such distorted incentives can translate into distinct outcomes as well as normative evaluations of strategic situations and international agreements. The relevance of our results, of course, depends essentially on one's view of real-world political decision makers. In reality, politicians can be driven by various incentives, such as public welfare, personal power or prestige, the probability of re-election, political dogmata, religious beliefs, the contributions of lobby groups etc. Hence, our analysis, in assuming strictly revenue-maximizing governments, is not an attempt to derive general results or predictions but rather aims at highlighting the crucial role played by assumptions about the incentives of decision makers in the analysis of strategic environmental policy and IEAs.

A main focus of the research on international agreements, in particular IEAs, has been on how to overcome Prisoner's dilemmas and other strategic deadlocks so that cooperation can be maintained. To our knowledge, the question of whether or not cooperation is desirable in the first place has not been addressed. In general, cooperation is a necessary but not a sufficient condition for the attainment of first-best outcomes in strategic situations. Decision makers need to have the "right" incentives, too, otherwise the global optimum will not be reached even if all parties concerned fully cooperate. Therefore, research on designing economic, institutional and legal mechanisms that facilitate international cooperation is highly important; if, however, decision makers are driven by any incentives other than pure welfare maximization, cooperation might be harmful and the Prisoner's dilemma might turn into a "Prisoner's blessing". To illustrate this point is the main goal of this paper.

Our analysis is concerned with two strands of literature. First, this study is related to the research on strategic environmental policy.[1] This literature shows that, in general, using environmental policy as a trade policy instrument is not first-best. However, if direct trade intervention is infeasible e.g. due to WTO rules, second-best environmental policies can diverge from the Pigouvian rule reflecting a trade-off between strategic trade incentives and environmental concerns.

The results obtained in this study show that strategic and non-strategic environmental policies might have quite different positive and normative implications if one adopts a public choice view of governments.

In particular, we find that strategic environmental policy can not only lead to a

[1] See Barrett (1994), Kennedy (1994), Rauscher (1994), Ulph (1996) and Greaker (2003), among others.

laxer but also to a stricter emission regulation as compared to first-best. A similar result was obtained by Greaker (2003), but it arises due to fundamentally different reasons. In Greaker (2003), strategic environmental policy leads to a regulation that is stricter than that prescribed by the Pigouvian principle if emissions are an inferior input into production. In our case, however, the possibility of such a "green strategy" arises due to the government's very negligence of environmental damage.

Furthermore, we show that full cooperation does not necessarily lead to a jointly optimal outcome in terms of welfare, and can be Pareto-dominated by non-cooperative Nash-behavior. To our best knowledge, this result is novel to the literature on environmental treaties. In his study of a trade model with governments that respond to lobby groups, Ornelas (2008) finds that a cooperative multilateral trade agreement does not necessarily lead to the global optimum and therefore regional trade agreements might bring about an improvement. However, Ornelas (2008) does not offer an explicit analysis of how the cooperative multilateral agreement compares with non-cooperation, but simply states that "a cooperative multilateral trade agreement normally improves upon a non-cooperative equilibrium". In our case, the opposite might hold, as a cooperative agreement can cause a welfare loss as compared to the non-cooperative situation.

Second, our study relates to the papers by Panagariya and Schiff (1994) and Clarke and Collie (2008) who examine export tax games between revenue-maximizing and welfare-maximizing governments. Our results reaffirm some of the findings of these papers, but contradict others therein.

Panagariya and Schiff (1994) consider a third-market model with a perfectly competitive export market. As the production of the exported good does not cause an externality, export policy boils down to maximizing the domestic industry's profits. In our model, there is Cournot competition on export markets and production of the export good causes emission of a pollutant. In such a setting, subsidizing exports - not taxing them - would be the optimal unilateral trade policy for welfare-maximizing governments. Assuming that WTO rules are in place that prohibit direct trade intervention in the form of export subsidies, governments use emission taxes not only for environmental regulation but also for putting in place hidden trade policies. In such a framework, the welfare effects of tax policies are more subtle. In agreement with Panagariya and Schiff (1994), we find that it is possible for a government that maximizes tax revenue to achieve a higher level of welfare. However, as opposed to Panagariya and Schiff (1994), in our model a tax revenue-maximizing government does not always set higher tax rates, but the opposite might be the case. Hence, welfare-maximizing governments might achieve lower welfare than revenue-maximizing governments, and revenue-maximizing governments might end up setting lower taxes than welfare-maximizing governments.

Clarke and Collie (2008) examine an export tax game where there is Bertrand competition on the export market and goods are differentiated. Also in Clarke and Collie (2008), welfare consists of net firm profits. The authors conclude that if exports are close enough substitutes, welfare under tax revenue maximization is always higher than under welfare maximization and delegating emission tax policy to revenue-maximizing policy makers is the unique Nash-equilibrium. We find, however, that even if exports are perfect substitutes, the opposite of both results can hold. This apparent contradiction is explained by an additional environmental effect that is due to emissions and by the different modes of competition on the export market in Clarke and Collie (2008) and in this study.

The contributions of our findings are twofold. First, we derive results so far absent from the literature and enhance the understanding of the interplay of environmental policy and international trade when the assumption of ideal, strictly welfare-maximizing policy makers is dropped. Governments having the "right" incentives might be outperformed by governments essentially acting in self-interest because the former lack the ability to commit to cooperative policies. Second, our results inform the debate on IEAs and trade. If governments are Leviathans rather than good dictators, cooperative agreements might not be desirable and the breakdown of such agreements due to the Prisoner's dilemma might in fact lead to an increase in welfare for the signatories.

The remainder of this paper is structured as follows. In section 2 a simple model is developed; in section 3, international environmental agreements are analyzed; in section 4 a delegation game is studied, and in section 5 the conclusions are presented.

2.2 The model

For our analysis, we develop a version of the Brander and Spencer (1985) 2-stage game, where, in the first stage, governments of polluter countries set environmental policies, and, in the second stage, firms play Cournot-Nash. We then make welfare comparisons between the good dictator and the Leviathan case.

The model consists of three countries A, B and C (rest of the world). In country A and B there is one firm each producing a normal homogeneous good. The total production is exported to country C. The two firms compete in quantities on the export market.

Production is accompanied by emission of a local pollutant[2] for which governments set a tax.

In the first subgame, governments A and B simultaneously set emission taxes.[3] In the second subgame, firms simultaneously decide on output levels, taking emission taxes as given. We solve the model by backwards induction, considering the second stage of the game first.

2.2.1 Firm's problem

We will assume that the two firms are symmetric and neither has means to influence its government's decision on the emission tax, so that each firm faces the

[2]The assumption of a local pollutant is not crucial for the analysis. Qualitatively, all results obtained readily extend to the case of a global pollutant.

[3]Taxes and permits are equally efficient instruments for emission policy. Hence, all results obtained also hold for the case of auctioned permits where the goal of a Leviathan regulator is to maximize revenue from permit auctioning.

following profit maximization problem:

$$\max_{x_i} \Pi_i(x_i, x_j) = R_i(x_i, x_j) - C_i(x_i, t_i) \tag{2.1}$$

with the subscript denoting the country ($i = A, B;\ i \neq j$), x being output, Π being profit, R being revenue, C being costs and t being the emission tax. We assume that the cost function is increasing in both its arguments, and that the cross-derivative is positive:[4]

$$\frac{\partial C_i}{\partial x_i} > 0, \frac{\partial C_i}{\partial t_i} > 0 \text{ and } \frac{\partial^2 C_i}{\partial x_i \partial t_i} > 0 \tag{2.2}$$

It follows from Shepard's lemma that emissions (e) correspond to the partial derivative of the cost function with respect to the emission tax (the price of emissions):

$$e_i(x_i, t_i) = \frac{\partial C_i(x_i, t_i)}{\partial t_i} \tag{2.3}$$

A first-order condition for a profit maximum obtains from taking the partial derivative of (2.1) with respect to x_i:

$$\frac{\partial \Pi_i}{\partial x_i} = \frac{\partial R_i}{\partial x_i} - \frac{\partial C_i}{\partial x_i} = 0 \tag{2.4}$$

Throughout the paper we assume that second-order conditions and, where applicable, Routh-Hurwitz stability conditions are satisfied. It follows that the Cournot-Nash equilibrium is unique and stable.[5] Furthermore, the firms' output choices are strategic substitutes:

$$\frac{\partial^2 \Pi_i}{\partial x_i^2} < 0 \tag{2.5}$$

$$|\frac{\partial^2 \Pi_i}{\partial x_i^2}| > |\frac{\partial^2 \Pi_i}{\partial x_i \partial x_j}| \tag{2.6}$$

[4]The last assumption means that we treat emissions as a normal input.
[5]See Tirole (1988) chapter 5.7.

$$\frac{\partial^2 \Pi_i}{\partial x_i \partial x_j} < 0 \tag{2.7}$$

Lemma 1. *Equilibrium output of firm i decreases (increases) in the emission tax of country i (j).*

Proof. See Appendix. □

As the two firms are symmetric and the equilibrium is unique, the firms' output choices will be symmetric functions of the emission taxes in both countries.

2.2.2 The benchmark case

Let us first assume that governments maximize welfare and cooperate in setting emission taxes. This means that strategic rent-shifting incentives are absent, and the external effect that emission taxation in one country has on welfare of the other country is fully internalized.

Welfare consists of firm profits minus environmental damage from emissions. We assume that damage in country i is a convex function of emissions in country i:

$$\gamma D'(e_i) > 0 \text{ and } \gamma D''(e_i) > 0 \tag{2.8}$$

with $\gamma \geq 0$.

The parameter γ is a measure of the harmfulness of emissions, which means that the higher γ is, the higher is total and marginal environmental damage from pollution.

Hence, governments solve the following joint maximization problem:

$$\max_{t_i, t_j} W_{i+j} = \Pi_i(x_i, x_j, t_i) + \Pi_j(x_i, x_j, t_j) + t_i e_i + t_j e_j - \gamma(D(e_i) + D(e_j)) \tag{2.9}$$

The first-order conditions yield the jointly optimal emission tax t^*:

$$t^* = \gamma D'(e^*) - \frac{\frac{\partial R_i}{\partial x_j}\frac{dx_j}{dt_i} + \frac{\partial R_j}{\partial x_i}\frac{dx_i}{dt_i}}{\frac{\partial^2 C_i}{\partial t_i^2} + \frac{\partial^2 C_i}{\partial t_i \partial x_i}\frac{dx_i}{dt_i} + \frac{\partial^2 C_j}{\partial t_j \partial x_j}\frac{dx_j}{dt_i}} \tag{2.10}$$

where e^* is the efficient emission level for both countries.

The second term on the RHS of (2.10) is negative so that the governments' jointly optimal emission tax lies above marginal damage. This divergence from the Pigouvian rule is explained by the market power the exporters have on the third country market. By setting relatively strict emission taxes governments implicitly tax exports and thus contract production. Thereby, exporting countries extract rents from rest of the world.

If governments act strategically, t^* will not be the Nash-equilibrium of the emission tax game. This is shown in the subsequent section.

