

Environmental Policy and Transboundary Externalities

Coordination and Commitment in Open Economies

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Abstract

This thesis consists of an introductory chapter and four papers, which relate to environmental policy in the presence of transboundary environmental damage.

Paper [I] concerns public policy in a multi-jurisdiction framework with transboundary environmental damage. Each jurisdiction is assumed large in the sense that its government is able to influence the world-market producer price of the externality-generating good. This gives rise to additional incentives of relevance for national public policy in the non-cooperative Nash equilibrium. With the uncoordinated equilibrium as the reference case, the welfare effects from coordinated changes in public policy variables are analyzed.

Paper [II] analyses welfare effects of coordinated changes in environmental and capital taxation in the presence of transboundary environmental externalities and wage bargaining externalities. In the wage bargaining between firms and labor unions, firms use the threat of moving abroad to moderate wage claims, which means that domestic policy influences wage formation abroad. The specific framework implies welfare effects of policy coordination that correspond to each of the respective international interaction mentioned above.

In paper [III], national governments face political pressure from environmental and industrial lobby groups, while pollution taxes are determined in an international negotiation. It is shown that a general increase in the environmental concern and the weight the governments attach to social welfare both tend to increase the pollution tax. However, allowing for asymmetries between the countries means that a general increase in the environmental concern has the potential to reduce the pollution tax.

Paper [IV] studies national environmental policies in an economic federation characterized by decentralized leadership. The federal government sets emission targets for each member country, which are implemented by the national governments. Although all national governments have commitment power vis-à-vis the federal government, one of them also has commitment power vis-à-vis the other member countries. This creates incentives to act strategically toward the federal government, as well as toward other members.

Keywords: environmental policy, transboundary externalities, lobbying, international negotiations, policy coordination, endogenous world-market prices, optimal taxation, economic federation

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To our two-month old son – you have provided life one extra dimension!

Umeå, October 2008

Lars Persson

This thesis consists of a summary and the following four papers:

- [I] Aronsson, T., Persson, L. and Sjögren, T. (2008) Mixed Taxation, Public Goods and Transboundary Externalities: A Model with Large Jurisdictions. Umeå Economic Studies 747.
- [II] Aronsson, T., Persson, L. and Sjögren, T. (2008) Does Wage Bargaining Justify Environmental Policy Coordination? Umeå Economic Studies 754.
- [III] Persson, L. (2007) Environmental Policy Negotiations, Transboundary Pollution and Lobby Groups in Small Open Economies. Umeå Economic Studies 722.
- [IV] Persson, L. (2008) Environmental Policy, Decentralized Leadership and Horizontal Commitment Power. Umeå Economic Studies 753.

1 Introduction

This thesis comprises four theoretical papers on transboundary environmental problems and optimal taxation. Paper [I] focuses on optimal taxation and public good provision in an economy where each jurisdiction (country) is large in the sense that its government is able to influence the world-market producer price of an externality-generating commodity. Paper [II] studies the welfare effects of environmental policy coordination in the presence of wage bargaining and international firm mobility. Paper [III] analyses pollution taxes determined in negotiations between countries, when each national government is subject to pressure from political interest groups. Finally, paper [IV] addresses transboundary environmental problems and optimal taxation from the perspective of a member state in an economic federation with decentralized leadership.

In addition to summarizing the four papers, this introductory chapter provides background to the relevant policy context. This chapter is also meant to give the reader a basic understanding of the theories used to describe environmental problems and economic policy.

2 Environmental Externalities

In line with the concern for environmental problems in general, and climate change in particular, it is safe to say that environmental policy is currently of great interest. Concern for the environment has inspired a substantial amount of research in economics for a long time. As a point of reference, Pigou analyzed externality correction as early as 1920. The concept of environmental quality is multi-dimensional and refers to a variety of issues such as air and water quality, climate change, the willingness to preservation of wildlife and old growth forests for future generations, conservation of biodiversity, etc. In an economic context, the value individuals attach to environmental quality can be measured - at least in principle - by their willingness to pay for the utility the environment provides. Based on the value of these services, economic policy - such as taxes, quotas and emission permits - provides a useful set of tools for handling environmental challenges.

From an optimal-policy point of view, it is important to distinguish between local and transboundary environmental damage. As for local environmental damage, it here affects residents within a specified region or jurisdiction (coun-

try), whereas transboundary environmental damage also affects the well-being of residents in other regions or jurisdictions (countries). Because national governments can be expected to act in their own self-interest, national policies typically fail to internalize transboundary environmental damage. The reason is that each national government underestimates its social costs of the domestic contribution to the global environmental problem. This suggests that international environmental policy coordination is generally required to fully internalize transboundary environmental damage.

The observations above constitute the point of departure for the present thesis, which aims to explore different aspects of economic policy in economies with transboundary environmental problems. The rest of Section 2 provides a short introduction to optimal taxation in the presence of environmental damage, whereas Section 3 discusses strategic behavior among large actors, policy coordination, international bargaining over environmental policy and economic federations, respectively. Section 3 also summarizes the four papers.

2.1 Optimal Taxation and Environmental Externalities

In the environmental economics literature, the natural environment is often thought of as a public good. Accordingly, since the utility of such goods accrues to all agents in society, the standard efficiency condition of setting the private marginal cost of the good equal to the private marginal benefit is not applicable. Instead, the presence of a public good argues for governments (or supranational authorities) to provide these goods efficiently. Clean air is subject to deterioration via air pollution, which is caused by the actions of individual agents' - both consumers and producers (e.g., decisions of car travel, production technology etc). That is, the choice of consumption and/or production of pollution-generating goods by individual agents will be of importance for the air quality (the provision of clean air). However, a pollution-generating agent typically considers his/her contribution to the environmental deterioration to be so small that it does not matter for the whole.¹ In other words, the individual agent takes the total level of pollution (environmental deterioration) in society as exogenously given when deciding about his/her private actions. This outcome argues for a use of policy instruments to change the behavior of the

¹The economic literature uses the term 'externality' when the private actions of one agent directly affect the well-being of other agents - without any transactions between the parties.

pollution-generating agent. By using corrective taxes, it is possible to adjust the ‘price’ of the externality-generating activity and thereby change the behavior of agents. As mentioned above, Pigou (1920) introduced the idea of taxing externality-generating activities. This intuitive idea has, thereafter, been used in a variety of studies and is referred to as a Pigouvian tax.²

The early literature dealing with externality correction typically rests on the assumption that the externality of interest is the only distortion in the economy. This gives an intuitive understanding of the market failure arising from the particular externality, as it keeps the analysis close to the benchmark of perfect competition. However, from the perspective of real world economies, the assumption of one single distortion is, of course, unrealistic. Due to informational asymmetries and for political and administrative expediency, lump-sum taxes are typically not available in real world public policy, meaning that other ‘distortionary’ taxes must be used for redistribution and revenue collection. That is, environmental policy is not performed in isolation and needs to be analyzed simultaneously with other public policies. In the environmental economics literature, second-best economies typically rest on this idea.³

The early literature dealing with environmental problems to some extent neglects the difficulties arising from transboundary externalities. A starting point is the seminal contribution by Sandmo (1975), who sets out a rather stylized model showing that the Pigouvian principle holds even though the government uses distortionary taxes (besides the environmental tax) to satisfy its revenue constraint. Another influential contribution is the paper by Bovenberg and Goulder (1996), who analyze how optimal tax rates on intermediate inputs deviate from the Pigouvian principle. Their results show that the optimal tax on the externality-generating input depends on the marginal cost of public funds, which reflects how costly it is to raise additional tax revenue when taking into account the distortionary effect of increased taxation. Specifically, it is shown that the traditional Pigouvian correction becomes optimal only if the marginal cost of public funds equals unity, which means that public funds are no more

²For a critique of the traditional Pigouvian approach, see e.g. Baumol (1972).

³The basic idea of second-best was introduced in the economics literature by Ramsey (1927) and developed by Diamond and Mirrlees (1971). However, Lipsey and Landcaster (1956-7) formulated the ‘general theory of second-best’, saying that: if there is one Paretian condition not attainable for the policy maker, the other Paretian conditions are, in general, not desirable.

costly than private funds at the margin.⁴ Pirttilä and Tuomala (1997) also contribute to this specific strand of literature by analyzing optimal tax policy in the presence of both externalities and asymmetric information between the government and the private sector.⁵ It is shown that the presence of two ability-types (with respect to productivity) implies a social valuation of the environmental damage not only reflecting individuals' marginal willingness to pay to avoid the externality, but also influences redistribution via the self-selection constraint. Specifically, if environmental quality and leisure are complements, environmental deterioration makes high-ability types' mimicking of low-ability types less attractive from the high-ability type's point of view, which means that the externality becomes less harmful if the government wants to deter mimicking of low-ability types. Moreover, the set of tax policy instruments in Pirttilä and Tuomala (1997) refers to commodity and income taxes - commonly denoted as mixed taxation in the literature. In model-economies without environmental externalities, the mixed taxation problem has been used rather extensively in the literature; see e.g. the seminal papers by Mirrlees (1976), Atkinson and Stiglitz (1976) and Edwards et al. (1994).

2.2 Optimal Taxation and Transboundary Externalities

Thus far, the focus in this section has been on domestically generated pollution that is within a country's borders. However, in the case of e.g. green house gas emissions, it becomes relevant to study optimal tax policy in the presence of transboundary pollution. In such cases, the implementation of Pigouvian taxes becomes a bit more complicated. As indicated above, national governments most likely underestimate the cost of the externality-generating activity from a global perspective and, thereby, implement a policy that may be suboptimal for society as a whole. The problem of transboundary pollution has, however, been analyzed in the economic literature. To begin with, Barrett (1990, 1994) addresses issues related to the implementation of international environmental

⁴ Another study in this particular area of research is Bovenberg and van der Ploeg (1998), who study welfare effects from an environmental tax reform in the presence of involuntary unemployment. The tax reform is designed so that the additional tax revenue from a raise in environmental taxes is used to reduce distortionary taxes on labor.

⁵ Their paper builds on a framework developed in Boadway and Keen (1993) and Edwards et al. (1994). However, the idea of asymmetric information, two ability-types and self-selection was addressed earlier by e.g. Stiglitz (1982).

agreements (cooperative outcomes). The first of these two papers discusses cooperative solutions in general, while the second paper explores properties of so-called self-enforcing international environmental agreements.⁶ Given some restrictive assumptions, it is shown that, if signatories of the international environmental agreement act as Stackelberg leaders, the agreement achieves a high degree of cooperation when the difference between a non-cooperative and a cooperative outcome (in terms of global benefits) is small. If the difference is large, the relatively few signatories abate much more while the non-signatories abate slightly less in comparison to the non-cooperative equilibrium. However, since there are so many non-signatories in the case with a large difference, the total free-rider effect becomes large and the agreement has little effect.

The subsequent literature considering transboundary externalities addresses a variety of important issues such as labor mobility, international trade and comparisons of cooperative and non-cooperative resource allocations. For instance, Aronsson and Blomquist (2003) study both cooperative and non-cooperative outcomes in a framework characterized by labor mobility, mixed taxation, two ability-types and transboundary environmental damage. One should also mention Cremer and Gahvari (2004) who pay explicit attention to the issue of tax competition when transboundary emissions arise via the production of so-called ‘dirty’ goods. They consider commodity and emission taxes (emissions arise in production) and find that a harmonization of emission taxes above their uncoordinated outcome would result in a reduction of aggregate emissions and a rise in overall welfare. Finally, the problem of transboundary externalities has also been analyzed within economic federations (see below).

3 The Environmental Policy Context

This section aims to address relevant aspects of the real world environmental policy context, while also motivating and summarizing each paper in the present thesis.

⁶‘Self-enforcing’ is meant to imply that no signatory country has any incentive to leave the agreement, and no no-signatory country has any incentive to join. Other examples within this strand of literature are Mäler (1989), Carraro and Siniscalco (1993) and Carraro (2003). See also Rubio and Ulph (2006) for an extended version of the framework developed in Barrett (1994).

3.1 Large Actors

By looking at the real world policy context, it is obvious that actors such as the European Union, the US, Russia and China play important roles. From an economic-theory point of view, these actors are of particular interest since they typically represent a significant share of world markets, meaning that their actions are likely to influence world market prices of externality-generating goods. As for the existing literature on environmental policy, it typically focuses on cases where decisions by single countries do not have a significant impact on world-market prices - i.e., small open-economy models. However, considering the actors mentioned above (considered large actors in what follows) the price-taking assumption appears less realistic. Instead, these countries should be modeled as if they are able to affect world market prices. In such cases, a so-called emission leakage arises via the domestic environmental policies implemented by national governments.⁷ The reason is that domestic policies with the aim of reducing pollution influence the world market price of externality generating goods and, thereby, affect (possibly increase) total pollution. It is, therefore, relevant to analyze environmental externalities and public policy in a world-economy comprised of large actors, whose governments recognize - and incorporate into their policy decisions - their influence on the world-market prices of externality-generating goods. To my knowledge, there are no previous studies dealing with mixed taxation (see the literature mentioned above) in the context of large open economies and transboundary pollution.

3.2 Policy Coordination

From a global perspective, the best solution to transboundary externalities is to implement a cooperative equilibrium, in which all externalities are fully internalized at the global level. However, such equilibrium appears to be unrealistic from a practical policy point of view. It is more likely that countries agree upon smaller projects that improve the resource allocation in comparison to the

⁷The leakage mechanism may arise in a variety of setups. For example, Gurtzgen and Rauscher (2000) introduce a model with an endogenous number of firms that are affected by domestic policies. The domestic environmental policy affects the number of firms, which, in the end, has an effect on the consumer prices and on foreign emissions - a leakage via market-structure effects. Similarly, Conconi (2003) introduces a model with international trade, large countries and interest-groups, where emission leakage arises via a terms of trade effect.

non-cooperative alternative. It is important to note that, although it has no domestic welfare effect, a marginal change in a domestic policy instrument influences welfare abroad via the transboundary externality. Because such a policy may be welfare improving from a global perspective, there might be reasons for national policy coordination.

Paper [I]: Mixed Taxation, Public Goods and Transboundary Externalities: A Model with Large Jurisdictions

Paper [I] is based on a two-country model, where asymmetric information between the government and the private sector characterize each country. The information asymmetry is modeled in a self-selection framework with two ability-types, where the decision-maker observes income but not ability. Each national government faces a mixed tax problem where, in addition to public good provision, nonlinear income taxes as well as linear production and commodity taxes are implemented. Furthermore, the national governments behave as Nash competitors toward one another. It is assumed that one of the consumption goods gives rise to transboundary environmental damage and that the countries are 'large' in the sense that each national government recognizes - and incorporates into its policy decisions - how its policy decisions influence the world-market producer price of the externality-generating good. Given this framework, the countries interact via international trade and the environmental damage they impose on each other.

By comparison with small open (price-taking) economies, the assumption of endogenous world-market prices creates additional incentives of relevance for national public policy. It is shown that the endogenous world-market price creates additional incentives when determining income taxation, commodity taxation and public good provision. For instance, the marginal value that the government attaches to reduced environmental damage constitutes mechanisms that refer to the endogenous world market price; the world market price influences the self-selection constraint as well as the value of net exports. The welfare effect of international policy coordination - where the non-cooperative Nash equilibrium constitutes the reference case - is studied in a case where the utility is weakly separable in the public good and in the environmental damage, and where the domestic welfare is increasing in the producer price of the dirty good.⁸ The

⁸The domestic welfare affect of an increase in the producer price is made up of a self-selection effect, a terms of trade effect and a demand effect on the dirty good.

results suggest that a coordinated increase in the production tax accompanied by a budget-balancing change in public production leads to increased welfare - holding hours of work, disposable income and the commodity tax constant. This result is driven by the endogenous world-market producer price, which is increasing in the production tax and the reallocation of resources to public production. Specifically, if the additional tax revenues are used to increase public production - while the hours of work and disposable income is held constant - the world-market producer price increases via the reduced supply of the dirty good.

By focusing on a special case of the model where, in addition to the assumptions made above, the non-cooperative Nash equilibrium is symmetric and the self-selection constraint does not bind, the analysis of policy coordination is taken a step further. It is shown, among other things, that: (i) it can be welfare improving to increase the production tax, and/or the commodity tax, while spending the additional tax revenues on public good production, and (ii) it can be welfare improving to increase the average income tax, while spending the additional tax revenues on public good production. Each such policy reform would reduce environmental damage via the world-market producer price.

3.3 Wage Bargaining and Transboundary Externalities

Transboundary externalities may also arise from activities other than those associated with the environment, such as wage bargaining between firms and trade unions in open economies where firms can move production abroad. In this case, it is reasonable to assume that firms use the threat of moving production abroad to moderate wage claims. This, in turn, means that policies affecting profits also affect the credibility of the threat. The basic intuition is that a larger potential 'outside' profit contributes to lower wage rates, since the firm's rent in the bargaining most likely increases with the threat. Policies undertaken by any national government, therefore, may give rise to transboundary externalities via the above-described wage bargaining mechanism. As a national government is unlikely to consider its own influence on the outcome of wage bargaining abroad, the uncoordinated equilibrium is inefficient from a global perspective. Aronsson and Sjögren (2004) address this wage bargaining externality in a setup without environmental externalities. They study welfare effects arising from policy coordination with respect to the marginal taxation of labor income, unemployment

benefits and a public good. The results suggest that a coordinated decrease in the hours of work and a coordinated reduction of unemployment benefits tend to increase welfare. The increase in welfare is possible because even though the fall-back outcome is affected by domestic policies, the fall-back profits facing domestic firms are treated as exogenous by the national governments.

Given the arguments above, where firms have the ability to move production abroad, it appears reasonable to assume that some inputs in production (e.g. capital) are internationally mobile. However, international mobility may give rise to international tax competition and, therefore, inefficiently low tax rates and inefficiently low public spending in a non-cooperative equilibrium.⁹ On the other hand, Koskela and Schöb (2002) study optimal labor and capital income taxation in the presence of unemployment and find that mobile capital should be taxed at a higher rate than immobile labor. The intuition behind this result is that, in a situation with unemployment, labor supply becomes locally infinitely elastic.¹⁰ However, since none of the earlier studies have incorporated the wage bargaining externality explained above to a framework with (transboundary) environmental damage, paper [II] mainly contributes to the literature by studying the welfare effect from coordinated changes in environmental and capital taxes in such a context.

Paper [II]: Does Wage Bargaining Justify Environmental Policy Coordination?

Paper [II] studies public policy in a multi-country framework characterized by a transboundary environmental externality and a labor market imperfection arising via wage bargaining between a labor union and a firm. Within each country, competitive firms produce a single output using labor, capital and energy. The use of energy is assumed to create a negative transboundary environmental externality. Paper [II] analyses welfare effects of coordinated changes in environmental and capital taxation, where the pre-reform resource allocation is a non-cooperative Nash equilibrium. From a global perspective, the uncoordinated equilibrium is inefficient both because of the transboundary environmental externality and because of the wage bargaining externality explained above. Specifically, national governments do not take into account that their behav-

⁹See e.g. Zodrow and Mieszkowski (1986) and Wildasin (1989).

¹⁰A study dealing with policy coordination in the presence of unemployment is Fuest and Huber (1999).

ior potentially gives rise to transboundary environmental damage and that the profit earned by domestic firms constitutes the fall-back profit in other countries.

The welfare effect of a coordinated increase in the emission and capital tax becomes indeterminate in the general framework. However, it is shown that the welfare effect of each reform is made up of two parts, each corresponding to the respective externality discussed above. By assuming quasi-linear utility functions and a Cobb-Douglas production technology, it is, however, possible to derive conditions under which the welfare effects are possible to sign. As for a coordinated increase in the emission tax, it improves welfare if the ratio of the net tax revenue¹¹ and the wage is smaller than the output elasticity of labor. This result can be interpreted as a ‘double-dividend’ because both the environmental externality and the wage bargaining externality are reduced. If, on the other hand, the ratio of the net tax revenue and the wage is larger than the output elasticity of labor, the welfare effect is ambiguous. The reason is that a coordinated increase in the emission tax may reinforce the international wage bargaining externality. The welfare effect from a coordinated increase in the capital income tax becomes zero if utility functions are quasi-linear and production technology is characterized by Cobb-Douglas. However, if these assumptions are relaxed the total welfare effect becomes ambiguous.

3.4 International Negotiations and Interest-Groups

In addition to the increasingly important international perspective on environmental policy, national governments also face political pressure from interest groups (referred to as ‘lobby-groups’ in what follows).¹² The reason for lobbying is that governmental use of economic policy tools (such as taxes) affects individual agents, which create incentives for influencing the use of these tools. In the economic literature, lobbying is commonly studied within the menu auction model developed by Grossman and Helpman (1994).¹³ In the menu auction model, lobby-groups offer an incumbent government a set of campaign contri-

¹¹The net tax revenue is defined as the sum of the lump-sum tax per employed worker and the unemployment benefit.

¹²Examples of interest groups that are concerned with environmental issues are Greenpeace and the Swedish Society for Nature Conservation (Naturskyddsforeningen).

¹³The model developed by Grossman and Helpman (1994) originates from Bernheim and Whinston (1986). The term ‘menu auction’ refers to a situation where bidders announce a ‘menu’ of offers - associated with specific actions - to an ‘auctioneer’.

butions in return for particular policies. The incumbent government recognizes that the probability of re-election depends on the amount spent on campaigning and voters' utility derived from current governmental policies.

The literature dealing with the combination of lobbying and environmental policy has mainly focused on policies decided upon at the national level. For instance, Fredriksson (1997) supports, to some extent, the expected intuition that 'green lobbying' leads to a stricter environmental policy at the national level when pollution remains within country borders. However, Aidt (2005) shows that an increase in environmentalism may lead to lower pollution taxes and increased worldwide pollution. This particular result, however, rests on the assumption that pollution is immobile and environmentalists care sufficiently about pollution that arises abroad. The intuition is that if environmentalists are very concerned with pollution abroad, the lobby group is willing to accept more pollution at home in return for less pollution abroad, which means a lower domestic tax on pollution.

There are few studies dealing with transboundary externalities in combination with lobbying. One is Conconi (2003) who extends the lobby-group literature by introducing both international trade and transboundary pollution. In her paper, it is shown that such interactions between countries imply, among other things, that one country's increase in pollution taxes, triggered by lobbying, improves the terms of trade for the other country, which, in turn, leads to increased production and emissions. Although the environmental lobby-group literature - including Conconi (2003) - addresses a variety of interesting aspects, it has so far neglected international environmental policy. Paper [III], therefore, contributes to the literature by studying the combination of (i) lobbying at the national level and (ii) international environmental policy determined in negotiations between countries. Within such a context, paper [III] sheds some light on how environmental policies are affected by changes in lobbying activities as well as in government objectives.¹⁴

Paper [III]: Environmental Policy Negotiations, Transboundary Pollution and Lobby Groups in Small Open Economies

In paper [III], national governments face political pressure from environmental

¹⁴To isolate the mechanisms arising from the negotiation of environmental policy and the transboundary pollution, respectively, paper [III] disregards the international trade aspect addressed by Conconi (2003).

as well as industrial lobby groups. Environmental policies - here defined as pollution taxes - are determined in a negotiation between the national governments, and each country is assumed to be small in the sense of treating world market prices as exogenous. It is also assumed that the countries both generate and are affected by transboundary pollution. The political pressure on the national governments is modeled so that environmental and industrial lobby groups at the national level offer the incumbent domestic government a contribution schedule that depends on the pollution tax. The incumbent governments use these contributions to finance campaign spending and, thereby, increase the probability of re-election. The objective of each national government in the bargain with other countries is to maximize a weighted sum of aggregate campaign contributions and aggregate social welfare. Given the rents from the bargain between the national governments - here defined as the difference between the 'contract outcome' and the 'no-contract' outcome - the outcome will be pollution taxes that maximize the product of these rents.

It is shown that a general increase in environmental concern - here defined as an increase in the number of environmentalists in both countries (the number of countries is normalized to two) - as well as in the weight the governments attaches to social welfare, tends to increase the pollution tax in a symmetric equilibrium. On the other hand, an increase in the number of environmentalists in just one country may reduce the other country's pollution tax in a symmetric equilibrium. The underlying mechanism is that if one country is willing to 'accept' a higher domestic tax on pollution, the other country indirectly uses this to negotiate a lower tax on its own pollution. Moreover, allowing for asymmetries between the two countries gives rise to results that are potentially even more interesting. It is shown that a general increase in the environmental concern may reduce the pollution tax, since the increase in environmental concern tends to increase as well as decrease the pollution tax. The mechanism that tends to increase the pollution tax is more or less standard, but the mechanism that works to reduce the pollution tax is, perhaps, more counterintuitive. The intuition for the latter mechanism is that the government becomes more eager to reach an agreement when the domestic environmental concern increases, meaning that the pressure on the other country to implement a strict environmental policy reduces in the bargain. One conclusion from paper [III] is, therefore, that

an increase in the environmental concern does not necessarily lead to a stricter environmental policy for the global economy as a whole.

3.5 Environmental Policy and Economic Federations

As indicated above, the literature on optimal taxation in the presence of transboundary environmental externalities typically focuses on tax and expenditure policies to implement non-cooperative and cooperative resource allocations, or welfare effects of policy coordination, without paying much attention on the institutional structure within which the public policy is decided upon. In a European context, however, the European Union (EU) plays an important role for environmental policy cooperation, suggesting that a fiscal-federalism-like framework may provide insights of relevance for environmental policy. For instance, the supranational (federal) level of the EU determines emission targets (maximum allowable emissions) for greenhouse gases in each member country, while each member country is responsible for the implementation of these targets. Given this observation, it is relevant to study a federal decision structure's influence on the incentives underlying national public policies implemented by member countries.

The economic literature characterizes economic federations as structures with several levels of governments, where each level has its own policy instruments and responsibilities. This characterization implies that countries - with their national and lower level governments - as well as supranational authorities with several member countries, are considered economic federations. Depending on which level of government has commitment power, economic federations may be thought of as either centralized or decentralized. A centralized federation is interpreted so that each lower level government acts as a follower vis-à-vis the federal level. That is, the federal government is able to commit to its policies, whereas the lower level governments are not. It has been argued that EU member countries have commitment power vis-à-vis the federal government and, therefore, act as first movers (denoted vertical leadership in what follows).¹⁵ Hence, the EU is typically thought of as a decentralized economic federation.

Silva and Caplan (1997), and Caplan and Silva (1999) characterize environmental policy outcomes in a federation which - depending on the level that makes credible commitments - is interpreted as either centralized or decen-

¹⁵See e.g. Jones and Clark (2001, p. 2).

tralized. Their results highlight the importance of the distribution of policy instruments between the levels of government. Given model specific assumptions, it is shown that it is socially desirable to give regional governments the tax (price) instrument, while giving the central government a quantity instrument. With the EU as a source of inspiration, Aronsson et al. (2006) consider an economic federation comprising two lower level governments (countries) and a federal government. The federal government is assumed to decide upon an emission target for each country, which is to be implemented through national tax policies. The economic federation is characterized by decentralized leadership, modelled so that the national (lower level) governments are first movers vis-à-vis the federal government, and the environmental targets are, therefore, conditioned on the national tax policies. Their results show that decentralized leadership creates incentives for each national government to influence the emission targets decided by the federal government. This implies that each country implements commodity taxes that do not satisfy the additivity property, and that the marginal labor income tax is, in part, also used to relax the emission target.¹⁶

Returning once again to the EU, it also appears reasonable to view the member countries as heterogeneous among themselves with respect to horizontal commitment power, meaning that one of the countries may act as first mover vis-à-vis the others. For instance, it is plausible that large countries, such as Germany and France, can be more committed to national objectives than small countries such as Luxemburg and Sweden. This follows from the argument that relatively large countries play an important role for the economic development within the federation, and the smaller countries, therefore, act as if they are followers vis-à-vis the large countries. These arguments give a reason to extend the existing literature on environmental policy in economic federations, which has so far neglected the issue of horizontal commitment power. Paper [IV], therefore, deals with optimal taxation and transboundary environmental problems in a decentralized economic federation, where the member countries differ with respect to horizontal commitment power.

¹⁶ Apart from the problem of environmental externalities, there are studies addressing issues such as pure public good provision, tax competition and redistribution within federations characterized by decentralized leadership; see e.g. Caplan et al. (2000), Köthenburger (2004) and Aronsson (2007).