2.2.3 The good dictator's problem

If governments maximize welfare non-cooperatively, government i chooses t_i in order to maximize national welfare, given the strategic choice of t_j by government j:

$$\max_{t_i} W_i(t_i) = \Pi_i(x_i, x_j, t_i) + t_i e_i - \gamma D'(e_i) \tag{2.11}$$

Differentiating (2.11) with respect to t_i, substituting in (2.1) and (2.4), and exploiting symmetry gives us the Nash-emission tax for the good dictator case, which we denote as t^{NG}:

$$t^{NG} = \gamma D'(e_i) - \frac{\frac{\partial R_i}{\partial x_j}\frac{dx_j}{dt_i}}{\frac{\partial^2 C_i}{\partial t_i^2} + \frac{\partial^2 C_i}{\partial t_i \partial x_i}\frac{dx_i}{d_t i}} \tag{2.12}$$

The second term on the RHS of (2.12) is positive so that the Nash-emission tax for the good dictator case lies below marginal damage in both countries. This result is explained by the rent-shifting incentives of the governments, which implicitly subsidize exports *via* lax environmental regulation in order to increase the home firm's market share.

Re-establishing a central result of the strategic environmental policy literature[6] we note that:

Lemma 2. *Emission taxes in the Nash-equilibrium are below the efficient level.*

Proof. The proof follows by inspection of (2.10) and (2.12). □

Hence, the choice of exporter countries that is individually rational leads to a jointly suboptimal outcome. Governments are trapped in a classic Prisoner's dilemma.

2.2.4 The Leviathan's problem

Let us now take the case of Leviathan governments. Government i chooses t_i in order to maximize emission tax revenue, given the strategic choice of t_j by government j:

$$\max_{t_i} R_i(t_i) = t_i e_i(x_i, t_i) \tag{2.13}$$

Differentiating the above equation with respect to t_i and rearranging yields the Nash-emission tax for the Leviathan case, which we denote as t^{NL}:

$$t^{NL} = \frac{-\frac{\partial C_i}{\partial t_i}}{\frac{\partial^2 C_i}{\partial t_i^2} + \frac{\partial^2 C_i}{\partial t_i \partial x_i}\frac{dx_i}{dt_i}} \tag{2.14}$$

Note that the Leviathan equilibrium emission tax is independent of marginal environmental damage because the Leviathan is only interested in tax revenue and has no environmental concerns.

2.2.5 Welfare analysis

Let us now compare the good dictator and the Leviathan cases in terms of welfare. Comparing (2.12) with (2.14), it becomes clear that it depends on the harmfulness

[6] See e.g. Barrett (1994), Kennedy (1994), Rauscher (1994), Ulph (1996) and Nannerup (1998).

of emission whether the good dictators or the Leviathans set higher emission taxes. The following Proposition illustrates this key role of γ.

Proposition 1. *If γ lies below (above) a critical value $\overline{\gamma}$, the Leviathans sets a higher (lower) emission tax rate than the good dictators.*

(a) If the Leviathans set a lower emission tax than the good dictators, i.e. if $\gamma > \overline{\gamma}$, the good dictators achieve a higher welfare than the Leviathans.

(b) If the Leviathans set an emission tax higher than the good dictators but lower than a critical value, i.e. if $\underline{\gamma} < \gamma < \overline{\gamma}$, the Leviathans achieve a higher welfare than the good dictators.

Proof. See Appendix. □

The intuition behind Proposition 1 is straightforward. Leviathans do not care about environmental damage but only about revenue. Therefore, the Leviathan emission tax in equilibrium depends directly only on the cost structure of the firms, i.e. how much emissions they produce, and is independent of the harmfulness of emissions. Equilibrium emissions taxes in the good dictator case, however, depend directly on the harmfulness of emissions. Thus, the damage parameter γ, that measures the harmfulness of emissions, determines the relative positions of the emission taxes that are jointly optimal (t^*), and Nash-equilibria for good dictators (t^{NG}) and Leviathans (t^{NL}), respectively. While the good dictator emission taxes always lie below the jointly optimal level, the Leviathan emission taxes can be either above or below t^*. Hence, if the Leviathans set taxes that lie above t^{NG}, but not too far above t^*, they achieve a higher welfare level.

The less harmful emissions are, the lower are both the jointly optimal and the good dictator-emission tax. Hence, for relatively harmless emissions ($\gamma < \underline{\gamma}$), the Leviathans set emission taxes that are higher than t^* and yield a lower level of welfare than the good dictators. In such a case, environmental damage is lower under Leviathans, but so are firm profits; as the latter more than outweigh the former, welfare is higher under good dictators. On the other hand, if emissions are relatively harmful ($\gamma > \overline{\gamma}$), Leviathans set emission taxes that lie below t^{NG} and thus also below t^*. This means that environmental damage is higher and firm profits are lower under Leviathans; hence, again welfare is higher in the good dictator case. However, if γ lies between the specified critical values, Leviathans perform better in welfare terms.

Finally, it must be noted that the possibility of revenue-maximizing governments reaching a higher welfare level than welfare-maximizing governments is only given because the good dictators are unable to overcome the Prisoner's dilemma and to commit to the first-best emission taxes.

2.3 International environmental agreements

To study international environmental agreements (IEAs) from a public choice angle, we first define an IEA as a cooperative agreement between governments on jointly optimal emission taxes. For the case of good dictators this corresponds to the benchmark case studied in subsection 2.2.2. As this is the first-best situation, clearly an IEA is desirable from a welfare point of view. However, as the emission tax game is a Prisoner's dilemma, game theory predicts that the IEA will not hold, and the countries will end up in a Pareto-inferior Nash-equilibrium.

For the Leviathan case, the emission taxes under an IEA are derived by solving the following problem:

$$\max_{t_i,t_j} W_{i+j}(t_i,t_j) = t_i e_i(x_i,t_i) + t_j e_j(x_j,t_j) \tag{2.15}$$

Rearranging the first-order conditions we get the cooperative emission tax for the Leviathan case:

$$t^{CL} = \frac{-\frac{\partial C_i}{\partial t_i}}{\frac{\partial^2 C_i}{\partial t_i^2} + \frac{\partial^2 C_i}{\partial t_i \partial x_i}\frac{dx_i}{dt_i} + \frac{\partial^2 C_j}{\partial t_j \partial x_j}\frac{dx_j}{dt_i}} \tag{2.16}$$

Comparing (2.16) with (2.14) we find that cooperating Leviathan governments always set higher emission taxes than non-cooperative Leviathans. The reason for this is that cooperative Leviathans internalize the tax revenue externality that is ignored by non-cooperative Leviathans. Higher taxes in one country lead to an increase in output and emissions of the firm in the other country, and thus emission tax revenue increases there. However, also cooperating Leviathans ignore environmental damage from emissions. Therefore, the welfare comparison between the two cases is *a priori* ambiguous. It could be that the breakdown of an IEA between Leviathan governments due to the Prisoner's dilemma brings about a welfare gain for both parties. This is shown in the following proposition.

Proposition 2. *If $\gamma < \gamma^c$, the Nash-equilibrium Pareto-dominates a fully cooperative IEA between Leviathan governments. Hence, if $\gamma < \gamma^c$, the breakdown of an IEA leads to an increase in welfare for both signatory countries.*

Proof. See Appendix. □

The above result is easily explained by the incentive structure of Leviathan governments. Neither in the cooperative, nor in the non-cooperative case do Leviathans care about environmental damage. Hence, the equilibrium emission tax rates under an IEA and under strategic behavior are independent of the harmfulness of emissions γ. However, the jointly optimal tax rate t^* depends on γ, which therefore determines the relative positions and distances of t^{NL} and t^{CL}, respectively, to t^*. As the emission taxes under an IEA are always higher than in the absence of cooperation, the likelihood that an IEA leads to a welfare gain for signatories is higher if emissions are relatively harmful. If emissions cause relatively little damage, the efficient tax rate is low and thus cooperation is more likely to be undesirable from a welfare perspective.

Proposition 2 demonstrates that the Prisoner's dilemma that the governments are facing might in fact be beneficial for the welfare of signatory countries. If governments are not strictly maximizing welfare, but rather follow other objectives, cooperation in general does not lead to the first-best outcome. In such a case, the Nash-equilibrium might Pareto-dominate full cooperation in welfare terms.

In conclusion we can state that if governments are run by good dictators rather than Leviathans, IEAs always increase the welfare of signatories. If Leviathans engage in cooperation this need not necessarily be the case. From a static game-theoretic point of view, an IEA should be viable in neither case due to the Prisoner's dilemma. However, if one views adherence to an international agreement as an infinitely repeated game rather than a one-shot decision, cooperation can be sustained in equilibrium if discount rates are not too high. In such a case, whether or not our analysis admits a favorable view of IEAs eventually also depends on whether one sees governments rather as good dictators or rather as Leviathans. The main point made here is that if the governments' incentives in any way diverge from the - arguably optimistic - assumption of pure welfare maximization, IEAs might not bring about any welfare gain and might even be harmful for the signatories.[7]

2.4 The delegation game

In section 2.2.5 we have found that revenue-maximizing governments can reach a higher welfare level than welfare maximizers if the harmfulness of emissions lies within a critical range. This begs the following question. If governments really are good dictators, but revenue maximizing yields higher welfare, why do governments not delegate emission policy to a Leviathan whenever this is preferable over welfare maximization? In this section we show that a commitment problem might render this strategy infeasible.

We now consider a 3-stage delegation game where the governments can either delegate emission tax policy to a welfare-maximizing or to a revenue-maximizing policy maker in the first stage of the game. In the second stage, the policy makers choose emission taxes, and the third stage is the firms' Cournot-Nash game.

The nature of the delegation game in general depends on all parameters of the

[7] E.g. an IEA could also be undesirable for the signatory countries if one makes a less radical definition of the Leviathan as a government that maximizes a convex combination of social welfare and tax revenue.

model and can be a Prisoner's dilemma, a coordination game or a game where the Pareto-optimal outcome is the unique Nash-equilibrium. In order to be able to derive explicit results and to highlight the important role the damage parameter γ plays, we assume specific functional forms for our model and study a linear-quadratic example.

We assume that unit production costs are constant and that one unit of output is accompanied by one unit of emissions so that there is no abatement technology. Hence, firm i has the following cost function:

$$C_i = (c - t_i)x_i \tag{2.17}$$

Firms face a linear inverse demand function:

$$P(x_i + x_j) = \alpha - x_i - x_j \tag{2.18}$$

Damage from emissions per country is quadratic:

$$D(e_i) = \gamma e_i^2 \tag{2.19}$$

In this model, delegating emission tax policy to Leviathan policy makers is Pareto-efficient and a Nash-equilibrium only for a relatively small interval of γ. This is shown in the following proposition.[8][9]

Proposition 3. *The game-theoretic nature of the delegation game depends exclusively on the parameter γ, i.e. on the harmfulness of emissions.*

(a) For $0 \leq \gamma < 1$, delegating emission tax policy to Leviathan policy makers in both countries is Pareto-superior to a situation where both countries delegate emission tax policy to good dictators.

(i) For $0 \leq \gamma < 0.77$, the unique Nash-equilibrium is for both governments to delegate emission tax policy to good dictator policy makers,

[8] We only consider equilibria in pure strategies.

[9] We round the critical values to two digits after the comma.

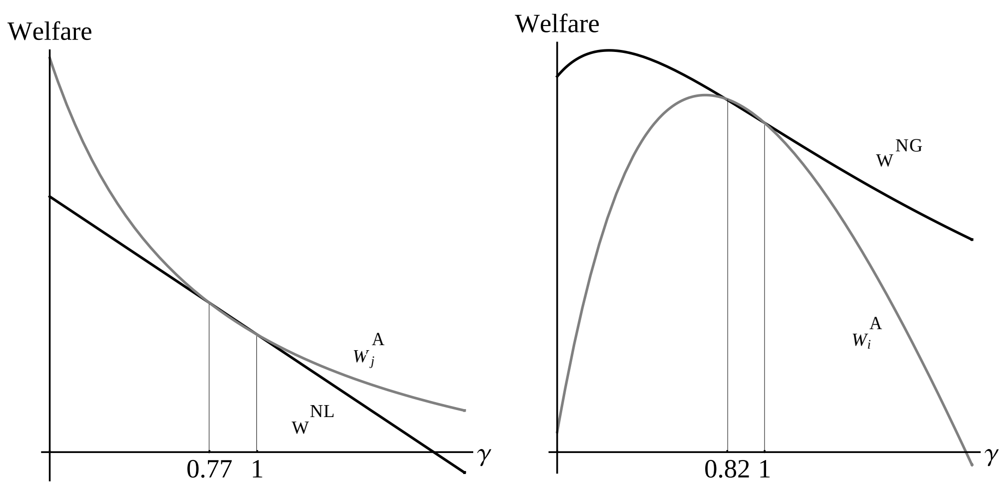
i.e. the delegation game is a Prisoner's dilemma.