Paper [IV]: Environmental Policy, Decentralized Leadership and Horizontal Commitment Power

Given an economic federation where the federal government determines emission targets for each of the member countries, paper [IV] studies the optimal use of linear production taxes and non-linear income taxes at the national (member state) level. Taking Aronsson et al. (2006) as a starting point, the economic federation is assumed to be decentralized in the sense that each member country acts as a first mover vis-à-vis the federal government - interpreted so that the federal government chooses emission targets conditional on the national public policy. In addition, one of the two member countries, the horizontal Stackelberg leader, also acts as first mover vis-à-vis the other member country - the horizontal follower. That is, the horizontal Stackelberg leader chooses its policy while anticipating, and incorporating into its decision problem, how the horizontal follower and the federal government respond to its policy.

By primarily focusing on the horizontal Stackelberg leader, the results show that, in addition to the standard result that environmental taxation should reflect the marginal willingness to pay for reduced environmental damage, the heterogeneity with respect to commitment power between member countries creates additional incentives for influencing the environmental targets imposed by the federal government. Specifically, the horizontal Stackelberg leader uses its commitment power to loosen its own emission target, while tightening it for the horizontal follower. These results rest on how the federal government determines the emission targets implemented by the national governments. In equilibrium, the emission targets for each country is (in principle) chosen so that the value of the marginal product of the bad input equals the sum of marginal willingness to pay for reduced environmental damage, adjusted for differences in the marginal utility of income between the countries. For the horizontal Stackelberg leader, this creates an opportunity to influence the emission targets directly via the domestic choice of labor (reflected in the marginal income tax) and indirectly via its influence on the horizontal follower's behavior (reflected both in the production tax and the marginal income tax). However, it is important to bear in mind that these specific results presuppose that all member countries act as first movers vis-à-vis the federal government.

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Mixed Taxation, Public Goods and Transboundary Externalities: A Model with Large Jurisdictions*

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Abstract

This paper concerns income taxation, commodity taxation, production taxation and public good provision in a multi-jurisdiction framework with transboundary environmental damage. We assume that each jurisdiction is large in the sense that its government is able to influence the world-market producer price of the externality-generating commodity. The decision-problem facing the government in each such jurisdiction is represented by a two-type model (with asymmetric information between the government and the private sector). We show how the possibility to influence the world-market producer price adds mechanisms of relevance for redistribution and externality-correction which, in turn, affect the domestic use of taxation and public goods. Finally, with the noncooperative Nash equilibrium as a reference case, we consider the welfare effects of policy coordination.

Keywords: Trade and Environment, Optimal Taxation, Externalities.

JEL Classification: F18, H21, H23.

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1 Introduction

In the literature on transboundary environmental problems, it has been recognized that national environmental policies may fail to fully internalize externalities, and that policy cooperation among countries (or regions) is generally required in order to reach a globally optimal resource allocation. There are several sources of inefficiency associated with noncooperative policies; for instance, individual countries are likely to disregard the transboundary component of the environmental damage they cause, since their policy-decisions are typically governed by national objectives, and their policies may also give rise to side effects via changes in the price system. However, despite the existence of certain supranational agreements, there is still substantial room for policies decided upon at the national level or by subgroups of countries such as the EU, suggesting that the incentives underlying decentralized policies are important to understand.

This paper concerns optimal taxation and public good provision at the national level, as well as the welfare effects of policy coordination, in an economy where the aggregate consumption of a particular good, to be called 'dirty good', generates a transboundary environmental problem. Our study is based on a framework with mixed taxation, where each national government faces a non-linear income tax as well as linear commodity and production taxes. This set of tax instruments provides a reasonably realistic description of the tax system that many national governments have at their disposal. It also implies that the use of distortionary taxes is a consequence of optimization under informational restrictions; it is not a consequence of any (arbitrary) restriction imposed on the set of tax instruments.

Contrary to earlier literature on environmental policy under mixed taxation (see below), we assume that the countries are large in the sense that each national government is able to significantly affect the world-market producer price of the externality-generating good. Such a framework is interesting to consider for at least two reasons. First, although many countries are small enough to make the 'price-taking government' assumption realistic, the environmental policy scene is also characterized by large actors such as the U.S. and some other countries, as well as by subgroups of countries acting together such as the EU, where the price-taking assumption appears to be less realistic. Our study takes this observation to its extreme point by analyzing a world-economy comprising

a number of large actors, whose governments recognize (and incorporate into their decision-problems) that their policies will affect the world-market producer prices of externality-generating commodities. Second, our approach integrates earlier literature on the so called 'leakage' phenomenon with the theory of mixed taxation, which makes it possible to compare large and small open economies with respect to the whole tax structure; not just with respect to environmental policy.

The literature on fiscal policy in second best economies with transboundary environmental problems is relatively small by comparison with the corresponding literature dealing with fiscal policy in second best economies with local (i.e. within-jurisdiction) environmental damage¹. Earlier research in the former category, nevertheless, addresses a variety of issues such as comparisons between noncooperative and cooperative regimes with respect to tax policies², labor mobility³, fiscal competition due to international trade⁴ and strategic aspects of public policy in the context of economic federations⁵. However, none of the studies that we are aware of combines transboundary environmental problems and mixed taxation in the context of large open economies. An interesting observation (discussed many times in other contexts) is that there might be emission-leakage associated with the environmental policy decided upon by national governments; for instance, if higher emission taxes in a particular jurisdiction significantly reduces the demand for the externality-generating good, then the producer price will also decrease which, in turn, tends to increase the emissions abroad⁶. This suggests that, if the country is large in the sense that its government can significantly influence the world-market producer price of the externality-generating good, then it may have incentives to modify its use

¹Earlier literature on fiscal policy under environmental externalities often abstracts from international (or interregional) spillover effects of environmental damage by focusing on 'one-country' model-economies. See the seminal contribution by Sandmo (1975) and the subsequent work by e.g. Pirttilä and Tuomala (1997) and Cremer and Gahvari (2001). See also the related research on environmental policy reforms and so called 'double-dividends', e.g. Bovenberg and de Mooij (1994), Bovenberg and Goulder (1996), Parry et al. (1999) and Aronsson (1999).

²See Aronsson and Blomquist (2003).

³See Aronsson and Blomquist (2003).

⁴See Cremer and Gahvari (2004, 2005).

⁵See Silva and Caplan (1997), Caplan and Silva (1999) and Aronsson et al. (2006).

⁶Various mechanisms by which emission-leakage may appear have been discussed by e.g. Gurzgen and Rauscher (2000), Conconi (2003) and Lai and Hu (2005). See also the empirical study by Sengupta and Bhardwaj (2004), which is a case study applied to India.

of environmental policy. Our paper incorporates this mechanism into the theory of income and commodity taxation.

As the number of countries is of no particular concern in what follows, the present paper focuses on a two-country model, in which each country is characterized by two-ability types. The countries interact both via the environmental damage they impose on each other and international trade⁷. Our paper contributes to the literature in primarily two ways. The first is by characterizing the income, commodity and production tax structure, as well as the provision of national public goods, in a noncooperative Nash equilibrium, where each country implements its own policy conditional on the policies chosen by the other country. We show how the additional policy incentives associated with the endogenous world-market producer price affect the domestic use of income taxation, commodity taxation and public good provision in a noncooperative Nash equilibrium, relative to the policy rules that would apply with fixed producer prices. Furthermore, our results show that the ability to influence the world-market producer price provides an incentive for each national government to implement a production tax (in addition to the income and commodity taxes) as well as to deviate from production efficiency in the public production. The second is by analyzing the welfare effects of policy coordination, where the noncooperative Nash equilibrium constitutes the reference case. Although the welfare effects of policy coordination are typically ambiguous in the general case, we show for a special case of the model that welfare improving policy coordination may include, e.g., an increase in the production tax or commodity tax accompanied by increased public production, or increased average income taxation accompanied by increased public production. The intuition is that each such reform contributes to reduced environmental damage (either directly or indirectly via the world-market producer price).

The outline of the study is as follows. In section 2, we present the model, the outcome of private optimization and market equilibrium conditions, whereas the decision-problem of the government is discussed in section 3. Section 4 concerns optimal taxation and public good provision at the national level, while policy

⁷We abstract from international factor mobility throughout the paper. Therefore, although the policy incentives discussed below would also appear in a more general framework (with factor mobility being yet another source of interaction between the countries), allowing for factor mobility is clearly an important extension for future research.

coordination is dealt with in section 5. We summarize and discuss the results in section 6.

2 The Model

Consider an economy comprising two jurisdictions, which will be called 'countries' in what follows. We begin by describing the consumers in each such country. Having done that, we continue with the production side and market equilibrium conditions.

2.1 The Consumers

In each country, i (where $i = 1, 2$), there are two types of consumers; a low-ability type (denoted by l) and a high-ability type (denoted by h). The distinction between ability-types refers to productivity, meaning that the high-ability type is more productive and faces a higher before-tax wage rate than the low-ability type. Since the number of individuals of each such ability-type is not important for the analysis to be carried out below, it will be normalized to one for notational convenience.

The preferences of ability-type j ($j = l, h$) in country i are described by the utility function $U^{i,j} = U(C^{i,j}, X^{i,j}, Z^{i,j}, G^i, E)$, where $C^{i,j}$ denotes (the consumption of) an environmentally clean good, $X^{i,j}$ an environmentally dirty good, $Z^{i,j}$ leisure, G^i a national public good and E the environmental damage. We assume that $C^{i,j}$ and $X^{i,j}$ are normal goods. Leisure is defined as $Z^{i,j} = H - L^{i,j}$, where H is a time endowment and $L^{i,j}$ the hours of work. The function $U(\cdot)$ is increasing in $C^{i,j}$, $X^{i,j}$, $Z^{i,j}$ and G^i , decreasing in E and strictly quasiconcave. We also assume that the environmental damage is caused by the aggregate consumption (measured over all countries) of the dirty good (see below), and that the consumers treat E as exogenous. The clean good is untaxed and its price is normalized to one. The consumer price of the dirty good is given by $Q^i = P + t^i$, where P is the producer price and t^i the commodity tax decided upon by the government in country i . Therefore, as both commodities are subject to international trade, the producer prices are assumed to be equalized across countries.

The consumer chooses $C^{i,j}$, $X^{i,j}$ and $L^{i,j}$ to maximize utility subject to the

budget constraint,

$$w^{i,j}L^{i,j} - T^i(w^{i,j}L^{i,j}) - C^{i,j} - Q^iX^{i,j} = 0, \quad (1)$$

where $T^i(\cdot)$ is the income tax decided upon by the government in country i . Since the optimal tax and expenditure problem below will be defined in terms of conditional indirect utility functions, it is convenient to follow Christiansen (1984) by solving the consumer's optimization problem in two stages. In the first stage, the utility maximization problem is solved conditional on the hours of work. This problem is written

$$\max_{C^{i,j}, X^{i,j}} U(C^{i,j}, X^{i,j}, Z^{i,j}, G^i, E)$$

subject to

$$B^{i,j} = C^{i,j} + Q^iX^{i,j}$$

in which $B^{i,j}$ is treated as a fixed post-tax income. The solution to this problem gives the conditional demand functions

$$X^{i,j} = X(Q^i, B^{i,j}, Z^{i,j}, G^i, E) \quad (2)$$

$$C^{i,j} = C(Q^i, B^{i,j}, Z^{i,j}, G^i, E) \quad (3)$$

and the conditional indirect utility function

$$V^{i,j} = V(Q^i, B^{i,j}, Z^{i,j}, G^i, E). \quad (4)$$

In the second stage, we can derive the hours of work by maximizing the conditional indirect utility function with respect to $L^{i,j}$ subject to the budget constraint

$$B^{i,j} = w^{i,j}L^{i,j} - T(w^{i,j}L^{i,j}). \quad (5)$$

The first order condition for this problem is written

$$V_B^{i,j}w^{i,j}(1 - T_I^{i,j}) - V_Z^{i,j} = 0 \quad (6)$$

where $V_B^{i,j} = \partial V^{i,j} / \partial B^{i,j}$ and $V_Z^{i,j} = \partial V^{i,j} / \partial Z^{i,j}$ represent the marginal utility of private income and leisure, respectively, while $I^{i,j} = w^{i,j}L^{i,j}$ is the labor

income facing ability-type j in country i and $T_I^{i,j} = \partial T^i(I^{i,j}) / \partial I^{i,j}$ the corresponding marginal income tax rate.

2.2 Production

The production side in each country consists of one public and two private sectors. The public sector production function is written $G^i = F_G^i(L_G^{i,l}, L_G^{i,h})$, where $L_G^{i,j}$ is the amount of labor of ability-type j ($j = l, h$) that the public sector uses. We assume that both inputs are essential, that the marginal product of each factor is positive and diminishing, and that the production technology is characterized by constant returns to scale.

Turning to private production, the clean good is produced in sector c , whereas the dirty good is produced in sector x . Production in each sector is characterized by constant returns to scale. Given these characteristics, the number of firms in each sector is not, itself, important and will be normalized to one. The production functions can be written $F_c^i(L_c^{i,h}, L_c^{i,l})$ and $F_x^i(L_x^{i,h}, L_x^{i,l})$, where $L_c^{i,j}$ and $L_x^{i,j}$ represent the amount of labor of ability-type j used by sector c and x , respectively, in country i . Normalizing with respect to the low-skilled labor type in each sector, we have

$$f_c^i(n_c^i) = \frac{F_c^i(L_c^{i,h}, L_c^{i,l})}{L_c^{i,l}} \quad (7)$$

$$f_x^i(n_x^i) = \frac{F_x^i(L_x^{i,h}, L_x^{i,l})}{L_x^{i,l}} \quad (8)$$

where $n_c^i = L_c^{i,h} / L_c^{i,l}$ and $n_x^i = L_x^{i,h} / L_x^{i,l}$.