(ii) *For* $0.77 < \gamma < 0.82$*, there are two Nash-equilibria where either both governments delegate emission tax policy to good dictators or to Leviathans, respectively, i.e. the delegation game is a pure coordination game.*

(iii) *For* $0.82 < \gamma < 1$*, the unique Nash-equilibrium is for both governments to delegate emission tax policy to Leviathan policy makers, i.e. the delegation game leads both governments to the Pareto-efficient outcome.*

(b) *For* $\gamma > 1$*, delegating emission tax policy to good dictator policy makers in both countries is Pareto-superior to a situation where both countries delegate emission tax policy to Leviathans. As delegating emission tax policy to a good dictator is also the dominant strategy, the delegation game leads both governments to the Pareto-efficient outcome.*

Proof. See Appendix. □



(a) W^{NL} vs. W_j^A (b) W^{NG} vs. W_i^A

Figure 2.1: The game theoretic nature of the delegation game depends on γ

Figure 2.1 illustrates Proposition 3. In 2.1(a) we plot the equilibrium welfare of a country in the Leviathan - Leviathan outcome and in case it deviates by delegating emission tax policy to a good dictator (W_j^A) as a function of the harmfulness of emissions. Only for $0.77 < \gamma < 1$ such a deviation is not welfare improving. In 2.1(b) there is equilibrium welfare of a country in the good dictator - good dictator outcome and in case it deviates by delegating emission tax policy to a Leviathan (W_i^A). For $0.82 < \gamma < 1$ such a deviation is welfare improving. Hence, the results of Proposition 3 follow.

The various intervals characterized in Proposition 3 have intuitive explanations. In the cases (i) and (iii) of part (a), delegating emission tax policy to a good dictator and to a Leviathan policy maker, respectively, are dominant strategies. A Leviathan sets higher emission taxes than a good dictator leading to less environmental damage ('environmental effect') and lower firm profits ('profit effect'). In case (i), the emissions are relatively harmless, therefore the negative profit effect dominates the positive environmental effect from the point of view of government i irrespective of government j's choice. In case (iii) the opposite holds. For the intermediate range given by case (ii), the best response of government i if government j delegates emission tax policy to a good dictator (Leviathan) is to do the same. If government j chooses a good dictator policy maker, government i's best response is also to delegate emission tax policy to a policy maker that sets a relatively low emission tax, i.e. to a good dictator. This causes higher environmental damage, but also higher firm profits which leaves country i better off than in the asymmetric outcome. However, if government j delegates emission tax policy to a Leviathan who sets higher taxes that a good dictator, government i's best response is also to choose a Leviathan. Hence, governments face a coordination problem.

Part (b) of Proposition 3 is simply explained by the fact that the harmfulness of emissions is above a critical value so that Leviathans set lower emission taxes than good dictators. This means that environmental damage under good dictators is lower than under Leviathans. As environmental damage is valued relatively high for $\gamma > 1$, the environmental effect always dominates the profit effect so that delegation to a good dictator is the dominating strategy.

If $\gamma = 0$, the emissions cause no harm and the emission tax game collapses to an export tax game. A well-known finding by Brander and Spencer (1985) is that the Nash-equilibrium of this game is a subsidy on exports, while the Pareto-optimum is export taxation. Therefore, the Leviathans achieve a higher welfare level in equilibrium. However, delegation to a Leviathan policy maker is not a Nash-equilibrium, so that the game is a Prisoner's dilemma where both governments delegate to welfare-maximizing policy makers and are stuck in a Pareto-suboptimal situation. As there is no emission damage, this result can be directly compared to Clarke and Collie (2008), who find that for perfect substitutes, delegating the decision on export taxation to revenue maximizers is both Pareto-efficient and a Nash-equilibrium. The reason for these divergent results is that we consider the case of Cournot competition, while in Clarke and Collie (2008) competition is à la Bertrand. Such a dependence of optimal policies on the nature of competition on the export market is typical for models of strategic trade policy, as has been lucidly demonstrated by Eaton and Grossman (1986).

2.5 Conclusions

In this paper, we have taken a public choice perspective on strategic environmental policy and on IEAs.

We have shown that governments that are maximizing tax revenue instead of welfare might outperform welfare-maximizing governments in terms of welfare. This perhaps counterintuitive result is due to the strategic situation between the governments of exporting countries. The lack of ability to commit to cooperation because of the Prisoner's dilemma leaves welfare-maximizing governments in a Pareto-suboptimal situation. Revenue maximizers face the same commitment difficulty, and might as well end up in a Pareto-suboptimal equilibrium from the governments' point of view. However, from a social welfare perspective, the Nash-emission tax under revenue-maximizing governments might be preferable to the Nash-emission tax under welfare maximizers.

Furthermore, we have demonstrated that even fully cooperative IEAs might not be desirable. If revenue-maximizing rather than welfare-maximizing governments conclude agreements, they might lead to a welfare loss for both countries. In such cases, the breakdown of an IEA due to the Prisoner's dilemma brings about a Pareto-improvement from the social perspective. Concerning policy implications, this study informs the debate surrounding IEAs and the world trade system. In an earlier study on strategic environmental policy, we have shown that fully cooperative IEAs between welfare-maximizing governments might lead to a global welfare loss if one takes into account their effects on third countries. In this paper we show that if governments are not driven by "textbook" incentives, the very same countries that signed the IEAs might end up being worse off than before.

Finally, studying a delegation game, we have shown that the harmfulness of emissions is the key parameter for determining the game theoretic nature of strategic interaction between governments and both the positive and normative properties of Nash-equilibria. Delegation of emission policy to either welfare-maximizing or revenue-maximizing governments might be Pareto-dominating. Furthermore, the Pareto-superior delegation decision can be the unique Nash-equilibrium for some parameter values. In general, the delegation game can be of several game theoretic types including the Prisoner's dilemma and the coordination game.

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Appendix

Proof of Lemma 1

Totally differentiating equations (1.3) and rearranging yields:

$$\frac{dx_i}{dt_i} = \frac{\frac{\partial^2 C_i}{\partial x_i \partial t_i}[\frac{\partial^2 R_j}{\partial x_j^2} - \frac{\partial^2 C_j}{\partial x_j^2}]}{[\frac{\partial^2 R_i}{\partial x_i^2} - \frac{\partial^2 C_i}{\partial x_i^2}][\frac{\partial^2 R_j}{\partial x_j^2} - \frac{\partial^2 C_j}{\partial x_j^2}] - \frac{\partial^2 R_j}{\partial x_j \partial x_i}\frac{\partial^2 R_i}{\partial x_i \partial x_j}} \tag{2.20}$$

By assumptions (2.2) and (2.5), the nominator is negative while it follows from (2.6) that the denominator is positive so that $\frac{dx_i}{dt_i} < 0$.

An analogous calculation yields:

$$\frac{dx_i}{dt_j} = \frac{-\frac{\partial^2 C_j}{\partial x_j \partial t_j}\frac{\partial^2 R_i}{\partial x_i \partial x_j}}{[\frac{\partial^2 R_i}{\partial x_i^2} - \frac{\partial^2 C_i}{\partial x_i^2}][\frac{\partial^2 R_j}{\partial x_j^2} - \frac{\partial^2 C_j}{\partial x_j^2}] - \frac{\partial^2 R_j}{\partial x_j \partial x_i}\frac{\partial^2 R_i}{\partial x_i \partial x_j}} \tag{2.21}$$

By assumptions (2.2) and (2.7), the nominator is positive while it follows from (2.6) that the denominator is positive so that $\frac{dx_i}{dt_i} < 0$. □

Proof of Proposition 1

At $\gamma = 0$, emissions cause no damage and the good dictator's problem essentially collapses to the pure rent shifting game between the governments, and the emission tax is *de facto* an export tax. As Brander and Spencer (1985) have shown, the equilibrium policy in the rent shifting game is an export subsidy, which translates into an emission subsidy in our model. Even ruling out the possibility of an emission subsidy, the equilibrium policy for good dictators at $\gamma = 0$ is a zero tax, while Leviathans would still set a strictly positive tax. Note that the Leviathan equilibrium emission tax is independent of γ, while the emission tax in the good dictator case is increasing in γ. Hence, above a threshold level of γ, which we denote by $\underline{\gamma}$, the good dictator equilibrium emission tax is higher than in the Leviathan case.

(a) If $\gamma < \underline{\gamma}$, emission taxes in the Leviathan equilibrium, are lower than in the good dictator equilibrium. Lemma 2 shows that in the good dictator case, emission taxes are below the jointly optimal level t^*. Hence, the Leviathan taxes being even below the good dictator taxes yield a lower welfare.

(b) If $\gamma > \underline{\gamma}$, emission taxes in the Leviathan equilibrium, are higher than in the good dictator equilibrium. This is a necessary but not sufficient condition for the Leviathan case to be welfare superior. If the Leviathan taxes exceed the jointly optimal level t^* by a sufficient margin, welfare under good dictators is higher. Hence, if and only if γ is higher than $\underline{\gamma}$, but lower than a critical value $\overline{\gamma}$, the Leviathans yield a higher welfare than good dictators in equilibrium.

□

Proof of Proposition 2

If governments are run by Leviathans, emission taxes under an IEA are always higher than in the Nash-case, and, in both cases, taxes are independent of environmental damage. However, the jointly optimal emission tax t^* is increasing in the harmfulness of emissions γ. Hence, the relative positions of the cooperative, non-cooperative and jointly optimal emission taxes are determined by γ. It follows that below a critical value γ^c, the Nash-emission tax yields a higher welfare than the taxes under an IEA. □

Proof of Proposition 3

Straightforward calculation yields firm output in the symmetric equilibrium of the Cournot-Nash game, i.e. the third stage of the game, as function of the home and foreign emission tax

$$x_i = \frac{(\alpha - c - 2t_i + t_j)}{3} \tag{2.22}$$

Welfare-maximizing policy makers solve the following problem

$$\max_{t_i} W_i = \pi_i + t_i e_i - \gamma D(e_i) = (\alpha - x_i - x_j - c + t_i)x_i - \gamma x_i^2 \tag{2.23}$$

Substituting (2.22) into the first-order conditions of the above problem and simplifying yields the equilibrium tax rate t^{NL}. Substituting t^{NG} back into (2.23) gives welfare for the case where both governments delegate emission policy to welfare-maximizing policy makers

$$W^{NG} = \frac{2(a-c)^2(1+2\gamma)}{(5+4\gamma)^2} \tag{2.24}$$

Revenue-maximizing policy makers solve the following problem

$$\max_{t_i} R_i = t_i e_i = t_i x_i \tag{2.25}$$

Substituting (2.22) into the first order conditions of the above problem and simplifying yields the equilibrium tax rate t^{NL}. Substituting t^{NL} back into (2.25) gives welfare for the case where both governments delegate emission policy to revenue maximizing policy makers

$$W^{NL} = -\frac{2}{81}(a-c)^2(2\gamma - 5) \tag{2.26}$$

If country i delegates emission policy to a revenue-maximizing policy maker and country j to a welfare-maximizing policy maker, welfare in the asymmetric equilibrium corresponds to

$$W_i^{NA} = -\frac{2(a-c)^2(2\gamma-5)(1+4\gamma)^2}{(17+28\gamma)^2} \tag{2.27}$$

$$W_j^{NA} = \frac{50(a-c)^2(1+2\gamma)}{(17+28\gamma)^2} \tag{2.28}$$

Comparing (2.24), (2.26), (2.27), and (2.28), it becomes clear that the ratio of welfare in the various equilibria depends only on γ. If both countries delegate emission tax policy to revenue-maximizing policy maker, welfare is higher than in the case where both countries choose welfare-maximizing policy makers if and only if $\frac{W^{NL}}{W^{NG}} > 1$. Hence, for $\gamma < 1$, Leviathans yield higher welfare. The critical values for γ defining the game theoretic nature of the delegation game can similarly be calculated by solving $\frac{W^{NL}}{W_j^{NA}} = 1$ and $\frac{W^{NG}}{W_i^{NA}} = 1$ for γ. $\square$

Chapter 3

Unilateral climate policy and optimal containment in an open economy

Co-authored with Frank Krysiak

Abstract

Without a broad international agreement, climate policy is less effective, due to carbon leakage, and more costly, due to causing unemployment and a loss of competitiveness on international markets. We investigate whether these negative effects can be addressed by partially containing the policy's effects to intermediate goods sectors, such as electricity or transportation services. We use a three-sector model to study a policy that taxes emissions caused by intermediate goods production while subsidizing the intermediate good. We show that such containment is second-best for combating carbon leakage, maintaining international market positions, and can reduce climate-policy-induced unemployment.

3.1 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 notable emission reductions, and it seems unlikely that binding emission constraints will be accepted by the majority of emitters within the next years.

Despite this lack of global action, some governments pursue an active climate policy. 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 domestic pressure.

Three arguments are frequently used to question the value of a unilateral climate policy. First, such a policy is seen as ineffective, because costly emission constraints will drive emission-intensive industries to less active countries, so that national emission reductions will be partially compensated by emission increases in other countries (carbon leakage). Second, in the presence of labor market imperfections, national emission reductions 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 can become less competitive, so that favorable trade positions can 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.

[1] To avoid awkward terminology, we refer to a national climate policy that is enacted outside the context of a global agreement including 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.

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 policy with tariffs or export subsidies could mitigate the negative effects of unilateral action. However, by the WTO Agreement on Subsidies and Countervailing Measures, export subsidies are generally outlawed, while import tariffs on many goods categories are bound or even cut to zero by the agreements of the Uruguay Round, and national leeway for tariffs might be further reduced once the Doha Round is concluded. The legality of alternative trade measures such as border tax adjustments for energy inputs is disputed, and thus their applicability remains controversial and uncertain.

Therefore, the literature focuses on less direct measures. The most frequently discussed option is to differentiate climate policy between sectors that are open to international trade and those that are not. Such policy differentiation is reasonable from a national perspective, although it induces inefficiencies, (Hoel, 1996; Withagen et al., 2007).

However, policy differentiation is not a universally applicable solution. A substantial part of emissions is not directly caused by final goods sectors. Rather, it results from the production of intermediate goods, and many export industries are affected more by climate policy via increasing prices of these goods than via 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. Policy differentiation is not feasible if sectors that differ with regard to their exposure to international competition do not directly

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

cause emissions but rather contribute to a country's emissions by using emissions-intensive intermediate goods. It is not possible to differentiate an emission tax levied in an intermediate goods sector according to where the intermediate good is used in final goods production. Thus, the benefits of adjusting emission taxes to the exposure to international competition cannot be reaped.

But, as markets for important emission-intensive intermediate goods, such as electricity or transportation services, are often national, it is possible 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 inducing abatement, such as the use of more efficient power plants, wind or solar energy) and to subsidize electricity to shield final goods production from increasing electricity prices (thereby reducing the negative side effects of unilateral climate policy).

Such a policy induces inefficiencies and alters the dynamic incentives of climate policy. But it could be a reasonable tool for a transitory climate policy until broad international agreements are reached.

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 concepts 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 a small open economy to investigate whether interventions in an intermediate goods market are a reasonable way to alleviate the side effects of unilateral climate policy. Our setup consists of a general equilibrium model of a three-sector economy. One sector produces an intermediate good and is environmentally regulated, and the two other sectors produce final goods with one sector being open to international trade and one sector producing solely for the home country's internal market. 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.

In this setup, we consider the above three arguments against unilateral climate policy and show that each of the 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. Typically, it consists of an emission tax and a subsidy on the intermediate good.[3] Except for the case of maintaining market power, the optimality of intervening in the intermediate goods market is not due to strategic behavior.

In the following section, we briefly review the related literature. Then we set up our model. In Section 3.4, we derive the optimal policy and analyze how our approach relates to the concept of policy differentiation. Section 3.5 concludes the paper.

3.2 Review of the Literature

Our study relates to three distinct strands of literature. The first of these is the literature on optimal policies in the presence of distortions such as factor immobility,

[3] In the case of maintaining market power, it can be optimal to tax the intermediate good.

wage rigidity, or 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 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) investigate 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 minimum domestic 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,[4] 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

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

climate policy unilaterally. Both Hoel (1996) and Withagen et al. (2007) find 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 both carbon leakage and 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 to analyze the effects of unilateral climate policies. Böhringer and Rutherford (2002) study sectorally differentiated tax regimes, and Dessus and O'Connor (2003) estimate ancillary benefits from unilateral climate policy in Chile. Carbone et al. (forthcoming) study a setting where countries set nationally optimal emission targets and can afterwards trade emission rights internationally. Surprisingly, substantial emissions reductions can be achieved in this way.

Finally, Copeland and Taylor (2005) explore a general equilibrium model with many countries and demonstrate that 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.[5] 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 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 even entirely offsetting the tax-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.

3.3 The Model

We consider a small open economy that consists of three sectors. One sector provides an intermediate good, like electricity or transportation services, that is used for production in two final goods sectors. One of the final goods is traded internationally, whereas the other is a domestic good. This vertical model structure where the product of the upstream industry is not traded internationally resembles the setup of Hamilton and Requate (2004), who study strategic environmental

[5]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).

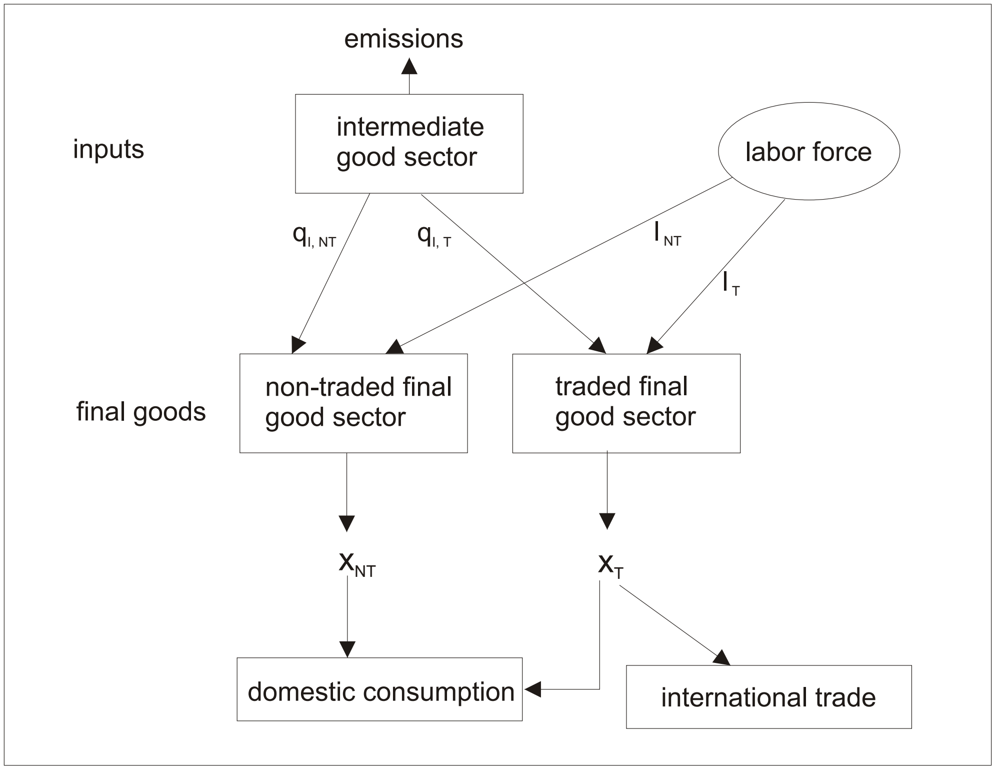

Figure 3.1: The Model structure

policy.

Figure 3.1 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 above mentioned final good with national and foreign products being perfect substitutes. Furthermore, the resources needed to produce the intermediate good (such as fossil fuels) are imported. All other markets are national.

Greenhouse gas emissions arise only in the intermediate goods sector, which is consequently the subject of environmental regulation. In industrialized countries, a large fraction of greenhouse gas emissions results from the production of intermediate goods like electricity generation and transportation services.[6] For instance, trucks, that are mainly used for commercial 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).[7] Thus emissions from intermediate goods production are indeed quantitatively important. Furthermore, as we show in Section 3.4.4, our main conclusions remain valid in more general settings.

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

The emission tax leads to a higher price of the intermediate good (e.g., 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, and the feasibility of border tax adjustments is uncertain, we consider an accompanying intervention in the intermediate goods

[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.

[7]These intermediate goods are usually traded mostly 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).

market.[8]

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

$$c_I(q_I, a_I) = c_P(q_I) + q_I c_A(a_I), \tag{3.1}$$

where q_I denotes output, a_I is abatement, and $c_P, c_A : \mathbb{R}_+ \to \mathbb{R}_+$ are twice differentiable, strictly increasing cost functions with $c_P(0) = c_A(0) = 0$. Emissions are given by $e = q_I(\bar{\epsilon} - a_I)$. Thus $c_A(a_I)$ are the costs of reducing emissions per unit of production from their baseline level $\bar{\epsilon}$, whereas $c_P(q_I)$ are the production costs in the absence of abatement. We assume that c_A is a strictly convex function, whereas c_P might be linear (which implies constant returns to scale) or strictly convex (implying decreasing returns to scale).[9]

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. In 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 goods sectors by production functions that depend on the quantity of the intermediate good and labor. The production functions are given by $f_{NT}(l_{NT}, q_{I,NT}) : \mathbb{R}^2_+ \to \mathbb{R}_+$, for the non-trading sector, and by $f_T(l_T, q_{I,T}) : \mathbb{R}^2_+ \to \mathbb{R}_+$, for the trading sector. The variables

[8]Such an intervention conforms to WTO rules, as the policy subsidizes the domestic use of the intermediate good. Even if a fraction of the intermediate good is imported or exported, the intervention causes no distortion of international trade in the intermediate good, because the subsidy would not differentiate between imports and domestic production and would not be paid for exports.

[9]c_P could also be a strictly concave function, corresponding to increasing returns to scale. In this case, the second-order conditions need to be analyzed to assure that the optimal policy does indeed correspond to a welfare maximum. This will hold, as long as the curvature of c_P is not too large, that is, as long as the scale effect is not too strong.

l_T, l_{NT} denote the labor inputs of the final goods sectors and $q_{I,T}, q_{I,NT}$ are the quantities of the intermediate good used there. We assume that the production functions exhibit constant returns to scale and 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

$$l_{NT} + l_T = \bar{L}. \tag{3.2}$$

The climate policy consists of 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 final goods 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.