We assume that the government implements a revenue tax in sector x at the rate τ^i , while the good produced in sector c is untaxed. We also assume that the workers are perfectly mobile between sectors (yet immobile between countries), which means that the type-specific wage rates in each country will be the same in both sectors. The first order conditions for profit maximization can be written as

$$\begin{aligned}
w^{i,h} &= \frac{\partial f_c^i(n_c^i)}{\partial n_c^i}, \\
w^{i,l} &= f_c(n_c^i) - n_c^i \frac{\partial f_c^i(n_c^i)}{\partial n_c^i}, \\
w^{i,h} &= (1 - \tau^i) P \frac{\partial f_x^i(n_x^i)}{\partial n_x^i} \text{ and} \\
w^{i,l} &= (1 - \tau^i) P \left[f_x(n_x^i) - n_x^i \frac{\partial f_x^i(n_x^i)}{\partial n_x^i} \right]. \tag{9}
\end{aligned}$$

2.3 Equilibrium

By using equations (9) together with the identities

$$L^{i,h} - L_G^{i,h} = L_c^{i,h} + L_x^{i,h} \tag{10}$$

$$L^{i,l} - L_G^{i,l} = L_c^{i,l} + L_x^{i,l} \tag{11}$$

we can define $w^{i,j}$, $L_c^{i,j}$ and $L_x^{i,j}$ as functions of $L^{i,h} - L_G^{i,h}$, $L^{i,l} - L_G^{i,l}$ and $(1 - \tau_x^i) P$, i.e.

$$w^{i,j} = w^{i,j} \left(L^{i,h} - L_G^{i,h}, L^{i,l} - L_G^{i,l}, (1 - \tau_x^i) P \right) \tag{12}$$

$$L_c^{i,j} = L_c^{i,j} \left(L^{i,h} - L_G^{i,h}, L^{i,l} - L_G^{i,l}, (1 - \tau_x^i) P \right) \tag{13}$$

$$L_x^{i,j} = L_x^{i,j} \left(L^{i,h} - L_G^{i,h}, L^{i,l} - L_G^{i,l}, (1 - \tau_x^i) P \right) \tag{14}$$

for $j = l, h$. By substituting equations (13) and (14) into the production functions, we obtain 'the equilibrium supply functions'

$$S_c^i = S_c^i \left(L^{i,h} - L_G^{i,h}, L^{i,l} - L_G^{i,l}, (1 - \tau_x^i) P \right) \tag{15}$$

$$S_x^i = S_x^i \left(L^{i,h} - L_G^{i,h}, L^{i,l} - L_G^{i,l}, (1 - \tau_x^i) P \right). \tag{16}$$

Since the two goods are subject to international trade, the equilibrium condition in the market for the dirty good can be written as

$$\sum_{i=1}^2 S_x^i - \sum_{i=1,2} \sum_{j=h,l} X^{i,j} = 0. \quad (17)$$

As long as equation (17) is fulfilled, Walras' law implies that the market for the clean good is in equilibrium as well. By using $Q^i = P + t^i$, equation (17) implicitly defines the producer price of the dirty good, i.e.

$$P = P(\mathbf{B}^1, \mathbf{L}^1, \mathbf{L}_G^1, t^1, \tau_x^1, G^1, \mathbf{B}^2, \mathbf{L}^2, \mathbf{L}_G^2, t^2, \tau_x^2, G^2, E) \quad (18)$$

where $\mathbf{B}^i = (B^{i,h}, B^{i,l})$, $\mathbf{L}^i = (L^{i,h}, L^{i,l})$ and $\mathbf{L}_G^i = (L_G^{i,h}, L_G^{i,l})$ for $i = 1, 2$. To derive equation (18), we have used $L^{i,j} = H - Z^{i,j}$ and suppressed the time endowment.

The environmental damage facing the residents in each country equals the sum of the consumption of the dirty good taken over both countries⁸, i.e.

$$E = \sum_{i=1,2} \sum_{j=h,l} X^{i,j}. \quad (19)$$

3 The Public Decision-Problem

We assume that each national government faces a utilitarian social welfare function⁹

$$W^i = \sum_{j=l,h} V^{i,j}. \quad (20)$$

The tax instruments are the production tax, income tax and commodity tax, which are used for purposes of redistribution and public good provision. Therefore, the government budget constraint can be written as

$$\tau^i S_x^i + \sum_{j=h,l} T^{i,j} + t^i \sum_{j=h,l} X^{i,j} - \sum_{j=h,l} w^{i,j} L_G^{i,j} = 0 \quad (21)$$

⁸This formulation can be exemplified by the climate problem.

⁹Alternative approaches would be to assume (as in many comparable studies) that the government is maximizing the utility of one ability-type subject to a minimum utility restriction for the other, or to assume that the government uses a general social welfare function. All qualitative results derived below would hold also under the alternative formulations.

where $T^{i,j} = T^i(w^{i,j} L^{i,j})$.

Since $T^i(\cdot)$ is a general labor income tax, which can be used to implement any desired combination of consumption and hours of work for each ability-type, it is convenient to use $B^{i,h}$, $L^{i,h}$, $B^{i,l}$ and $L^{i,l}$, instead of the parameters of the income tax function, as direct decision-variables in the optimal tax and expenditure problem. Therefore, let us rewrite the budget constraint of the government by combining equation (21) with the individual budget constraints and the zero profit conditions following from the assumption of constant returns to scale in production, i.e.

$$0 = S_c^i + PS_x^i + t^i \sum_{j=h,l} X^{i,j} - \sum_{j=h,l} B^{i,j}. \quad (22)$$

The informational assumptions are conventional; the government observes the income of each individual, although ability is private information. The latter means that, in the absence of appropriate type-revealing mechanisms, the government would not be able to observe whether any given worker is a low-ability or high-ability type. We concentrate on the 'normal' case, where the government wants to redistribute from the high-ability to the low-ability type. Therefore, the relevant aspect of self-selection is to prevent the high-ability type from pretending to be a low-ability type. The self-selection constraint that may bind then becomes

$$V^{i,h} = V(Q^i, B^{i,h}, Z^{i,h}, G^i, E) \geq V(Q^i, B^{i,l}, \hat{Z}^{i,h}, G^i, E) = \hat{V}^{i,h} \quad (23)$$

where $\hat{V}^{i,h}$ denotes the utility of a high-ability mimicker and $\hat{Z}^{i,h} = H - \phi^i L^{i,l}$ the amount of leisure consumed by the mimicker. The term $\phi^i = w^{i,l}/w^{i,h} < 1$ denotes the wage ratio (or relative wage rate) in country i . By using equations (12), the wage ratio can be written as $\phi^i = \phi^i(L^{i,h} - L_G^{i,h}, L^{i,l} - L_G^{i,l}, (1 - \tau^i)P)$, in which P is determined by equation (18). Note that the mimicker faces the same before-tax and disposable income as the low-ability type; however, as the mimicker is more productive than the low-ability type, he/she also consumes more leisure than the low-ability type.

The Lagrangean can be written as

$$\begin{aligned} \mathcal{L}^i = & W^i + \rho^i [F_G(\mathbf{L}_G^i) - G^i] + \lambda^i [V^{i,l} - \hat{V}^{i,h}] + \gamma^i [S_c^i + PS_x^i + t^i \sum_{j=h,l} X^{i,j} \\ & - \sum_{j=h,l} B^{i,j}] + \mu^i [E - \sum_{n=1,2} \sum_{j=h,l} X^{n,j}] \end{aligned}$$

for $i = 1, 2$, where W^i , $V^{i,j}$, $\hat{V}^{i,h}$, $X^{i,j}$, S_c^i and S_x^i were defined above, whereas ρ^i , λ^i , γ^i and μ^i are Lagrange multipliers. Note also that P is endogenous to the national government in country i and determined by equation (18). The decision-variables facing the government in country i are $L^{i,l}$, $B^{i,l}$, $L^{i,h}$, $B^{i,h}$, $L_G^{i,l}$, $L_G^{i,h}$, t^i , τ^i and G^i . Note also that equation (19) appears as an explicit constraint in the Lagrangean, meaning that E will be treated as an additional (and artificial) decision-variable. The first order conditions are presented in the Appendix.

4 The Noncooperative Nash Equilibrium

It is convenient to start the analysis by evaluating how an increase in the world-market producer price of the externality-generating good affects the national welfare. In the Appendix, we show that

$$\frac{\partial \mathcal{L}^i}{\partial P} = \frac{\gamma^i}{\beta^i} \left[\frac{\lambda^i L^{i,l} \hat{V}_Z^{i,h}}{\gamma^i} \frac{\partial \phi^i}{\partial P} + NX^i - \frac{\mu^i}{\gamma^i} \sum_{j=h,l} \frac{\partial X^{k,j}}{\partial Q^k} \right] \quad (24)$$

for $k \neq i$, where $\beta^i = 1 + \partial P / \partial t^i > 0$, and $NX^i = S_x^i - \sum_{j=h,l} X^{i,j}$ is the net export of the dirty good.

Equation (24) shows that the welfare effect of an increase in P can be decomposed into three parts. The first term on the right hand side appears because the wage ratio depends on the producer price of the dirty good. If $\partial \phi^i / \partial P > 0$, a higher producer price leads to an increase in the wage ratio, which makes mimicking less attractive and contributes to relax the self-selection constraint. In this case, therefore, the first term within the square bracket contributes to higher welfare. By analogy, if $\partial \phi^i / \partial P < 0$, the first term within the square bracket contributes to lower welfare. The second term, $\gamma^i NX^i / \beta^i$, represents a terms of trade effect. If the country is a net exporter of the dirty good, a higher producer price increases the value of the net exports which, in turn, leads to

higher welfare for country i . The opposite argument applies if the country is a net importer of the dirty good.

The final term on the right hand side of equation (24) arises because an increase in the producer price of the dirty good leads to a lower demand for the dirty good in the other country (conditional on the commodity tax implemented by the other country). This effect reduces the environmental damage which, in turn, leads to increased welfare for country i if $\mu^i/\gamma^i > 0$, and decreased welfare for country i if $\mu^i/\gamma^i < 0$. We can interpret μ^i/γ^i as the real shadow price that the government in country i attaches to a reduction in the environmental damage. The determination of this shadow price is the issue to which we will turn next.

Following earlier research on environmental policy and mixed taxation¹⁰, it is convenient to define the shadow price of environmental damage over the shadow price of the government's budget constraint, μ^i/γ^i , as this real shadow price will play an important role in the optimal tax and expenditure policy to be analyzed below. One may interpret μ^i/γ^i as the marginal value that the government in country i attaches to reduced environmental damage measured in terms of its tax revenues. Let us define

$$MWP_{E,B}^{i,j} = -\frac{\partial V^{i,j}/\partial E}{\partial V^{i,j}/\partial B^{i,j}}, \quad \widehat{MWP}_{E,B}^{i,h} = -\frac{\partial \widehat{V}^{i,h}/\partial E}{\partial \widehat{V}^{i,h}/\partial B^{i,l}}$$

as the marginal willingness to pay for a small reduction in the environmental damage by ability-type i and the mimicker, respectively. To simplify the exposition, we will also use the following short notations¹¹;

¹⁰See e.g. Pirttilä and Tuomala (1997), Aronsson and Blomquist (2003) and Aronsson et al. (2006).

¹¹Note that μ^i/γ^i is calculated by using the first order conditions for E , $B^{i,l}$ and $B^{i,h}$, which explains why compensated derivatives of the demand for the dirty good in country i appear in the expression for μ^i/γ^i along with uncompensated derivatives of the demand for the dirty good in the other country, k . The intuition is that the government in country i only recognizes the domestic budget effects of its own environmental policy.

$$\begin{aligned}
\text{(i)} \quad \alpha &= \sum_{i=1,2} \frac{\partial S_x^i}{\partial P} - \sum_{i=1,2} \sum_{j=h,l} \frac{\partial X^{i,j}}{\partial Q^i} > 0 \\
\text{(ii)} \quad \frac{\partial \tilde{X}^{i,j}}{\partial E} &= \frac{\partial X^{i,j}}{\partial E} + \frac{\partial X^{i,j}}{\partial B^{i,j}} MW P_{E,B}^{i,j} \\
\text{(iii)} \quad \frac{1}{\sigma^i} &= 1 - \sum_{j=l,h} \frac{\partial \tilde{X}^{i,j}}{\partial E} - \sum_{j=l,h} \frac{\partial X^{k,j}}{\partial E} \\
\text{(iv)} \quad \frac{1}{\tilde{\sigma}^i} &= \frac{1 + (1 - \sigma^i) [\sum_j (\partial X^{k,j} / \partial Q^k)] / \alpha \beta^i}{\sigma^i}
\end{aligned}$$

which refer to, respectively, (i) the increased net supply of the dirty good caused by an increase in the producer price, i.e. the partial derivative of equation (17) with respect to P , (ii) the change in the compensated demand for the dirty good caused by increased environmental damage, (iii) the environmental feedback effect that would apply under a fixed producer price, and (iv) the full environmental feedback effect. The component $(1 - \sigma^i) / \alpha \sigma^i$ of the expression for $1 / \tilde{\sigma}^i$ measures the change in the producer price¹² of the dirty good that would arise from a marginal decrease in E which, if multiplied by $\sum_j (\partial X^{k,j} / \partial Q^k)$, gives the corresponding change in the demand for the dirty good in the other country (country k). Consider Proposition 1;

Proposition 1. *In the noncooperative Nash equilibrium, the shadow price of environmental damage over the shadow price of the government's budget constraint in country i can be written as*

$$\begin{aligned}
\frac{\mu^i}{\gamma^i} &= \tilde{\sigma}^i \left[\sum_{j=h,l} MW P_{E,B}^{i,j} + \lambda^{i,*} \left(MW P_{E,B}^{i,l} - \widehat{MW P}_{E,B}^{i,h} \right) - t^i \sum_{j=h,l} \frac{\partial \tilde{X}^{i,j}}{\partial E} \right] \\
&+ \frac{\tilde{\sigma}^i (1 - \sigma^i)}{\alpha \beta^i} \left[\frac{\lambda^i L^{i,l} \hat{V}_Z^{i,h}}{\gamma^i} \frac{\partial \phi^i}{\partial P} + NX^i \right]
\end{aligned}$$

where $\lambda^{i,*} = \lambda^i \hat{V}_B^{i,h} / \gamma^i$.

¹²As the national government recognizes the domestic budget consequences of its environmental policy, this effect is calculated with the domestic utility held constant. See also footnote 11.

Proof: See the Appendix.

The environmental feedback effect, $\bar{\sigma}^i$, captures that a change in the externality - due to a change in the demand for the dirty good - 'feeds back' into the demand equations (both directly and indirectly via the world-market producer price). To guarantee stability of the model, we follow earlier literature¹³ by assuming that the environmental feedback effect is positive.