We do not impose a budget constraint on the policy and do not account for inefficiencies caused by raising the necessary revenue to cover a potential gap between the expenditures for the subsidy and the revenue of the emission tax. In effect, this amounts to assuming that profits gained by the policy are spent for a lump-sum transfer to the households, whereas incurred losses are covered by a lump-sum tax. This assumption is for presentational simplicity only; it does not affect our main conclusions. As the policy induces a tax revenue, it is always possible to have a strictly positive subsidy. Thus in a budget-neutral policy, the optimal subsidy is either the subsidy that we derive in the following sections (if it can be financed) or the maximum subsidy that can be financed by the tax revenue.

The firms in the intermediate goods sector maximize their profit

$$\pi_I = (p_I + \sigma) q_I - c_P(q_I) - q_I c_A(a_I) - \tau q_I(\bar{\epsilon} - a_I), \tag{3.3}$$

leading to

$$p_I = c'_P(q_I^*) - \sigma + c_A(a_I^*) + \tau(\bar{\epsilon} - a_I^*), \tag{3.4}$$

$$\tau = c'_A(a_I^*). \tag{3.5}$$

Total emissions are given by $e = q_I^*(\bar{\epsilon} - a_I^*)$. With Eqs. (3.3)–(3.5), we get

$$\tau = c'_A\left(\bar{\epsilon} - \frac{\tilde{e}}{q_I^*}\right), \tag{3.6}$$

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

$$q_I^* = q_{I,T}^* + q_{I,NT}^*, \tag{3.7}$$

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

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

$$p_I = p_{NT}\frac{\partial f_{NT}(l_{NT}, q_{I,NT})}{\partial q_{I,NT}}, \tag{3.8}$$

$$w = p_{NT}\frac{\partial f_{NT}(l_{NT}, q_{I,NT})}{\partial l_{NT}}, \tag{3.9}$$

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

$$p_I = p_T\frac{\partial f_T(l_T, q_{I,T})}{\partial q_{I,T}}, \tag{3.10}$$

$$w = p_T\frac{\partial f_T(l_T, q_{I,T})}{\partial l_T}, \tag{3.11}$$

where p_T is the international price of the traded good. Instead of using a numeraire, we normalize prices so that $p_I + p_T + p_{NT} + w = 1$.

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

$$p_T y_T + p_{NT} y_{NT} \leq p_T f_T(l_T, q_{I,T}) + p_{NT} f_{NT}(l_{NT}, q_{I,NT}) - c_P(q_I) - q_I c_A(a_I). \tag{3.12}$$

To gain a reference point, we first consider a 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 emission target $\tilde{e}$ is the emission tax* (3.6) *without an accompanying measure (i.e., $\sigma^* = 0$).*

Proof. Maximizing $U(y_T, y_{NT})$ under the budget constraint (3.12), the market clearing constraints (3.2), (3.7), and $y_{NT} = f_{NT}(l_{NT}, q_{NT})$ with regard to y_T, y_{NT}, l_T, $q_{I,T}$, l_{NT}, $q_{I,NT}$, q_I and a_I yields first-order conditions that equal Eqs. (3.4)–(3.5), (3.8)–(3.11) for $\sigma = 0$. The necessary tax to meet the target $\tilde{e}$ follows from (3.6). □

3.4 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. In the following sections, we inquire whether the problems of carbon leakage, induced unemployment, and loss of a favorable trade position can be reduced by a (partial) containment of the effects of climate policy to the intermediate goods sector.

3.4.1 Reducing Carbon Leakage

The causes and the magnitude of carbon leakage have been extensively discussed in the literature (e.g. 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. But they facilitate a clear separation of the intervention incentives attributable to carbon leakage from those related to terms-of-trade effects.

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

$$E = (Y_T + y_T - f_T(l_T, q_{I,T}))\,\bar{q}_T\bar{\epsilon} + \tilde{e} + E^{NT,F}. \tag{3.13}$$

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

To assess the costs caused by carbon leakage, we assume that the home country benefits from the decreasing global emissions via 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 $E \in \mathbb{R}_+$. As is standard, we subtract this damage from our measure of national welfare and assume that 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*[10] $\left.\frac{\partial U(y_T, y_{NT})}{\partial y_T}\right|_{y_T^*, y_{NT}^*} > d'(E^*)\bar{q}_T\bar{\epsilon}$. *Then, from a national perspective, it is optimal to subsidize the intermediate good. The optimal subsidy is*

$$\sigma^* = \frac{d'(E^*)\,\bar{q}_T\,\bar{\epsilon}\,p_T}{\left.\frac{\partial U(y_T, y_{NT})}{\partial y_T}\right|_{y_T^*, y_{NT}^*} - d'(E^*)\,\bar{q}_T\,\bar{\epsilon}} \cdot \left.\frac{\partial f_T(l_T, q_{I,T})}{\partial q_{I,T}}\right|_{l_T^*, q_{I,T}^*}. \tag{3.14}$$

The necessary tax τ to constrain total national emissions to $\tilde{e}$ is given by Eq. (3.6).

Proof. See Appendix. □

So, in the case of unilateral climate policy, it is optimal to subsidize the intermediate good. This is intuitive, because there are two 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 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.

[10] This condition assures that it is socially optimal to consume the traded good.

The optimal subsidy is easily interpretable. The numerator depicts the reduction in damage, if an additional unit of the traded 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-goods sector. The denominator equals the marginal social value of increased consumption normalized by the price of the traded good.[11]

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

$$\frac{\partial(x_T - y_T)}{\partial\sigma} = \frac{c_A(a_I) + c'_P(q_{I,T} + q_{I,NT})}{p_I c''_P(q_{I,T} + q_{I,NT})}. \tag{3.15}$$

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

$$\frac{\partial B}{\partial\sigma} = -\frac{\sigma - \tau(\bar{\epsilon} - a_I)}{c''_P(q_{I,T} + q_{I,NT})}. \tag{3.16}$$

With the optimal tax and subsidy, we get

$$d'(E^*)\,\bar{\epsilon}\,\bar{q}_T \frac{\partial(x_T - y_T)}{\partial\sigma} + \frac{\partial U(y_T, y_{NT})}{\partial y_T}\frac{\partial B}{\partial\sigma} = 0. \tag{3.17}$$

So the optimal subsidy balances its positive effects on the damage through less carbon leakage with its negative effect on utility via reduced national income. The reduction in national income stems from the inefficient factor allocation induced by the subsidy. Due to the subsidy, the final goods sectors calculate with a price of the intermediate good that does not reflect the marginal costs of supplying this good. Consequently, they use a socially suboptimal factor combination, which reduces national income.

The optimal subsidy does not directly depend on the production or the price

[11] The marginal damage is subtracted, because the policy results only in a second-best allocation. The price of the traded good is not influenced, so that consumers do not take the damage caused by increased consumption into account.

of the non-traded good, because there are no distortions in this sector and, due to its seclusion from international trade, it is not an apt vehicle for reducing carbon leakage. However, the non-traded goods sector indirectly affects the optimal subsidy via the sectoral factor allocation.

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 Eq. (3.14) 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 optimal not to intervene in the intermediate goods market.

The optimality of subsidizing the intermediate good is also not due to the national emission target being exogenous. Optimizing national welfare (including the national damage caused by national emissions and carbon leakage) with regard to (t, σ) without a fixed emission target leads to an optimal subsidy again given by Eq. (3.14) and $\tau = d'(E^*)p_T/((\partial U(y_T, y_{NT})/\partial y_T) - d'(E^*)\bar{q}_T\bar{\epsilon})$. In this case, 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.

The type of intervention studied here results in only a second-best outcome. A first-best result would be achievable by a tariff/export subsidy on the traded final good.[12] Such an intervention would increase domestic production of the traded good and decrease its domestic consumption without interfering with the optimal factor combination. However, such a policy is infeasible under WTO rules.

Finally, carbon leakage can also be caused by declining prices for fossil fuels induced by emission limits in the home country. As we consider a small open economy, this type of carbon leakage is not covered by our analysis. However, the containment strategy would also be helpful in this case, as it increases production

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

of the intermediate good (and thus domestic fossil fuel consumption) compared to a single-instrument policy.

3.4.2 Market Distortions and Policy-Induced Unemployment

Another reason for using a policy mix are national market imperfections, such as price rigidities, factor immobility, or pre-existing market interventions. As unilateral climate policy is often criticized for being likely to lead to unemployment, we shall discuss a simple case of wage rigidities. The wage cannot adjust downward, so that a climate policy that reduces the marginal productivity of labor causes unemployment.

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 3.2, 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 the latter literature in that there are no pre-existing interventions; the economy is in an efficient equilibrium before the introduction of the climate policy. Our approach differs from the former 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.

In our case, an emission tax increases the price of the intermediate good, which in turn induces a decline in the marginal productivity of labor, resulting in unemployment. A subsidy on the intermediate good could be used 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 climate policy. Then the optimal policy* (τ^*, σ^*) *consists of the tax* (3.6) *and the following subsidy*

$$\sigma^* = \min\{\frac{l_T^*}{q_T^*}\bar{w}, c_A(a_I^*) + \tau^*(\bar{\epsilon} - a_I^*)\}. \tag{3.18}$$

Proof. See Appendix. □

So, if 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 can 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 optimal, if the traded 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 is the case, if the traded-goods 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 and feasible 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 suggests that if such a sub-

[13] There can be situations, where a subsidy on labor is not politically feasible. For instance, subsidizing labor can be costly, because the total labor force has 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 much smaller expenditures.

sidy is used for other reasons, for example to reduce carbon leakage, there is the additional benefit that it reduces unemployment.

3.4.3 Maintaining Market Power

If the country committed to a reduction in greenhouse gas emissions is a large supplier or demander of the traded good, then changes of the net excess demand for that good will influence world prices. In the context of our model, this means that unilateral climate policy indirectly changes the terms of trade by causing a reallocation of factors between the non-traded-goods and the traded-goods sector and thereby leads to changes in production. 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 had already been in place before the implementation of the emission target, this intervention would no longer be optimal and would need to be updated.

For analyzing the large country case, we need to slightly modify the model developed in Section 3.3 by altering the budget constraint (3.12) to

$$\begin{aligned} p_T(m_T)y_T + p_{NT}y_{NT} \leq\ & p_T(m_T)f_T(l_T, q_{I,T}) + p_{NT}f_{NT}(l_{NT}, q_{I,NT}) \\ & - c_P(q_I) - q_I c_A(a_I). \end{aligned} \tag{3.19}$$

where $m_T := x_T - y_T$ is the country's net excess demand for the traded good and where $p_T(m_T)$ is the international price in dependency on this excess demand.

We assume that although the country's export industry is large in the aggregate, each individual firm is small and thus acts under perfect competition. Hence, the incentives for adjusting the terms of trade are located on the government level not the firm level.

In principle, "optimization" of the terms of trade should take the form of direct trade measures such as export or import tariffs. Thus, 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, ruling out direct trade intervention, the government has an incentive to use an intervention in the intermediate goods sector as a secondary trade policy instrument. This is shown in the following proposition.

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

$$\sigma^* = m_T^* \, p_T'(m_T^*) \cdot \left. \frac{\partial f_T(l_T, q_{I,T})}{\partial q_{I,T}} \right|_{l_T^*, q_{I,T}^*} \tag{3.20}$$

The necessary tax to constrain total national emissions to $\tilde{e}$ is given by Eq. (3.6).