In the first row, all terms within the square bracket are well understood from earlier research (e.g. Pirttilä and Tuomala 1997), and our discussion of each of these components will, therefore, be brief. The consumers' marginal willingness to pay for reduced environmental damage is captured by the first term, which (by the assumptions made earlier) contributes to increase the marginal value that the government attaches to reduced environmental damage. The second term appears because a change in E will affect the self-selection constraint. If the low-ability type is willing to pay more (less) at the margin than the mimicker for reduced environmental damage, the government attaches a higher (lower) marginal value to reduced environmental damage than it would otherwise have done, as a reduction in E in this case contributes to relax (tighten) the self-selection constraint. As for the final term, note that a change in the environmental damage influences the revenues from the commodity tax: if a reduction in E leads to increased tax revenues via the demand for the dirty good, *ceteris paribus*, then the tax revenue effect reinforces the environmental motive behind the public policy and contributes, therefore, to increase μ^i/γ^i . The opposite argument applies if an increase in E leads to higher tax revenues.

The second row of the formula for μ^i/γ^i appears because the world-market producer price of the dirty good is endogenous to the government in country i . Suppose, to begin with, that $1 - \sigma^i < 0$, in which case an increase in the environmental damage (with the utility facing the domestic residents held constant at the optimum) leads to a higher world-market producer price of the dirty good¹⁴, *ceteris paribus*. In this case, and if $\partial\phi^i/\partial P > 0$ (< 0), which means that a higher (lower) producer price contributes to relax the self-selection

¹³See Sandmo (1980). See also, e.g., Pirttilä and Tuomala (1997) and Aronsson and Blomquist (2003).

¹⁴Although $1 - \sigma^i$ cannot be signed unambiguously in the general case, we show in the Appendix that it is negative if the environmental damage is weakly separable from the other goods in the utility function.

constraint, the government will attach a lower (higher) value to reduced environmental damage than it would otherwise have done. Note also that country i may either be a net exporter or net importer of the dirty good: if country i is a net exporter, so $NX^i > 0$, the second term on the right hand side contributes to reduce μ^i/γ^i , while it contributes to increase μ^i/γ^i if country i is a net importer of the dirty good. The intuition is, of course, that the higher world-market producer price (caused by increased environmental damage) generates an extra benefit if the country is a net exporter and an extra cost if the country is a net importer. Interpretations analogous to those discussed above - yet with the opposite qualitative effects of the terms in the second row - will follow if $1 - \sigma^i > 0$.

In the interpretations of the optimal tax formulas to be presented below, we will add the (realistic) assumption that the government attaches a positive marginal value to reduced environmental damage, i.e. $\mu^i/\gamma^i > 0$.

4.1 Commodity Taxation

Let us now turn to the commodity tax structure. To simplify the analysis, we shall use the following short notation;

$$\varphi^i = \frac{\sum_{n=1,2} (\partial S_x^n / \partial P)}{\sum_{n=1,2} (\partial S_x^n / \partial P) - \sum_{j=h,l} (\partial X^{k,j} / \partial Q^k)} \in (0, 1)$$

for $k \neq i$, for a scale variable that influences the relationship between the commodity tax on the dirty good and the shadow price that the government attaches to reduced environmental damage. This scale variable will be further discussed below. Consider Proposition 2;

Proposition 2. *In the noncooperative Nash equilibrium, the commodity tax on the dirty good implemented by country i can be written as*

$$t^i = \frac{\lambda^{i,*}}{\sum_j \partial \hat{X}^{i,j} / \partial Q^i} \left(X^{i,l} - \hat{X}^{i,h} \right) - \frac{\lambda^i L^{i,l} \hat{V}_Z^{i,h}}{\alpha \beta^i \gamma^i} \frac{\partial \phi^i}{\partial P} - \frac{NX^i}{\alpha \beta^i} + \varphi^i \frac{\mu^i}{\gamma^i}.$$

Proof: See the Appendix.

The first two terms on the right hand side are due to the self-selection constraint and are analogous to results derived in earlier research (Edwards et al. 1994

and Naito 1999). As $\partial \tilde{X}^{i,j} / \partial Q^i < 0$, the first term on the right hand side is positive if leisure is complementary with the dirty good in the sense that $X^{i,l} - \hat{X}^{i,h} < 0$, and negative if leisure is substitutable for the dirty good in the sense that $X^{i,l} - \hat{X}^{i,h} > 0$. The intuition is that the government may relax the self-selection constraint by implementing a higher (lower) commodity tax on goods that are complementary with (substitutable for) leisure, *ceteris paribus*¹⁵. The second term on the right hand side appears because a higher commodity tax reduces the world-market producer price of the dirty good which, in turn, affects the wage distribution. If $\partial \phi^i / \partial P > 0$ (< 0), an increase in this producer price makes mimicking less (more) attractive, which provides an incentive for the government to implement a lower (higher) commodity tax than it would otherwise have done.

The third term on the right hand side of the tax formula in Proposition 2 represents a terms of trade effect; as such, its qualitative influence on the tax depends on whether country i is a net exporter or a net importer of the dirty good. If the country is a net exporter, meaning that $NX^i > 0$, a higher producer price of the dirty good increases the value of the net export which, itself, is welfare improving and can be accomplished by lowering the commodity tax (recall that $\partial P / \partial t^i < 0$). In this case, therefore, the third term on the right hand side contributes to reduce the commodity tax. The effect would be the opposite, if country i is a net importer of the dirty good.

The desire to correct for the externality imposed on the domestic residents is captured by the fourth term on the right hand side, which reflects the additivity property discussed by Sandmo (1980). However, an important difference by comparison with earlier literature is that this effect is here scaled down with the factor $\varphi^i < 1$. The intuition is that, by implementing a smaller t^i than would be required by full (domestic) externality-correction, it follows that the domestic demand for the dirty good increases. Such a policy leads to a higher world-market producer price of the dirty good which, in turn, reduces the demand for the dirty good by the residents in the other country. The latter contributes to reduce E and is, therefore, welfare improving from the point of view of country i .

¹⁵Recall that the mimicker faces the same before-tax and disposable income as the low-ability type. Therefore, in the special case where leisure is weakly separable in terms of the utility function, we have $X^{i,l} - \hat{X}^{i,h} = 0$.

To further highlight the interpretation of the fourth term on the right hand side of the tax formula in Proposition 2, i.e. in order to focus solely on externality-correction, we consider the following special case;

Corollary 1. *In a symmetric noncooperative Nash equilibrium ($NX^i = 0$), and if the self-selection constraint does not bind ($\lambda^i = 0$), the commodity tax on the dirty good reduces to*

$$t^i = \varphi^i \frac{\mu^i}{\gamma^i} < \frac{\mu^i}{\gamma^i}.$$

The corollary means that the commodity tax falls short of the marginal value that each national government attaches to reduced environmental damage; in other words, the externality-correcting tax falls short of the tax that would follow from a standard Pigouvian tax formula for the domestic economy, i.e. μ^i/γ^i . Therefore, and by comparison with a globally optimal resource allocation, each national government does not only neglect that the environmental damage generated by the domestic residents affects the well-being of the residents in the other country; it also reduces the tax below the marginal value it attaches to the domestic externality in order to increase the world-market producer price of the externality-generating good, which reinforces the inefficient use of environmental policy in the Nash equilibrium.

4.2 The Production Tax

In a standard model for mixed taxation with fixed producer prices, in which the environmental damage depends on the aggregate consumption of the dirty good, production taxes would be redundant. In our framework, on the other hand, the production tax is not redundant. We can derive the following result;

Proposition 3. *In the noncooperative Nash equilibrium, the production tax implemented by country i is given by*

$$\tau^i = \frac{\chi^i}{\gamma^i} \frac{\partial \mathcal{L}^i}{\partial P}$$

where

$$\chi^i = - \frac{\partial P / \partial \tau^i}{\left(\partial F_x^i / \partial L_x^{i,h} \right) \sum_j (\partial L_x^{i,j} / \partial \tau^i) P} > 0$$

in which $\partial P/\partial \tau^i > 0$ and $\sum_j \partial L_x^{i,j}/\partial \tau^i < 0$.

Proof: See the Appendix.

Proposition 3 has a simple interpretation: if an increase in the world-market producer price leads to higher (lower) domestic welfare, then the government in country i will implement a positive (negative) production tax on the dirty good. Note also that, although the endogeneity of the world-market producer price is the only mechanism via which the production tax is operative, the production tax will, nevertheless, serve multiple purposes. This is seen from equation (24), where the national welfare effect of an increase in the world-market producer price is shown to depend on (i) a component relating to the wage distribution (which is due solely to the self-selection constraint), (ii) a terms of trade effect and (iii) a component representing externality-correction.

To illustrate the corrective role of the production tax more thoroughly, consider once again the special case of a symmetric equilibrium, in which we also add the assumption that the self-selection constraint does not bind;

Corollary 2. *In a symmetric noncooperative Nash equilibrium ($NX^i = 0$), and if the self-selection constraint does not bind ($\lambda^i = 0$), the production tax in country i reduces to*

$$\tau^i = -\frac{\mu^i \chi^i}{\gamma^i \beta^i} \sum_{j=h,l} \frac{\partial X^{k,j}}{\partial Q^k} > 0$$

for $k \neq i$.

In this case, therefore, the only reason for implementing a (positive) production tax is to increase the world-market producer price of the dirty good, which provides environmental benefits to country i as the consumption of the dirty good in the other country decreases. The motivation for using the corrective production tax highlighted by the corollary also relates to a more general result: if the government has fewer effective policy instruments than the number of variables it wishes to control, then the commodity tax on the dirty good no longer constitutes a perfect environmental policy instrument. The intuition is that the domestic government cannot use the commodity tax to control both the domestic and foreign consumption of the dirty good. Therefore, the government also uses other policy instruments - in this case the production tax - for the explicit purpose of externality-correction.

4.3 Labor Income Taxation

The arguments behind the use of commodity and production taxation also carry over, in a natural way, to the incentive structure underlying marginal income taxation. To shorten the tax formulas to be discussed below, let

$$MRS_{Z,B}^{i,j} = \frac{V_Z^{i,j}}{V_B^{i,j}} \text{ and } \widehat{MRS}_{Z,B}^{i,h} = \frac{\widehat{V}_Z^{i,h}}{\widehat{V}_B^{i,h}}$$

denote the marginal rate of substitution between leisure and private (disposable) income for ability-type j and the mimicker, respectively. We also use the short notations

$$\begin{aligned} \frac{\partial \tilde{X}^{i,j}}{\partial Z^{i,j}} &= \frac{\partial X^{i,j}}{\partial Z^{i,j}} - MRS_{Z,B}^{i,j} \frac{\partial X^{i,j}}{\partial B^{i,j}} \\ \Psi^{i,j} &= - \frac{\partial S_x^i / \partial L^{i,l} + \partial \tilde{X}^{i,l} / \partial Z^{i,l}}{\alpha} \end{aligned}$$

for how the conditional compensated demand for the dirty good changes in response to an increase in the use of leisure by ability-type j , and how the world-market producer price responds to a utility-compensated increase in the labor supply by ability-type j , respectively. Consider the following result;

Proposition 4. *In the noncooperative Nash equilibrium, the marginal income tax rates implemented by country i can be written as*

$$\begin{aligned} T_I^{i,l}(w^{i,l}L^{i,l}) &= \frac{\lambda^{i,*}}{w^{i,l}} \left(MRS_{Z,B}^{i,l} - \phi^i \widehat{MRS}_{Z,B}^{i,h} \right) - \frac{\lambda^{i,*} L^{i,l}}{w^{i,l}} \widehat{MRS}_{Z,B}^{i,h} \frac{\partial \phi^i}{\partial L^{i,l}} \\ &+ \left(t^i - \frac{\mu^i}{\gamma^i} \right) \frac{1}{w^{i,l}} \frac{\partial \tilde{X}^{i,l}}{\partial Z^{i,l}} - \frac{\Psi^{i,l}}{w^{i,l} \gamma^i} \frac{\partial \mathcal{L}^i}{\partial P} \end{aligned}$$

$$\begin{aligned} T_I^{i,h}(w^{i,h}L^{i,h}) &= - \frac{\lambda^{i,*} L^{i,l}}{w^{i,h}} \widehat{MRS}_{Z,B}^{i,h} \frac{\partial \phi^i}{\partial L^{i,h}} \\ &+ \left(t^i - \frac{\mu^i}{\gamma^i} \right) \frac{1}{w^{i,h}} \frac{\partial \tilde{X}^{i,h}}{\partial Z^{i,h}} - \frac{\Psi^{i,h}}{w^{i,h} \gamma^i} \frac{\partial \mathcal{L}^i}{\partial P}. \end{aligned}$$

Proof: See the Appendix.

The tax formulas in Proposition 4 distinguish between three basic motives for influencing the hours of work; (i) to relax the self-selection constraint (via channels not directly linked to the world-market producer price), (ii) to compensate the consumer for distortions created by the (less flexible) commodity tax, and (iii) to influence the world-market producer price of the dirty good.

We start by discussing the marginal income tax rate implemented for the low-ability type. The first motive for using income taxation mentioned above is captured by the first row on the right hand side, where both terms are analogous to results derived in earlier research (Stiglitz 1982). As the mimicker needs to forego less leisure than the low-ability type to accomplish a given increase in the before-tax income, one can show that $MRS_{Z,B}^{i,l} - \phi^i \widehat{MRS}_{Z,B}^{i,h} > 0$, which means that the first term on the right hand side contributes to increase the marginal income tax rate. The second term on the right hand side in the tax formula for the low-ability type, and the first term on the right hand side in the tax formula for the high-ability type, reflect that a change in the hours of work affects the wage distribution. If (as in Stiglitz 1982) $\partial\phi^i/\partial L^{i,l} < 0$ and $\partial\phi^i/\partial L^{i,h} > 0$, a decrease in the hours of work supplied by the low-ability type and an increase in the hours of work supplied by the high-ability type will contribute to reduce the wage inequality and, therefore, relax the self-selection constraint. As a consequence, these effects contribute to increase the marginal income tax rate of the low-ability type and decrease the marginal income tax rate of the high-ability type.

The first part of the second row in each tax formula in Proposition 4 serves to compensate the consumer for distortions created by the commodity tax¹⁶. To see the intuition behind this result, note that the government has no direct motive besides externality-correction to distort the consumption of the dirty good; in other words, the self-selection component, the terms of trade effect and the producer price effect only appear in the commodity tax formula in Proposition 2 because the government lacks direct tax instruments to relax the self-selection constraint and/or fully control the world-market producer price.

¹⁶This motive for using marginal income taxation was also addressed by Aronsson et al. (2006); let be in a simplified model without asymmetric information.

Therefore, if $t^i \neq \mu^i/\gamma^i$ at the optimum, the government may (in part) use marginal income taxation to compensate the consumers for the distortionary effect caused by the commodity tax. For instance, if $t^i > \mu^i/\gamma^i$, the commodity tax is interpretable as being 'too high' from the perspective of pure externality-correction, in which case it is welfare improving to stimulate the consumption of the dirty good. This constitutes, in turn, an incentive for the government to implement a higher marginal income tax rate if leisure is complementary with the dirty good ($\partial\tilde{X}^{i,j}/\partial Z^{i,j} > 0$), and a lower marginal income tax rate if leisure is substitutable for the dirty good ($\partial\tilde{X}^{i,j}/\partial Z^{i,j} < 0$), than it would otherwise have done. The argument will be the opposite if $t^i < \mu^i/\gamma^i$.

The second part of the second row in each tax formula in the proposition depends on the joint effect of two mechanisms; how the world-market producer price of the dirty good changes in response to an increase in the hours of work (captured by $\Psi^{i,j}$), and how an increase in the world-market producer price affects the domestic welfare (captured by $\partial\mathcal{L}^i/\partial P$). If, as one would normally expect, the world-market producer price decreases in response to an increase in the hours of work supplied domestically in the sense that $\Psi^{i,j} < 0$, and if an increase in the world-market producer price leads to higher domestic welfare, there is an incentive for the government to implement a higher marginal income tax rate for ability-type j than it would otherwise have done. The intuition behind other possible sign-combinations for $\Psi^{i,j}$ and $\partial\mathcal{L}^i/\partial P$ is analogous. Once again, note that the sign of $\partial\mathcal{L}^i/\partial P$ reflects a desire to reduce the wage inequality (which relaxes the self-selection constraint) and a desire to correct for the environmental externality; therefore, the incentive created by the producer price effect is a mixture of several underlying motives for tax policy.

To take the interpretation of the second row of each tax formula in Proposition 4 a bit further, we may use the expression for t^i in Proposition 2 and substitute into the expressions for the marginal income tax rates. The second row of the expression for the marginal income tax rate may then be rewritten as

$$\begin{aligned}
& - \left(t^i - \frac{\mu^i}{\gamma^i} \right) \frac{1}{w^{i,j}} \frac{\partial \tilde{X}^{i,j}}{\partial Z^{i,j}} - \frac{\Psi^{i,j}}{w^{i,j} \gamma^i} \frac{\partial \mathcal{L}^i}{\partial P} \\
& = \frac{\lambda^{i,*} \left(X^{i,l} - \hat{X}^{i,h} \right)}{w^{i,j} [\sum_j \partial \tilde{X}^{i,j} / \partial Q^i]} \frac{\partial \tilde{X}^{i,j}}{\partial Z^{i,j}} + \frac{1}{\alpha w^{i,j} \gamma^i} \frac{\partial S_x^i}{\partial L^{i,j}} \frac{\partial \mathcal{L}^i}{\partial P}.
\end{aligned} \tag{25}$$

In equation (25), the first term on the right hand side shows how a self-selection component familiar from the commodity tax formula (see Proposition 2) reappears in the expression for the marginal income tax rate. If $X^{i,l} - \hat{X}^{i,h} < 0$, in which case this self-selection component contributes to increase the commodity tax (and, therefore, reduce the consumption of the dirty good, *ceteris paribus*), there will be an incentive for the government to increase the consumption of the dirty good via the income tax. With $\partial \tilde{X}^{i,j} / \partial Z^{i,j} > 0$ (< 0), this mechanism means that the government implements a higher (lower) marginal income tax rate than it would otherwise have done. Incentive effects opposite to those just described will apply if $X^{i,l} - \hat{X}^{i,h} > 0$. The second term on the right hand side is also straight forward; if $\partial \mathcal{L}^i / \partial P > 0$, the government has an incentive to increase P , meaning that it will try to decrease the supply of the dirty good. This may, in turn, be accomplished by discouraging the labor supply via a higher marginal income tax rate. Again, the intuition is analogous if $\partial \mathcal{L}^i / \partial P < 0$.

Finally, note that Proposition 4 does not presuppose that the production tax is suboptimal from the perspective of the domestic government. In other words, as the national government is not able to perfectly control the world-market producer price of the externality-generating good by any single tax instrument, all tax instruments will be used, in part, for the purpose of exercising (let be imperfect) control of the world-market producer price.

As we did before, let us also here briefly address the corrective role of taxation by considering the special case of a symmetric equilibrium, in which we also add the assumption that the self-selection constraint does not bind. We can then derive the following corollary to Proposition 4;

Corollary 3. *In a symmetric noncooperative Nash equilibrium ($NX^i = 0$), and if the self-selection constraint does not bind ($\lambda^i = 0$), the marginal income tax rates reduce to*

$$T_I^{i,j} (w^{i,j} L^{i,j}) = \frac{\mu^i}{\gamma^i} \varepsilon^{i,j} > 0 \text{ for } \frac{\mu^i}{\gamma^i} > 0$$

for $j = l, h$, where

$$\varepsilon^{i,j} = -\frac{1}{\alpha\beta^i w^{i,j}} \frac{\partial S_x^i}{\partial L^{i,j}} \sum_{j=h,l} \frac{\partial X^{k,j}}{\partial Q^k} > 0 \text{ for } k \neq i.$$

Therefore, in the special case, the government implements (positive) marginal income tax rates in order to increase the world-market producer price. With t^k held constant, this will reduce the foreign consumption of the dirty good, which leads to higher domestic welfare.

4.4 Public Good Provision

Define

$$MRS_{G,B}^{i,j} = \frac{V_G^{i,j}}{V_B^{i,j}} \text{ and } \widehat{MRS}_{G,B}^{i,h} = \frac{\widehat{V}_G^{i,h}}{\widehat{V}_B^{i,h}}$$

to be the marginal rate of substitution between the public good and private disposable income for ability-type j and the mimicker, respectively, and

$$MRT_{C,G}^i = \frac{\partial F_c^i / \partial L^{i,l}}{\partial F_G^i / \partial L_G^{i,l}}$$

to be the marginal rate of transformation¹⁷ between the numeraire private good and the public good. The provision of the public good is characterized by the following optimality condition from the perspective of country i ;

¹⁷A cost benefit rule equivalent to that in Proposition 5 can be derived, if the first order condition for $L_G^{i,h}$ (instead of the first order condition for $L_G^{i,l}$) is used to calculate the marginal rate of transformation between the numeraire private good and the public good. This is seen by combining equations (A7) and (A8), which gives

$$\begin{aligned} & \frac{\partial F_c^i / \partial L^{i,l}}{\partial F_G^i / \partial L_G^{i,l}} - \frac{\partial S_x^i / \partial L^{i,l}}{\alpha\gamma^i (\partial F_G^i / \partial L_G^{i,l})} \frac{\partial \mathcal{L}^i}{\partial P} \\ &= \frac{\partial F_c^i / \partial L^{i,h}}{\partial F_G^i / \partial L_G^{i,h}} - \frac{\partial S_x^i / \partial L^{i,h}}{\alpha\gamma^i (\partial F_G^i / \partial L_G^{i,h})} \frac{\partial \mathcal{L}^i}{\partial P}. \end{aligned}$$

Proposition 5. *In the noncooperative Nash equilibrium, the provision of the national public good in country i is characterized by*

$$\sum_{j=l,h} MRS_{G,B}^{i,j} = MRT_{C,G}^i - \lambda^{i,*} [MRS_{G,B}^{i,l} - \widehat{MRS}_{G,B}^{i,h}]$$

$$- [t^i - \frac{\mu^i}{\gamma^i}] \sum_{j=l,h} \frac{\partial \tilde{X}^{i,j}}{\partial G^i} - \frac{1}{\alpha \gamma^i} \left[\sum_{j=l,h} \frac{\partial \tilde{X}^{i,j}}{\partial G^1} + \frac{\partial S_x^i / \partial L^{i,l}}{\partial F_G^i / \partial L_G^i} \right] \frac{\partial \mathcal{L}^i}{\partial P}.$$

Proof: See the Appendix.

Let us start by interpreting the first row of the formula in Proposition 5. The left hand side represents the sum of marginal rates of substitution between the public good and private consumption (i.e. the consumers' marginal willingness to pay for the public good), whereas the right hand side contains the marginal rate of transformation between the public good and the numeraire as well as a direct effect created by the self-selection constraint. Therefore, if the terms in the second row were absent, and if leisure is substitutable for (complementary with) the public good in the sense that $MRS_{G,B}^{i,l} - \widehat{MRS}_{G,B}^{i,h} > 0$ (< 0), we may relax the self-selection constraint by overproviding (underproviding) the public good relative to the Samuelson rule. This result is well understood from Boadway and Keen (1993).

The second row of the formula in Proposition 5 is, in a sense, analogous to the corresponding effects in the expressions for the marginal income tax rates (given by the second row of each formula in Proposition 4). To see this more clearly, suppose first that $t^i > \mu^i / \gamma^i$, in which case the commodity tax on the dirty good is 'too high' from the perspective of pure externality-correction. This mechanism constitutes, in turn, an incentive for the government to stimulate the consumption of the dirty private good by adjusting its provision of the public good. Accordingly, if the public good is complementary with (substitutable for) the dirty private good in the sense that $\partial \tilde{X}^{i,j} / \partial G^i > 0$ ($\partial \tilde{X}^{i,j} / \partial G^i < 0$), the government will provide more (less) of the public good than it would otherwise have done. The interpretation is analogous - yet with the opposite policy incentives - if $t^i < \mu^i / \gamma^i$. Once again, the intuition is that the government uses its other policy instruments, in this case the public good, at least in part

to compensate the consumers for the distortionary effect created by the commodity tax¹⁸.

Turning finally to the second part of the second row, which measures the policy incentives associated with the world-market producer price of the dirty good, there are two channels via which the provision of the public good can influence P . The first is via the demand for the dirty good. To illustrate, suppose first that an increase in the world-market producer price increases the domestic welfare (due, for instance, to decreased consumption of the dirty good abroad and/or that country i is a net exporter of the dirty good). In this case, and if the public good is complementary with (substitutable for) the dirty good in the sense that $\partial \tilde{X}^{i,j} / \partial G^i > 0$ (< 0), an increase (a decrease) in G^i leads to a higher world-market produce price and, therefore, higher domestic welfare. The second channel by which the government may influence the world-market producer price of the dirty good is via the supply side. If the government increases the supply of the public good, then the resources available to the private sector will decrease which, in turn, reduces the supply of the dirty private good. Again, the policy incentives will be the opposite to those just described if an increase in the world-market producer price leads to lower domestic welfare.

The assumption that the world-market producer price is endogenous for each national government is also important from the point of view of public production. We can derive the following production-inefficiency result¹⁹;

Corollary 4. *In the noncooperative Nash equilibrium, the production of the public good is, in general, characterized by production inefficiency in the sense that*

$$\frac{\partial F_c^i / \partial L^{i,l}}{\partial F_G^i / \partial L_G^{i,l}} \neq \frac{\partial F_c^i / \partial L^{i,h}}{\partial F_G^i / \partial L_G^{i,h}}.$$

The intuition behind this result is, of course, that a reallocation of low-ability

¹⁸ Another possible interpretation of the first term in the second row is that it captures a tax revenue effect of the public good; see e.g. Edwards et al. (1994) for such an interpretation of a corresponding term in a model without environmental externalities (i.e. where $\mu^i / \gamma^i = 0$). This interpretation is, perhaps, less obvious in our framework, since $t^i - \mu^i / \gamma^i$ times the change in the compensated conditional demand only measures part of the associated effect on the tax revenues.

¹⁹ This is analogous to Naito (1999).

labor from private to public production does not, in general, affect the world-market producer price in the same way as a corresponding reallocation of high-ability labor from private to public production. Therefore, this production-inefficiency result is solely due to the ability of the national government to influence the world-market producer price: if this price were fixed (as in the context of small open economies), the public production would be characterized by production-efficiency.

Let us finally consider the special case with a symmetric equilibrium with a non-binding self-selection constraint, which we also did in connection to the optimal tax structure. The following result is a direct consequence of Proposition 5;

Corollary 5. *In a symmetric noncooperative Nash equilibrium ($NX^i = 0$), and if the self-selection constraint does not bind ($\lambda^i = 0$), the optimal provision of the public good is characterized by*

$$\sum_{j=l,h} MRS_{G,B}^{i,j} = MRT_{C,G}^i + \frac{\mu^i}{\gamma^i} \psi^i < MRT_{C,G}^i \text{ for } \frac{\mu^i}{\gamma^i} > 0$$

where (for $k \neq i$)

$$\psi^i = \frac{\sum_{j=l,h} \partial S_x^i / \partial L^{i,j}}{\sum_{j=l,h} \partial F_G^i / \partial L_G^{i,j}} \frac{\sum_{j=l,h} (\partial X^{k,j} / \partial Q^k)}{\sum_{n=1,2} (\partial S_x^n / \partial P) - \sum_{j=h,l} (\partial X^{k,j} / \partial Q^k)} < 0.$$

In the special case exemplified by the corollary, the government in country i attempts to push up the world-market producer price of the dirty good in order to reduce the environmental damage created abroad. It does so by overproviding the public good relative to the Samuelson rule, which reduces the amount of resources available to the private sector and, therefore, the supply of the dirty private good.

5 Policy Coordination

As the noncooperative Nash equilibrium analyzed in section 4 is inefficient from the perspective of both countries, policy coordination becomes interesting to consider. Here, we do not interpret the concept of 'coordination' such that the

countries pool their resources in order to implement a cooperative equilibrium (even if this is a common approach in earlier literature). It is more realistic to assume that they agree upon smaller projects, the purposes of which are to improve the resource allocation by comparison with the noncooperative Nash equilibrium analyzed above. We will not discuss the conditions under which such international agreements are likely to be formed; only the welfare consequences if they arise.