Proof. See Appendix. □

Proposition 3 shows that the sign of the optimal intervention in the intermediate goods sector depends on the sign of m_T, that is, on whether the country is a net importer or exporter of the final good. In our case, the budget constraint (3.19) implies that the country exports the traded good, as the resources for the production of the intermediate good are imported. Thus 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 power in trade is an export tax.[14] As the intervention on the intermediate goods sector is used as a substitute for such a direct measure, the optimal intervention analogously contracts supply.

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 in the price of the intermediate good and thus to factor reallocation, the magnitude of the optimal intervention is indirectly dependent on the emission

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

target. Hence, setting an emission ceiling on the intermediate goods sector renders a previously optimal intervention suboptimal. In fact, the introduction of an emission tax will lead to a decrease in the size of the optimal intervention, as the emission tax is a substitute for the tax on the intermediate good.

The optimal intervention is neither equal nor equivalent to the optimal trade tariff, that is, to the inverse of the export demand supply elasticity,[15] due to two reasons. First, the output of the intermediate sector is an input in both final goods sectors. Hence, the intervention affects not only the production of the traded good as would be the case for a trade tax, but also changes output of the non-traded good. The reallocation of factors that leads to this change in output is inefficient, and thus comes at the cost of a decrease in national income. However, this loss is outweighed by an increase in national income due to the favorable change of the terms of trade. Second, a tax on a trading-sector input is an indirect measure as understood in the policy-targeting literature (see, e.g., Bhagwati and Ramaswami (1963), and Bhagwati and Srinivasan (1969)) and thus an inefficient instrument for the exploitation of monopoly 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, this section has shown that it can be optimal not only to subsidize the intermediate good but also to tax it. Thus if carbon leakage, unemployment, and market power are simultaneously important in devising a unilateral climate policy, it is not obvious whether the intermediate good should be subsidized or taxed. However, some intervention in the intermediate goods market is optimal in most cases. Furthermore, we have only considered a simple case of a large open economy, where the good in question is always an export good. In many cases, large countries have monopsony power in important markets. In such cases, the optimal intervention is a subsidy on the intermediate good (cf. Eq. (3.20)), so that

[15] Of course, the optimal intervention is not independent of the price elasticity of export demand. To see this, divide nominator and denominator of (3.20) by $p_T(m_T^*)$ to get $\sigma^* = p_T(m_T^*) \cdot \left.\frac{\partial f_T(l_T, q_{I,T})}{\partial q_{I,T}}\right|_{l_T^*, q_{I,T}^*} \frac{1}{\rho}$ where ρ corresponds to the elasticity. For $\rho \to -\infty$, the optimal intervention becomes zero, as the terms-of-trade effect of the intervention vanishes.

the direction of the intervention is clear, even if several intervention incentives apply simultaneously.

3.4.4 Differentiation or Containment?

Our analysis has shown that (partially) containing the effects of climate policy to the intermediate good sector is a reasonable strategy to combat negative side effects of a unilaterally enacted policy, such as carbon leakage or unemployment. A different approach to counter these effects is the policy differentiation analyzed in Hoel (1996) and Withagen et al. (2007). As we have argued in the introduction, the concepts of policy differentiation and containment are applicable in different settings; policy differentiation if trading and non-trading sectors cause emissions directly, containment if trading sectors contribute to overall emissions mainly by using emission-intensive intermediate goods as inputs in their production processes.

In most applications, there is a mixture of these cases: A part of emissions originates directly from final goods production and another part stems from the production of intermediate goods. Thus an important question arises: Which of these concepts should be used?

To analyze this question, we extend our model. We introduce a fourth sector that produces a final good, that directly causes emissions, and that is open to international trade. For simplicity, we assume that this sector is an export-only sector; that is, its product is not consumed within the country. Out of the three reasons for containment investigated in the preceding sections, we consider the case of carbon leakage, because carbon leakage is widely discussed in the literature and provides an important reason for policy differentiation. Thus we compare our concept of containment to a case of policy differentiation that is similar to the one discussed in Hoel (1996).

We model production possibilities in the fourth sector with a production function $f_R(l_R, e_R) : \mathbb{R}^2_+ \to \mathbb{R}_+$ that depends on the amount of labor l_R allocated to this sector and the emissions e_R of this sector. We assume that this production function exhibits constant returns to scale, is twice differentiable, strictly concave, and strictly increasing in both inputs. Again, we use the small-open-economy assumption; that is, the price p_R for the fourth sector's output is given and fixed. The constraint for labor supply becomes $l_{NT} + l_T + l_R = \bar{L}$, the budget constraint is

$$p_T y_T + p_{NT} y_{NT} \leq p_T f_T(l_T, q_{I,T}) + p_{NT} f_{NT}(l_{NT}, q_{I,NT}) + p_R f_R(l_R, e_R) \\ - c_P(q_I) - q_I c_A(a_I), \tag{3.21}$$

and total emissions are given by

$$E = (Y_T + y_T - f_T(l_T, q_{I,T}))\, \bar{q}_T \bar{\epsilon} + (Y_R - f_R(l_R, e_R))\, \bar{\epsilon}_R + \tilde{e} + E^{NT,F}. \tag{3.22}$$

Here, Y_R denotes global demand for the fourth sector's good, and foreign production of this good causes $\bar{\epsilon}_R$ units of emission per unit of output. Note that we now have a double carbon leakage effect: In both the traded final goods sector and the fourth sector, climate policy can induce a shift of production to foreign countries and thus an increase in foreign emissions.

To investigate the relation between policy differentiation and containment, we introduce an emission tax τ_R levied on emissions in the fourth sector that can differ from the tax τ charged for emissions in the intermediate goods sector. Under these assumptions, profit maximization in the fourth sector leads to

$$w = p_R \frac{\partial f_R(l_R, e_R)}{\partial l_R}, \tag{3.23}$$

$$\tau_R = p_R \frac{\partial f_R(l_R, e_R)}{\partial e_R}. \tag{3.24}$$

The following proposition shows that, in this setup, it is optimal to use policy differentiation and containment simultaneously.

Proposition 4. *Assume that*[16] $\left.\frac{\partial U(y_T,y_{NT})}{\partial y_T}\right|_{y_T^*,y_{NT}^*} > d'(E^*)\bar{q}_T\bar{\epsilon}$. *Then, from a national perspective, it is optimal to subsidize the intermediate good and to differentiate the emission taxes.*

The optimal subsidy is given by

$$\sigma^* = \frac{d'(E^*)\,\bar{q}_T\,\bar{\epsilon}\,p_T}{\left.\frac{\partial U(y_T,y_{NT})}{\partial y_T}\right|_{y_T^*,y_{NT}^*} - d'(E^*)\,\bar{q}_T\,\bar{\epsilon}} \cdot \left.\frac{\partial f_T(l_T, q_{I,T})}{\partial q_{I,T}}\right|_{l_T^*,q_{I,T}^*}. \tag{3.25}$$

The optimal taxes to constrain total national emissions to $\tilde{e}$ *are*

$$\tau^* = c_A'\left(\bar{\epsilon} - \frac{\tilde{e} - e_R^*}{q_I^*}\right), \tag{3.26}$$

$$\tau_R^* = \tau^*\left(1 - \frac{d'(E^*)\,\bar{q}_T\,\bar{\epsilon}}{\left.\frac{\partial U(y_T,y_{NT})}{\partial y_T}\right|_{y_T^*,y_{NT}^*}}\right) + d'(E^*)\bar{\epsilon}_R\frac{p_R f_R(l_R^*, e_R^*)}{e_R^*} \cdot \frac{\frac{\bar{\epsilon}\bar{q}}{\bar{\epsilon}_R} - \frac{p_T}{p_R}}{\left.\frac{\partial U(y_T,y_{NT})}{\partial y_T}\right|_{y_T^*,y_{NT}^*}}. \tag{3.27}$$

Proof. See Appendix. □

So, it is optimal to combine containment and policy differentiation. Emissions that are caused directly by an exporting sector should be taxed differently from emissions that originate from intermediate goods production. In addition, the intermediate good should be subsidized.

This is due to the double carbon leakage effect. If emissions were identically taxed and if there was no subsidy, the emission constraint would shift production to foreign countries and thereby increase foreign emissions. As discussed in Section 3.4.1, the subsidy on the intermediate good helps to reduce this negative effect. In addition, policy differentiation is useful for two reasons. First, emissions in the fourth sector are directly linked to exports (thus causing carbon leakage), whereas a part of the intermediate good is used in the production of the non-traded

[16] Again, this condition assures that it is optimal to consume the traded good.

final good (where there is no carbon leakage). This provides an incentive to tax these emissions differently.[17] Second, the subsidy on the intermediate good reduces the impact of the emission tax in this sector on carbon leakage, whereas no such attenuating measure exists in the fourth sector. Again, this renders policy differentiation reasonable.

Whether the optimal tax τ_R^* on emissions in the fourth sector is smaller or greater than that on emissions in the intermediate goods sector (τ^*) depends on the relative strength of the two carbon leakage effects (i.e., on $\bar{\epsilon}\,\bar{q}_T$ and $\bar{\epsilon}_R$), on the relative prices of the outputs, and on the emission intensity in the fourth sector. Analyzing (3.27) shows that we have $\tau_R < \tau$ if and only if $p_R < \tau^* \frac{e_R^*}{f_R(l_R^*, e_R^*)} + p_T \frac{\bar{\epsilon}_R}{\bar{\epsilon}\bar{q}_T}$. If the price of the fourth sector's output is small compared to the price of the traded final good, or if foreign production of the fourth sector's product causes much higher emissions per unit than foreign production of the traded final good, then the emissions in the fourth sector should be taxed less strongly than emissions in intermediate goods production.

Finally, it is instructive to compare this policy mix to the case where there is a fourth sector but where policy differentiation is not used. As can be easily shown, the optimal policy in the latter case consists of the tax (3.26) and the subsidy (3.25). Thus we get the same characterization of the optimal subsidy and the tax as in the case with policy differentiation,[18] only the tax is now applied to all emissions.

3.5 Conclusions

Theoretically, climate policy should be globally coordinated. But, in practice, such coordination is still lacking. In this paper, we have analyzed a unilateral cli-

[17]This effect is comparable to differentiating an emission tax between sectors with differing exposure to international competition and thus with differing shifts of production to foreign countries in response to climate policy.

[18]Note that although the expressions are the same, the actual value of these policy instruments will differ, because these equations are evaluated at different equilibrium values of the endogenous variables.

mate policy that reduces the national costs of the policy while being compatible with international trade rules. This concept extends the main idea of policy differentiation to sectors where such differentiation is infeasible, such as intermediate goods production. It consists of (partially) containing the effects of climate policy to the production of an intermediate good that is emission intensive but not traded internationally. 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 and serve mainly internal markets. The optimal containment strategy uses an emission tax to induce abatement efforts and a product subsidy (or tax) to control the effects on other sectors. We have shown that such a policy might help to counter three 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. Furthermore, we have shown that, in a setup with sectors that contribute directly and indirectly to aggregate emissions, it is optimal to combine the approaches of policy differentiation and containment.

Our analysis complements the literature on policy differentiation by considering the case of industries that are only indirectly accountable for greenhouse gas emissions due to using an emission-intensive intermediate good. In this quantitatively 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 goods sector. As in Hoel (1996) and Withagen et al. (2007), the costs of being a front runner in climate policy can be reduced by using a policy mix. Such a policy mix induces 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 or unemployment, this containment is reasonable from a national perspective.