Note that all public decision-variables have already been optimally chosen on a national basis in the noncooperative Nash equilibrium. Therefore, a coordinated infinitesimal change in one or several policy instruments only affects welfare because changes in the public decision-variables in country i give rise to welfare effects in country k and vice versa. Let us begin by characterizing the cost benefit rule. By observing that the national welfare function facing any country, i , equals the national Lagrangean in the noncooperative Nash equilibrium, i.e. $W^i = \mathcal{L}^i$, a straight forward application of the Envelope Theorem implies

$$dW^i = \sum_{j=l,h} \theta_L^{i,j} dL^{k,j} + \sum_{j=l,h} \theta_G^{i,j} dL_G^{k,j} + \theta_t^i dt^k + \sum_{j=l,h} \theta_B^{i,j} dB^{k,j} + \theta_\tau^i d\tau^k \quad (26)$$

for $k \neq i$, where (for $j = l, h$)

$$\theta_L^{i,j} = \mu^i \frac{\partial X^{k,j}}{\partial Z^{k,j}} + \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial L^{k,j}}$$

$$\theta_G^{i,j} = \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial L_G^{k,j}}$$

$$\theta_t^i = -\mu^i \sum_{j=l,k} \frac{\partial X^{k,j}}{\partial Q^k} + \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial t^k}$$

$$\theta_B^{i,j} = -\mu^i \frac{\partial X^{k,j}}{\partial B^{k,j}} + \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial B^{k,j}}$$

$$\theta_\tau^i = \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial \tau^k}.$$

Equation (26) implies that a policy reform may influence welfare via two channels; a direct effect on the foreign demand for the dirty good and an indirect effect via the world-market producer price. To simplify the analysis slightly,

let us add the (relatively common) assumption that the public good and the environmental damage are both weakly separable from the other goods in terms of the utility function. The simplification gained by this assumption is that neither the national public goods nor the environmental damage will directly affect the world-market producer price. Then, by assuming that the noncooperative Nash equilibrium described in the previous section constitutes the prereform equilibrium, and if each national government attaches a positive marginal value to reduced environmental damage (as we assumed above), we can immediately derive the following result from equation (26);

Proposition 6. *If $U^{n,j}$ is weakly separable in G^n and E and if $\partial \mathcal{L}^n / \partial P > 0$ (< 0) for $n = 1, 2$, a coordinated increase (decrease) in the production tax accompanied by a budget-balancing increase (decrease) in the resources spent on public production - with the hours of work and disposable income of each ability-type and the commodity tax held constant - leads to increased welfare. Furthermore, if $\partial \mathcal{L}^n / \partial P > 0$ and $\partial \phi^n / \partial P \leq 0$ for $n = 1, 2$, and if the net export is small enough not to be a dominant source of welfare change following increased commodity taxation, then a coordinated increase in the commodity tax accompanied by a budget-balancing increase in the resources spent on public production - with the hours of work and disposable income of each ability-type and the production tax held constant - leads to increased welfare.*

Proof: See the Appendix.

The intuition behind the first part of Proposition 6 is straight forward. A higher production tax in, say, country k contributes to increase the world-market producer price, ceteris paribus, which is desirable (undesirable) from the perspective of country i if $\partial \mathcal{L}^i / \partial P > 0$ ($<$). In addition, if country k uses the additional tax revenues to increase the public production - while the income tax is adjusted in such a way that the hours of work and private disposable income are held constant - the world-market producer price will increase even further, since the supply of the dirty good becomes smaller when resources are reallocated from the private to the public sector. In the second part of the proposition, the condition imposed on the net export is to avoid that that the sign of the national welfare change caused by an increase in the other country's commodity tax becomes dependent on whether the net export is positive or negative. The

intuition behind the second part is that an increase in the commodity tax in country k decreases the demand for the dirty good in country k ; this is welfare improving for country i as long as the associated decrease in the world-market producer price does not give rise to more wage inequality. Increased public production then plays the same role as in the first part of the proposition.

To take the analysis a step further, and by analogy to Corollaries 1, 2, 3 and 5, let us consider policy coordination in the special case where the prereform Nash equilibrium is symmetric and the self-selection constraint does not bind. As before, this special case enables us to address the corrective role of the tax and expenditure policies in a framework simple enough to derive several unambiguous results. By focusing on pairwise changes, which is a minimum requirement for budget balance for each national government, we can generalize Proposition 6 as follows;

Proposition 7. *If the prereform resource allocation is a symmetric noncooperative Nash equilibrium, if the self-selection constraint does not bind, and given the separability assumption in Proposition 6, it is welfare improving to;*

(i) increase the production tax - while the hours of work and private disposable income of each ability-type and the commodity tax are held constant - and then use the additional tax revenues to increase the public production,

(ii) increase the commodity tax - while the hours of work and private disposable income of each ability-type and the production tax are held constant - and then use the additional tax revenues to increase the public production,

(iii) reduce the hours of work and private disposable income simultaneously for each ability-type with the commodity and production taxes held constant, such that the tax revenues remain fixed, provided that leisure is not a strong enough substitute for the dirty good to completely offset the increase in the world-market producer price caused by a decrease in the supply of the dirty good, or

(iv) reduce the private disposable income - while the hours of work as well as the commodity and production taxes are held constant - and use the additional tax revenues to increase the public production.

The intuition behind policy reforms (i) and (ii) is the same as in the context of

Proposition 6 above; the only difference here is that the domestic welfare effect for country i of an increase in the world-market producer price reduces to

$$\frac{\partial \mathcal{L}^i}{\partial P} = -\frac{\mu^i}{\beta^i} \sum_{j=h,l} \frac{\partial X^{k,j}}{\partial Q^k} > 0$$

for $\mu^i > 0$, $i = 1, 2$ and $k \neq i$.

From the perspective of any country, i , policy reform (iii) is interpretable to mean $dL^{k,j} < 0$, $dB^{k,j} < 0$ and $dt^k = d\tau^k = dL_G^{k,j} = 0$ (for $k \neq i$ and $j = l, h$). Increased marginal income taxation in country k (which reduces $L^{k,j}$) is here accompanied by increased average income taxation (which reduces $B^{k,j}$). A smaller number of work hours leads to reduced supply of the dirty private good (recall that the resources used for public production are held constant), which gives rise to an increase in the world-market producer price of the dirty good. Furthermore, reduced private disposable income leads to lower demand for the dirty good in country k which is, in turn, welfare improving from the perspective of country i .

Finally, and again from the perspective of country i , we may interpret policy reform (iv) to imply $dB^{k,j} < 0$, $dL_G^{k,j} > 0$ and $dt^k = d\tau^k = dL^{k,j} = 0$ (for $k \neq i$ and $j = l, h$). This can be accomplished by a combination of higher marginal and average income taxation in such a way that the hours of work are held constant. As we mentioned above, a reduction in the private disposable income is, itself, welfare improving, as it leads to reduced demand for the dirty good abroad. Spending the additional tax revenues on public production, then means a reallocation of labor from the private to the public sector, which contributes to increase the world-market producer price of the dirty good and, therefore, decrease the foreign consumption of the dirty good.

6 Summary and Discussion

This paper concerns optimal taxation and public good provision in a two-country economy, where each country is characterized by two-ability types and asymmetric information between the government and the private sector. We assume that one of the consumption goods, referred to as a 'dirty' good, gives rise to transboundary environmental damage. Each national government faces a mixed tax problem, where the set of tax instruments consists of a nonlinear in-

come tax as well as linear commodity and production taxes on the dirty good. We also assume that each country is large in the sense that its government may significantly influence the world-market producer price of the externality-generating commodity via its tax and expenditure policies. The idea is to capture the incentives facing large actors on the environmental policy scene; an issue neglected in earlier comparable literature on mixed taxation.

We would like to emphasize the following results;

- In the noncooperative Nash equilibrium, the corrective component of the commodity tax falls short of the marginal value that the national government attaches to reduced environmental damage.
- If, in the noncooperative Nash equilibrium, an increase in the world-market producer price leads to higher (lower) domestic welfare - which, in turn, depends on the properties of the wage distribution and whether or not the country is a net exporter of the dirty good - the national government will implement a positive (negative) production tax on the dirty good.
- If, in the noncooperative Nash equilibrium, an increase in the world-market producer price leads to higher (lower) domestic welfare - and by comparison with the situation where the world-market producer price of the dirty good is fixed - the public policy also reflects a motive to reduce (increase) the hours of work and/or increase (decrease) the hours of work spent in public production relative to the hours of work spent in private production. As a consequence, the endogenous world-market producer price also affects the incentives underlying marginal income taxation and public good provision.
- The public production is characterized by production-inefficiency.
- In the noncooperative Nash equilibrium, the national government also (in part) uses the income tax and provision of the public good to compensate the consumers for distortions created by the commodity tax.
- Welfare improving policy coordination - where the noncooperative Nash equilibrium constitutes the prereform equilibrium - may include increased commodity and/or production taxation with the additional tax revenues spent on public production.

As a complement to the more general model, we have also analyzed the corrective role of taxation and public provision in a special case, where the noncooperative Nash equilibrium is symmetric and the self-selection constraint does not bind. In the noncooperative Nash equilibrium, we can then show; (i) that the commodity tax (which is, in this case, a pure environmental tax) falls short of the marginal value that each national government attaches to reduced environmental damage, (ii) that each national government implements a positive production tax, and (iii) that the marginal income tax rates and level of the public good are higher than they would have been had the government perceived the world-market producer price of the dirty good as fixed. In addition to the policy coordination result mentioned above, we show in the special case that (iv) a simultaneous coordinated increase in the marginal and average tax rates (in both countries), and (v) a simultaneous coordinated increase in the average tax rate and the provision of the public good, can be designed to increase welfare by comparison with the noncooperative Nash equilibrium.

Possible extensions of the analysis carried out here would be to consider a model that contains both small and large open economies (which differ with respect to the perceived endogeneity of the world-market producer price) and by incorporating the individual jurisdictions into an economic federation. We leave these and other extensions for future research.

7 Appendix

The first order conditions for country i can be written as

$$B^{i,h} : 0 = (1 + \lambda^i) V_B^{i,h} + \gamma^i \left(t^i \frac{\partial X^{i,h}}{\partial B^{i,h}} - 1 \right) - \mu^i \frac{\partial X^{i,h}}{\partial B^{i,h}} + \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial B^{i,h}} \quad (\text{A.1})$$

$$\begin{aligned} L^{i,h} : 0 = & - (1 + \lambda^i) V_Z^{i,h} + \lambda^i \frac{\partial \phi^i}{\partial L^{i,h}} L^{i,l} \hat{V}_Z^{i,h} \\ & + \gamma^i \left(w^{i,h} - t^i \frac{\partial X^{i,h}}{\partial Z^{i,h}} \right) + \mu^i \frac{\partial X^{i,h}}{\partial Z^{i,h}} + \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial L^{i,h}} \end{aligned} \quad (\text{A.2})$$

$$B^{i,l} : 0 = V_B^{i,l} - \lambda^i \hat{V}_B^{i,h} + \gamma^i \left(t^i \frac{\partial X^{i,l}}{\partial B^{i,l}} - 1 \right) - \mu^i \frac{\partial X^{i,l}}{\partial B^{i,l}} + \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial B^{i,l}} \quad (\text{A.3})$$

$$\begin{aligned} L^{i,l} : 0 = & -V_Z^{i,h} + \lambda^i \hat{V}_Z^{i,h} \left(\phi^i + \frac{\partial \phi^i}{\partial L^{i,h}} L^{i,l} \right) \\ & + \gamma^i \left(w^{i,l} - t^i \frac{\partial X^{i,l}}{\partial Z^{i,l}} \right) + \mu^i \frac{\partial X^{i,l}}{\partial Z^{i,l}} + \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial L^{i,l}} \end{aligned} \quad (\text{A.4})$$

$$\begin{aligned} t^i : 0 = & - (1 + \lambda^i) X^{i,h} V_B^{i,h} - X^{i,l} V_B^{i,l} + \lambda^i \hat{X}^{i,h} \hat{V}_B^{i,h} + \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial t^i} \\ & + \gamma^i \left[X^{i,h} + X^{i,l} + t^i \left(\frac{\partial X^{i,h}}{\partial Q^i} + \frac{\partial X^{i,l}}{\partial Q^i} \right) \right] - \mu^i \left(\frac{\partial X^{i,h}}{\partial Q^i} + \frac{\partial X^{i,l}}{\partial Q^i} \right) \end{aligned} \quad (\text{A.5})$$

$$\begin{aligned} G^i : 0 = & (1 + \lambda^i) V_G^{i,h} + V_G^{i,l} - \lambda^i \hat{V}_G^{i,h} - \rho^i + \gamma^i t^i \left(\frac{\partial X^{i,h}}{\partial G^i} + \frac{\partial X^{i,l}}{\partial G^i} \right) \\ & - \mu^i \left(\frac{\partial X^{i,h}}{\partial G^i} + \frac{\partial X^{i,l}}{\partial G^i} \right) + \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial G^i} \end{aligned} \quad (\text{A.6})$$

$$L_G^{i,l} : \rho^i \frac{\partial F_G^i}{\partial L_G^{i,l}} - \gamma^i \frac{\partial F_c^i}{\partial L_c^{i,l}} + \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial L_G^{i,l}} = 0 \quad (\text{A.7})$$

$$L_G^{i,h} : \rho^i \frac{\partial F_G^i}{\partial L_G^{i,h}} - \gamma^i \frac{\partial F_c^i}{\partial L_c^{i,h}} + \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial L_G^{i,h}} = 0 \quad (\text{A.8})$$

$$\begin{aligned} E : 0 &= (1 + \lambda^i) V_E^{i,h} + V_E^{i,l} - \lambda^l \hat{V}_E^{i,h} + \gamma^{it^i} \sum_j \frac{\partial X^{i,j}}{\partial E} \\ &+ \mu^i \left[1 - \sum_n \sum_j \frac{\partial X^{n,j}}{\partial E} \right] + \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial E} \end{aligned} \quad (\text{A.9})$$

$$\begin{aligned} \tau^i : 0 &= \gamma^i \left[\left(P \frac{\partial F_x^i}{\partial L_x^{i,h}} - \frac{\partial F_c^i}{\partial L_c^{i,h}} \right) \frac{\partial L_x^{i,h}}{\partial \tau^1} + \left(P \frac{\partial F_x^i}{\partial L_x^{i,l}} - \frac{\partial F_c^i}{\partial L_c^{i,l}} \right) \frac{\partial L_x^{i,l}}{\partial \tau^1} \right] \\ &+ \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial \tau^1}. \end{aligned} \quad (\text{A.10})$$