An important objection to intervening in the intermediate good market is that this reduces the incentives for adjustments in final goods production. Subsidizing electricity reduces the incentives to use more energy-efficient production equipment and hampers adjustments in labor allocation, that is, a reallocation of labor from sectors that are more affected by climate policy to less affected sectors. However, it seems likely that climate policy will be coordinated among the major emitters at some time in the future.[19] 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 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 international consensus is reached. Furthermore, as containment uses 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 containment on international negotiations. Our approach increases the effectiveness and decreases the costs of 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 in 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.[20] 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 blocks 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.

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

[20] For surveys, see Winters (1996) and Panagariya (1999).

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 an intermediate goods market, because it conforms to WTO rules, is easily implementable, and is able to address several 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 more sophisticated instruments, as these grant more degrees of freedom.

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Appendix

Proof of Proposition 1

As the policy is a second-best policy, we calculate the subsidy σ^* by assuming that all endogenous variables (i.e., $q_{I,NT}$, $q_{I,T}$, l_{NT}, l_T, a_I, p_I, p_{NT}, w) as well as τ^* (as implied by Eq. (3.6)) are functions of this policy measure. We maximize the utility of the representative individual minus the damage caused by global emissions with regard to σ under the constraints that (i) total consumption expenditures do not exceed national income; that (ii) consumption of the non-traded good equals production of this good; and that (iii) total labor supply matches total labor demand. Using $\frac{\partial U(y_T,y_{NT})/\partial y_T}{\partial U(y_T,y_{NT})/\partial y_{NT}} = \frac{p_T}{p_{NT}}$, which characterizes the optimal relative consumption levels of the representative individual, the first-order condition can be written as

$$\frac{\partial U(y_T, y_{NT})}{\partial y_T}\left((\sigma - (\bar{\epsilon} - a_I)\tau^*)\left(\frac{\partial q_{I,T}}{\partial \sigma} + \frac{\partial q_{I,NT}}{\partial \sigma}\right) + (q_T + q_{NT})\tau^* \frac{\partial a_I}{\partial \sigma}\right. \tag{3.28}$$

$$\left. -w\left(\frac{\partial l_{NT}}{\partial \sigma} + \frac{\partial l_T}{\partial \sigma}\right)\right) = d'(E)\bar{\epsilon}\bar{q}_{I,T}\left((p_I + \sigma - (\bar{\epsilon} - a_I)\tau^*)\right.$$

$$\left.\cdot\left(\frac{\partial q_{I,T}}{\partial \sigma} + \frac{\partial q_{I,NT}}{\partial \sigma}\right) + (q_T + q_{NT})\tau^* \frac{\partial a_I}{\partial \sigma}\right) - \nu p_T\left(\frac{\partial l_T}{\partial \sigma} + \frac{\partial l_{NT}}{\partial \sigma}\right)$$

where ν is the Lagrange coefficient of condition (iii) above.

To simplify this expression, we differentiate the characterization of firm behavior (Eqs. (3.4), (3.5), (3.6), (3.8),(3.10) and the zero-profit conditions for final goods sectors), the labor market constraint and our price normalization with respect to σ, taking the above mentioned endogenous variables as being functions of σ. After simplifying and exploiting constant returns to scale, we get the following expressions

$$\frac{\partial \tau^*}{\partial \sigma} = \frac{\tilde{e} c_A''}{\gamma (q_{I,T} + q_{I,NT})^2}, \qquad \frac{\partial a_I}{\partial \sigma} = \frac{1}{c_A''} \frac{\partial \tau^*}{\partial \sigma}, \tag{3.29}$$

$$\frac{\partial q_{I,T}}{\partial \sigma} = \frac{l_{NT}\, q_{I,T}}{(l_{NT}\, q_{I,T} - l_T\, q_{I,NT})\gamma}, \quad \frac{\partial q_{I,NT}}{\partial \sigma} = \frac{l_T\, q_{I,NT}}{(l_T\, q_{I,NT} - l_{NT}\, q_{I,T})\gamma}, \tag{3.30}$$

$$\frac{\partial l_T}{\partial \sigma} = \frac{l_{NT}\, l_T}{(l_{NT}\, q_{I,T} - l_T\, q_{I,NT})\gamma}, \quad \frac{\partial l_{NT}}{\partial \sigma} = \frac{l_{NT}\, l_T}{(l_T\, q_{I,NT} - l_{NT}\, q_{I,T})\gamma}, \tag{3.31}$$

with $\gamma := ((\bar{\epsilon} - a_I)\tilde{e}\, c_A'' + (q_{I,T} + q_{I,NT})^2 c_P'')/(q_{I,T} + q_{I,NT})^2$. Substituting Eqs. (3.29)-(3.31) into Eq. (3.28) yields Eq. (3.14). By our convexity assumptions, a solution of Eqs. (3.6) and (3.14) is necessarily a welfare maximum. □

Proof of Proposition 2

We calculate the subsidy as above, but now the market clearing constraint for the labor market is only an inequality. The first order condition equals (3.28) with $d'(E) \equiv 0$ and $w = \bar{w}$. The Lagrange coefficient ν is zero, whenever the labor market constraint is not binding. Differentiating the characterization of firm behavior and the price normalization with regard to σ yields

$$\frac{\partial \tau^*}{\partial \sigma} = \frac{\tilde{e} c_A''}{\gamma (q_{I,T} + q_{I,NT})^2}, \tag{3.32}$$

$$\frac{\partial a_I}{\partial \sigma} = \frac{1}{c_A''} \frac{\partial \tau^*}{\partial \sigma}, \tag{3.33}$$

$$\frac{\partial l_T}{\partial \sigma} = \left(\frac{1}{\gamma} - \frac{\partial q_{I,NT}}{\partial \sigma} \right) \frac{l_T}{q_{I,T}}, \tag{3.34}$$

$$\frac{\partial l_{NT}}{\partial \sigma} = \frac{\partial q_{I,NT}}{\partial \sigma} \frac{l_{NT}}{q_{I,NT}}, \tag{3.35}$$

$$\frac{\partial q_{I,T}}{\partial \sigma} = \frac{1}{\gamma} - \frac{\partial q_{I,NT}}{\partial \sigma}, \tag{3.36}$$

with the same γ as above. To calculate $\partial q_{I,NT}/\partial \sigma$, we differentiate the characterization of the representative consumer's consumption bundle used in the preceding proof with respect to σ, substitute Eqs. (3.32)-(3.36) as well as the solution of the first order condition for σ with $\nu = 0$. This yields $\partial q_{I,NT}/\partial\sigma = 0$. Substituting all these conditions into the first order condition, shows that $\sigma^* = \bar{w}\, l_T/q_{I,T}$, if $\nu = 0$.

Whenever $\nu \neq 0$, the labor market constraint is binding. In this case, we get Eqs. (3.29)-(3.31), as in the preceding proof. Substituting these into the first-order condition (3.28) (with $d'(E) \equiv 0$), leads to $\sigma^* = 0$.

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 $\sigma = c_A(a_I) + \tau^*(\bar{\epsilon} - a_I)$, as this subsidy reduces the price of the intermediate good to its level without climate policy. Consequently, the subsidy is either given by $\sigma^* = \bar{w}\, l_T/q_{I,T}$ or by this upper bound. □

Proof of Proposition 3

We calculate the second-best intervention σ as above; only the price of the traded good is now a function of the exported amount of this good. The first-order condition is

$$\begin{aligned}
&\frac{\partial U(y_T, y_{NT})}{\partial y_T}\frac{\partial y_T}{\partial \sigma} + \frac{1}{p_T}\left(\frac{\partial U(y_T, y_{NT})}{\partial y_T}\left(p_I\frac{\partial q_{I,NT}}{\partial \sigma} + w\frac{\partial l_{NT}}{\partial \sigma}\right)\right) \\
&+ \lambda\left(\left(\frac{\partial q_{I,T}}{\partial \sigma} + \frac{\partial q_{I,NT}}{\partial \sigma}\right)(\sigma + p_I - \tau^*(\bar{\epsilon} - a_I)) + \tau^*\frac{\partial a_I}{\partial \sigma}(q_{I,T} + q_{I,NT})\right. \\
&\left.\left(1 + \frac{p_T'}{p_T}m_T\right)\left(\frac{\partial y_T}{\partial \sigma}p_T - \frac{\partial q_{I,T}}{\partial \sigma}p_I - \frac{\partial l_T}{\partial \sigma}w\right)\right) = \nu\left(\frac{\partial l_T}{\partial \sigma} + \frac{\partial l_{NT}}{\partial \sigma}\right),
\end{aligned} \tag{3.37}$$

where λ and μ are the Lagrange coefficients of the representative consumer's budget constraint and of the labor market constraint. From analyzing the consumer's optimization problem, we get $\lambda = -(\partial U(y_T, y_{NT}/\partial y_T)/(p_T + p'_T m_T)$.

Again, we differentiate the characterization of firm behavior, the labor market constraint, Eq. (3.6), and the price normalization with respect to σ and get, with exploiting the constant returns to scale assumptions, Eqs. (3.29)-(3.31). Substituting these expressions and that for λ into Eq. (3.37) yields Eq. (3.20). $\square$.

Proof of Proposition 4

Condition (3.26) for τ^* is the direct analogue to Eq. (3.6). We calculate the tax τ_R as well as the subsidy σ by assuming that all endogenous variables (i.e., $q_{I,NT}$, $q_{I,T}$, l_{NT}, l_T, l_R, e_R, a_I, p_I, p_{NT}, w) as well as he tax needed to implement the emission limit (τ^*) 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 (σ, τ_R) under the constraints that (i) total consumption expenditures do not exceed national income; that (ii) consumption of the non-traded good equals production of this good; and that (iii) total labor supply matches total labor demand. The first-order conditions are

$$
\begin{aligned}
&\frac{1}{p_T}\frac{\partial U(y_T, y_{NT})}{\partial y_T}\left(\tau_R\frac{\partial e_R}{\partial \sigma} - \tau^*(q_{I,T} + q_{I,NT})\frac{\partial a_I}{\partial \sigma} + w\left(\frac{\partial l_R}{\partial \sigma} + \frac{\partial l_T}{\partial \sigma} + \frac{\partial l_{NT}}{\partial \sigma}\right)\right. \qquad (3.38)\\
&\left.-\left(\frac{\partial q_{I,T}}{\partial \sigma} + \frac{\partial q_{I,NT}}{\partial \sigma}\right)(\sigma - \tau^*(\bar{\epsilon} - a_I))\right) - \frac{d'(E)}{p_T}\left(\bar{\epsilon}\,\bar{q}_T\left(\tau_R\frac{\partial e_R}{\partial \sigma} + w\frac{\partial l_R}{\partial \sigma}\right.\right.\\
&\left.-\tau^*(q_{I,NT} + q_{I,T})\frac{\partial a_I}{\partial \sigma} - \left(\frac{\partial q_{I,T}}{\partial \sigma} + \frac{\partial q_{I,NT}}{\partial \sigma}\right)(\tau^*(\sigma - \bar{\epsilon} - a_I))\right)\\
&\left.-\bar{\epsilon}_R\frac{p_T}{p_R}\left(\tau_R\frac{\partial e_R}{\partial \sigma} + w\frac{\partial l_R}{\partial \sigma}\right)\right) = \nu\left(\frac{\partial l_R}{\partial \sigma} + \frac{\partial l_T}{\partial \sigma} + \frac{\partial l_{NT}}{\partial \sigma}\right),
\end{aligned}
$$

$$\frac{1}{p_T}\left(-\left(\frac{\partial U(y_T,y_{NT})}{\partial y_T}\left(-\frac{\partial e_R}{\partial \tau_R}\tau_R - w\left(\frac{\partial l_R}{\partial \tau_R}+\frac{\partial l_{NT}}{\partial \tau_R}+\frac{\partial l_T}{\partial \tau_R}\right)\right)+p_T\,\nu\right.\right. \tag{3.39}$$

$$\cdot\left(\frac{\partial l_R}{\partial \tau_R}+\frac{\partial l_{NT}}{\partial \tau_R}+\frac{\partial l_T}{\partial \tau_R}\right)+\left(\frac{\partial q_{I,NT}}{\partial \tau_R}+\frac{\partial q_{I,T}}{\partial \tau_R}\right)\left(\frac{\partial U(y_T,y_{NT})}{\partial y_T}\left(\sigma-\tau^*\,\bar{\epsilon}\right)\right)$$
$$+\left(\frac{\partial U(y_T,y_{NT})}{\partial y_T}\right)\left(\left(\frac{\partial q_{I,NT}}{\partial \tau_R}+\frac{\partial q_{I,T}}{\partial \tau_R}\right)\tau^* a_I\;+\left(q_{I,NT}+q_{I,T}\right)\tau^*\frac{\partial a_I}{\partial \tau_R}\right)\Bigg)$$
$$+\frac{d'(E)}{p_R}\left(\bar{\epsilon}_R\,p_T\left(\frac{\partial e_R}{\partial \tau_R}\tau_R+\frac{\partial l_R}{\partial \tau_R}w\right)+\bar{\epsilon}\,p_R\,\bar{q}_T\left(\frac{\partial a_I}{\partial \tau_R}\left(q_{I,NT}+q_{I,T}\right)\tau^*\right.\right.$$
$$\left.\left.-\frac{\partial e_R}{\partial \tau_R}\tau_R-\frac{\partial l_R}{\partial \tau_R}w+\left(\frac{\partial q_{I,NT}}{\partial \tau_R}+\frac{\partial q_{I,NT}}{\partial \tau_R}\right)\left(\sigma+p_I+\tau^*(a_I-\bar{\epsilon})\right)\right)\right)=0$$

where ν is the Lagrange coefficient of condition (iii) above.

To simplify these expressions, we use the same approach as above (with the characterization of firm behavior in the fourth sector being used in addition) to get Eqs. (3.29)-(3.31) with the exception of $\partial\tau^*/\partial\sigma$ which now equals $\frac{(\tilde{e}-e_R)c''_A}{\gamma(q_{I,T}+q_{I,NT})^2}$ and with γ now being defined as $\gamma := ((e_R-\bar{\epsilon})^2\,c''_A+(q_{I,T}+q_{I,NT})^3c''_P)/(q_{I,T}+q_{I,NT})^3$. Furthermore, we get $\partial l_R/\partial\sigma=\partial e_R/\partial\sigma=0$. For the derivatives with regard to τ_R, the following expressions can be gained in the same way.

$$\frac{\partial a_I}{\partial \tau_R}=\frac{1}{c''_A}\cdot\frac{\partial \tau^*}{\partial \tau_R},\;\frac{\partial e_R}{\partial \tau_R}=\frac{\partial \tau^*}{\partial \tau_R}\cdot\frac{\gamma\,(q_{I,T}+q_{I,NT})}{c''_P\,c''_A} \tag{3.40}$$
$$\frac{\partial q_{I,T}}{\partial \tau_R}=\frac{\partial \tau^*}{\partial \tau_R}\cdot\frac{\gamma_T\,q_{I,T}}{(l_{NT}\,q_{I,T}-l_T\,q_{I,NT})\gamma\,c''_P\,c''_A}, \tag{3.41}$$
$$\frac{\partial q_{I,NT}}{\partial \tau_R}=\frac{\partial \tau^*}{\partial \tau_R}\cdot\frac{\gamma_{NT}\,q_{I,NT}}{(l_T\,q_{I,NT}-l_{NT}\,q_{I,T})\gamma\,c''_P\,c''_A}, \tag{3.42}$$
$$\frac{\partial l_T}{\partial \tau_R}=\frac{\partial \tau^*}{\partial \tau_R}\cdot\frac{\gamma_T\,l_T}{(l_{NT}\,q_{I,T}-l_T\,q_{I,NT})\gamma\,c''_P\,c''_A}, \tag{3.43}$$
$$\frac{\partial l_{NT}}{\partial \tau_R}=\frac{\partial \tau^*}{\partial \tau_R}\cdot\frac{\gamma_{NT}\,l_{NT}}{(l_T\,q_{I,NT}-l_{NT}\,q_{I,T})\gamma\,c''_P\,c''_A}, \tag{3.44}$$
$$\frac{\partial l_R}{\partial \tau_R}=\frac{\partial \tau^*}{\partial \tau_R}\cdot\frac{\gamma\,l_R\,(q_{I,T}+q_{I,NT})}{e_R\,c''_P\,c''_A}. \tag{3.45}$$

Again, we have $\gamma := ((e_R-\bar{\epsilon})^2\,c''_A+(q_{I,T}+q_{I,NT})^3c''_P)/(q_{I,T}+q_{I,NT})^3$ and we have defined $\gamma_T := (l_R q_{I,NT}(q_{I,T} + q_{I,NT})^2\gamma - e_R(\tilde{e} - e_R)l_{NT}c''_A)/(e_R(q_{I,T} + q_{I,NT}))$ and $\gamma_{NT} := (l_R q_{I,T}(q_{I,T}+q_{I,NT})^2\gamma - e_R(\tilde{e}-e_R)l_T c''_A)/(e_R(q_{I,T}+q_{I,NT}))$.

Substituting these expressions into Eqs. (3.38)-(3.39) yields conditions (3.25) and (3.27). $\square$

Concluding remarks and outlook

The results of the three papers comprising this thesis and their interpretations are presented in the Introduction and Summary sections. In my concluding remarks, I would like to draw attention to what is not part of the thesis, and to questions that were not addressed in the three papers and those that might arise from them. The objective here is not to summarize the technical or theoretical limitations of the various models and the implicit or explicit assumptions that they incorporate, but rather a policy-focused overview of the research fields that could not be touched upon in the papers themselves, since they were written under the constraints of scope and space imposed on research papers in economics intended for publication. In addition, I would like to suggest some promising new avenues of research for future investigations.

In the first chapter, it has been shown that international environmental agreements between a subset of affected parties could lead to a global welfare loss, although they (at least partially) internalize an externality. However, if all countries cooperate, an agreement would necessarily be globally efficient. This begs the question of whether small agreements will expand and ultimately comprise all countries, in which case potential initial welfare losses might be outweighed by future gains from global cooperation, or continue to remain exclusive and lock-in inefficient settings. If sub-global agreements harm outsiders to the benefit of insiders, the countries concluding the agreements might not be interested in their enlargement. Hence, the dynamic properties of partial agreements have to be properly understood in order to be able to assess whether they constitute stumbling blocks or building blocks on the road towards global cooperation. For this, a dynamic model of international negotiations between a large number of countries is needed. A dynamic extension of the coalition model that has found wide application in the analysis of international climate negotiations might be an appropriate tool for this task. Dynamic analysis of this kind would certainly be an interesting and highly challenging project for future research.

A further step towards applied research in this field could consist in quantifying the welfare effects accruing from existing IEAs. From a methodological point of view, CGE-modeling could be an adequate tool for such empirically-driven quantitative analyses.

In the second chapter, the effects of relaxing the assumption of purely welfare-maximizing governments have been analyzed in a strategic environmental policy setting. As an illustration, governments were assumed to behave as revenue maximizers. This, of course, is a highly stylized setting the aim being simplicity and the clearest possible exposition of the results. In a more complex setting, possibly consisting of a lobbying model or a principal-agent setup, it would be possible to depict more realistic and nuanced political decision-making processes. This in turn, would facilitate empirically-driven positive analysis of real-world issues.

Another extension of the second chapter could be the introduction of additional policy dimensions into the government's decisions. One possibility is to consider a general equilibrium model where governments set an array of taxes, and interaction effects, for instance, between income and environmental taxes are present. In such a context, the incorporation of more complex political decision-making processes that diverge from the assumption of a good dictator that simply maximizes welfare might lead to interesting results informing the double-dividend discussion.

Optimal unilateral climate policy has been analyzed in the third chapter. Just as an analysis of the dynamic properties of international agreements, the topic of Chapter 1, would carry the discussion forward, an exploration of the dynamic implications of unilateral action for international negotiations would represent a natural extension of the results presented in chapter 3. If more and more countries implement emission reductions unilaterally, this will certainly have an impact on the dynamic international incentive structure and on the likelihood of reaching a broad international climate agreement. Again, coalition theory might be part of a framework that allows to investigate how unilateral policy measures affect international climate agreements over time.

The third chapter also highlights some legal uncertainties in the field of environmental policy and international trade law. As numerous environmental policy measures impact on international trade, the question arises which of these are potentially actionable under the WTO agreements. Although recently some environmental economists have done research on these issues, more integrated and interdisciplinary work is needed in this field to clarify the feasible legal framework of unilateral climate policy.

Lebenslauf

Stefan Csordás wurde am 24.7.1981 in Innsbruck, Österreich als Sohn von Adam und Rajam Csordás, wohnhaft in Innsbruck, Österreich, geboren. Ebendort besuchte er von 1991-1999 das Akademische Gymnasium Innsbruck, wo er im Juli 1999 die Matura mit Auszeichnung ablegte. Nach Ableistung des Militärdienstes studierte er von Oktober 2000 bis Juni 2001 Volkswirtschaftslehre an der Universität Innsbruck. Im Sommer 2001 folgte der Umzug nach Wien wo er ab Oktober 2001 Volkswirtschaftslehre an der Universität Wien und Wirtschaftsinformatik an der Technischen Universität Wien studierte. Im Rahmen dieser Studien verbrachte er jeweils ein Semester an der Freien Universität Berlin (WS 2003/04) und an der Universidad Católica Argentina (WS 2005/06) in Buenos Aires. Das Diplomstudium der Volkswirtschaftslehre an der Universität Wien schloss er im Juni 2005 mit dem Titel Mag.rer.soc.oec. mit Auszeichnung ab. Das Bakkalaureatsstudium der Wirtschaftsinformtik an der Technischen Universität Wien schloss er im Februar 2005 mit dem Titel Bakk.rer.soc.oec. ab, im September 2006 folgte ebendort der Abschluss des Masterstudiums der Wirtschaftsinformatik mit dem Titel Mag.rer.soc.oec. mit Auszeichnung. Im Oktober 2006 trat Stefan Csordás eine Stelle als Assistent an der Abteilung Umweltökonomie an der Universität Basel an, wo er gleichzeitig mit dem Doktoratsstudium der Staatswissenschaften begann. Im Jahre 2007 absolvierte er das *Swiss Program for Beginning Doctoral Students in Economics* am Studienzentrum Gerzensee. In den Frühjahrssemestern 2008 und 2009 hielt er als Lehrbeauftragter jeweils eine Übung in Umweltökonomie an der Universität Basel ab. Von März 2008 bis Februar 2009 arbeitete er gemeinsam mit Prof. Dr. Frank Krysiak ein vom WWZ-Forum finanziertes Forschungsprojekt zum Thema "Klimapolitik ohne Standortnachteile" aus. Die vorliegende Dissertation wurde von Prof. Dr. Frank Krysiak und Prof. Dr. Rolf Weder betreut und begutachtet. Das Doktorexamen legte Stefan Csordás am 21.12.2009 ab. Derzeit arbeitet er im Bereich Energie- und Umweltpolitik an der Weltbank in Washington, DC.