Note also that

$$\begin{aligned} \frac{\partial \mathcal{L}^i}{\partial P} &= - (1 + \lambda^i) X^{i,h} V_B^{i,h} - X^{i,l} V_B^{i,l} + \lambda^i \hat{X}^{i,h} \hat{V}_B^{i,h} + \lambda^i \frac{\partial \phi^i}{\partial P} L^{i,l} \hat{V}_Z^{i,h} \\ &+ \gamma^i \left[\sum_j X^{i,j} + NX^i + t^i \sum_j \frac{\partial X^{i,j}}{\partial Q^i} \right] \\ &- \mu^i \sum_n \sum_j \frac{\partial X^{n,j}}{\partial Q^i} \end{aligned} \quad (\text{A.11})$$

in which we have used that $S_x^i = \sum_j X^{i,j} + NX^i$, where NX^i is the net export of the dirty good. To simplify the expression for $\partial \mathcal{L}^i / \partial P$, define

$$\begin{aligned} A^i &= - (1 + \lambda^i) X^{i,h} V_B^{i,h} - X^{i,l} V_B^{i,l} + \lambda^i \hat{X}^{i,h} \hat{V}_B^{i,h} \\ &+ \gamma^i \left[\sum_j X^{i,j} + t^i \sum_j \frac{\partial X^{i,j}}{\partial Q^i} \right] - \mu^i \sum_j \frac{\partial X^{i,j}}{\partial Q^j} \end{aligned} \quad (\text{A.12})$$

and note that the first order condition for t^i can be written as

$$A^i + \left[A^i + \lambda^i \frac{\partial \phi^i}{\partial P} L^{i,l} \hat{V}_Z^{i,h} + \gamma^i NX^i - \mu^i \sum_j \frac{\partial X^{k,j}}{\partial Q^k} \right] \frac{\partial P}{\partial t^k} = A^i + \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial t^k} = 0 \quad (\text{A.13})$$

for $k \neq i$ (note that k is used here to denote the 'other country'). Therefore, by using equations (A11) and (A13), we have

$$\frac{\partial \mathcal{L}^i}{\partial P} = \lambda^i \frac{\partial \phi^i}{\partial P} L^{i,l} \hat{V}_Z^{i,h} + \gamma^i NX^1 - \mu^i \sum_j \frac{\partial X^{k,j}}{\partial Q^k} - \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial t^k}.$$

Rearrangement gives

$$\frac{\partial \mathcal{L}^i}{\partial P} = \frac{\lambda^i L^{i,l} \hat{V}_Z^{i,h} (\partial \phi^i / \partial P) + \gamma^i NX^i - \mu^i \sum_j \partial X^{k,j} / \partial Q^k}{1 + \partial P / \partial t^i}. \quad (\text{A.14})$$

Proof of Proposition 1

Define

$$\frac{\partial \tilde{X}^{i,j}}{\partial E} = \frac{\partial X^{i,j}}{\partial E} + \frac{\partial X^{i,j}}{\partial B^{i,j}} MW P_{E,B}^{i,j}. \quad (\text{A.15})$$

Substitute $V_E^{i,j} = -V_B^{i,j} MW P_{E,B}^{i,j}$ for $j = l, h$ into equation (A9). Next, use equations (A1) and (A3) to derive expressions for $V_B^{i,h}$ and $V_B^{i,l}$, respectively, and substitute into equation (A9). By using equation (A15), we can then derive

$$\begin{aligned} \frac{\mu^i}{\gamma^i} &= \sigma^i \left[\sum_j MW P_{E,B}^{i,j} + \frac{\lambda \hat{V}_B^{i,h}}{\gamma^i} \left(MW P_{E,B}^{i,l} - \widehat{MW P_{E,B}^{i,h}} \right) - t^i \sum_j \frac{\partial \tilde{X}^{i,j}}{\partial E} \right] \\ &\quad - \frac{\sigma^i}{\gamma^i} \frac{\partial \mathcal{L}^i}{\partial P} \left[\frac{\partial P}{\partial E} + \sum_j \frac{\partial P}{\partial B^{i,j}} MW P_{E,B}^{i,j} \right] \end{aligned} \quad (\text{A.16})$$

where

$$\begin{aligned} \frac{\partial P}{\partial E} &= \frac{1}{\alpha} \sum_n \sum_j \frac{\partial X^{n,j}}{\partial E} \\ \frac{1}{\sigma^i} &= \left[1 - \sum_j \frac{\partial \tilde{X}^{i,j}}{\partial E} - \sum_j \frac{\partial X^{k,j}}{\partial E} \right] \end{aligned}$$

for $k \neq i$.

Note that the expression within the square bracket in the second row of equation (A16) can be written as

$$\begin{aligned}
\frac{\partial P}{\partial E} + \sum_j \frac{\partial P}{\partial B^{i,j}} MW P_{E,B}^{i,j} &= \frac{1}{\alpha} \left(\sum_j \frac{\partial \tilde{X}^{i,j}}{\partial E} + \sum_j \frac{\partial X^{k,j}}{\partial E} \right) \\
&= -\frac{1}{\alpha} \left(1 - \sum_j \frac{\partial \tilde{X}^{i,j}}{\partial E} - \sum_j \frac{\partial X^{k,j}}{\partial E} - 1 \right) \\
&= -\frac{1}{\alpha} \left(\frac{1}{\sigma^i} - 1 \right).
\end{aligned}$$

Therefore,

$$\begin{aligned}
\frac{\mu^i}{\gamma^i} &= \sigma^i \left[\sum_j MW P_{E,B}^{i,j} + \frac{\lambda \hat{V}_B^{i,h}}{\gamma^i} \left(MW P_{E,B}^{i,l} - \widehat{MW P}_{E,B}^{i,h} \right) - t^i \sum_{j=h,l} \frac{\partial \tilde{X}^{i,j}}{\partial E} \right] \\
&\quad + \frac{1 - \sigma^i}{\alpha \gamma^i} \frac{\partial \mathcal{L}^i}{\partial P}.
\end{aligned} \tag{A.17}$$

Finally, by observing that the expression for $\partial \mathcal{L}^i / \partial P$ in equation (24) directly depends on μ^i / γ^i , we can derive the formula in Proposition 1. ■

Note also that if E is weakly separable in terms of the utility function, $1 - \sigma^i$ reduces to

$$1 - \sigma^i = -\sigma^i \sum_j \frac{\partial X^{i,j}}{\partial B^{i,j}} MW P_{E,B}^{i,j} < 0. \tag{A.18}$$

Proof of Proposition 2

By using equations (A1) and (A3) to derive expressions for $(1 + \lambda^i) V_B^{i,h}$ and $V_B^{i,l}$, respectively, substituting into equation (A5) and using the Slutsky condition gives

$$\begin{aligned}
0 &= -\lambda^i \hat{V}_B^{i,h} [X^{i,l} - \hat{X}^{i,h}] + \gamma^i t^i \sum_j \frac{\partial \tilde{X}^{i,j}}{\partial Q^i} - \mu^i \sum_j \frac{\partial \tilde{X}^{i,j}}{\partial Q^i} \\
&\quad + \frac{\partial \mathcal{L}^i}{\partial P} \left[\frac{\partial P}{\partial t^1} + \sum_j X^{i,j} \frac{\partial P}{\partial B^{i,j}} \right].
\end{aligned} \tag{A.19}$$

Note that equation (17) implies

$$\frac{\partial P}{\partial t^i} = \frac{\sum_j \partial X^{i,j} / \partial Q^i}{\alpha} < 0 \quad (\text{A.20})$$

$$\frac{\partial P}{\partial B^{i,j}} = \frac{\partial X^{i,j} / \partial B^{i,j}}{\alpha} > 0 \text{ for } j = l, h. \quad (\text{A.21})$$

Therefore, the expression within the square bracket in the second row of equation (A19) can be written as

$$\frac{\partial P}{\partial t^i} + \sum_j X^{i,j} \frac{\partial P}{\partial B^{i,j}} = \frac{1}{\alpha} \sum_j \frac{\partial \tilde{X}^{i,j}}{\partial Q^i} < 0.$$

Substituting into equation (A19) gives

$$t^i = \frac{\mu^i}{\gamma^i} + \frac{\lambda \hat{V}_B^{i,h}}{\gamma^i \Delta^i} (X^{i,l} - \hat{X}^{i,h}) - \frac{\partial \mathcal{L}^i}{\partial P} \frac{1}{\alpha \gamma^i} \quad (\text{A.22})$$

where $\Delta^i = \sum_j \partial \tilde{X}^{i,j} / \partial Q^i < 0$. Finally, by using the expression for $\partial \mathcal{L}^i / \partial P$ in equation (24) and substituting into equation (A22), we obtain the formula in Proposition 2. ■

Proof of Proposition 3

By using equations (9), we can rewrite equation (A10) to read

$$\tau^i P \underbrace{\frac{\partial F_x^i}{\partial L_x^{i,h}} \left(\frac{\partial L_x^{i,h}}{\partial \tau^i} + \frac{\partial L_x^{i,l}}{\partial \tau^i} \right)}_{-} + \frac{1}{\gamma^i} \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial \tau^i} = 0 \quad (\text{A.23})$$

where $\partial P / \partial \tau^i = -(\partial S_x^i / \partial \tau^i) / \alpha > 0$. Rearrangement gives the tax formula in the proposition. ■

Proof of Proposition 4

Consider first the marginal income tax rate of the low-ability type. By combining equations (A3) and (A4), we have

$$\begin{aligned} & MRS_{Z,B}^{i,l} \left[\lambda^i \hat{V}_B^{i,h} - \gamma^i \left(t^i \frac{\partial X^{i,l}}{\partial B^{i,l}} - 1 \right) + \mu^i \frac{\partial X^{i,l}}{\partial B^{i,l}} - \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial B^{i,l}} \right] \\ &= \lambda^i \hat{V}_Z^{i,h} \left(\phi^i + \frac{\partial \phi^i}{\partial L^{i,l}} L^{i,l} \right) + \gamma^i \left(w^{i,l} - t^i \frac{\partial X^{i,l}}{\partial Z^{i,l}} \right) + \mu^i \frac{\partial X^{i,l}}{\partial Z^{i,l}} + \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial L^{i,l}}. \end{aligned} \quad (\text{A.24})$$

By using equation (6), equation (A24) can be rewritten as

$$\begin{aligned}
T_I^{i,l} &= \frac{\lambda^{i,*}}{w^{i,l}} \left(MRS_{Z,B}^{i,l} - \widehat{MRS}_{Z,B}^{i,h} \phi^i \right) - \frac{\lambda^i}{w^{i,l} \gamma^i} L^{i,l} \hat{V}_Z^{i,h} \frac{\partial \phi^i}{\partial L^{1,h}} \\
&+ \frac{1}{w^{i,l}} \left(t^i - \frac{\mu^i}{\gamma^i} \right) \left(\frac{\partial X^{i,l}}{\partial Z^{i,l}} - MRS_{Z,B}^{i,l} \frac{\partial X^{i,l}}{\partial B^{i,l}} \right) \\
&- \left(\frac{\partial P}{\partial L^{i,l}} + MRS_{Z,B}^{i,l} \frac{\partial P}{\partial B^{i,l}} \right) \frac{1}{w^{i,l} \gamma^i} \frac{\partial \mathcal{L}^i}{\partial P}. \tag{A.25}
\end{aligned}$$

Now,

$$\frac{\partial P}{\partial L^{i,l}} = - \frac{\partial S_x^i / \partial L^{i,l} + \partial X^{i,l} / \partial Z^{i,l}}{\alpha} \tag{A.26}$$

$$\frac{\partial P}{\partial B^{i,l}} = \frac{\partial X^{i,l} / \partial B^{i,l}}{\alpha} \tag{A.27}$$

$$\frac{\partial \tilde{X}^{i,l}}{\partial Z^{i,l}} = \frac{\partial X^{i,l}}{\partial Z^{i,l}} - MRS_{Z,B}^{i,l} \frac{\partial X^{i,l}}{\partial B^{i,l}}. \tag{A.28}$$

Equations (A26) and (A27) imply

$$\frac{\partial P}{\partial L^{i,l}} + MRS_{Z,B}^{i,l} \frac{\partial P}{\partial B^{i,l}} = - \frac{\partial S_x^i / \partial L^{i,l}}{\alpha} + \frac{1}{\alpha} \left(- \frac{\partial X^{i,l}}{\partial Z^{i,l}} + MRS_{Z,B}^{i,l} \frac{V_Z^{i,l}}{V_B^{i,l}} \frac{\partial X^{i,l}}{\partial B^{i,l}} \right). \tag{A.29}$$

By substituting equations (A28) and (A29) into equation (A25), we obtain the expression for the marginal income tax rate of the low-ability type in the proposition. The procedure to derive the marginal income tax rate of the high-ability type is analogous. ■

Proof of Proposition 5

The starting point here is equation (A6). Note also that $V_G^{i,j} = V_B^{i,j} MRS_{G,B}^{i,j}$, which means that we can replace $V_G^{i,j}$ by $V_B^{i,j} MRS_{G,B}^{i,j}$. Then, use equations (A1) and (A3) to derive expressions for $V_B^{i,h}$ and $V_B^{i,l}$, respectively, substitute into the modified equation (A6) and use the Slutsky-like condition

$$\frac{\partial X^{i,j}}{\partial G^i} = \frac{\partial \tilde{X}^{i,j}}{\partial G^i} + MRS_{G,B}^{i,j} \frac{\partial X^{i,j}}{\partial B^{i,j}} \text{ for } j = l, h.$$

Rearrangement gives

$$\begin{aligned} \sum_j MRS_{G,B}^{i,j} &= \frac{\rho^i}{\gamma^i} - \lambda^{i,*} \left(MRS_{G,B}^{i,l} - \widehat{MRS}_{G,B}^{i,h} \right) - \left(t^i - \frac{\mu^i}{\gamma^i} \right) \sum_j \frac{\partial \tilde{X}^{i,j}}{\partial G^i} \\ &\quad - \frac{1}{\gamma^i} \left(\frac{\partial P}{\partial G^i} - \sum_j MRS_{G,B}^{i,j} \frac{\partial P}{\partial B^{i,j}} \right) \frac{\partial \mathcal{L}^i}{\partial P}. \end{aligned} \quad (\text{A.30})$$

Note that

$$\begin{aligned} \frac{\partial P}{\partial G^i} &= \frac{\sum_j \partial X^{i,j} / \partial G^i}{\alpha} \\ \frac{\partial P}{\partial B^{i,j}} &= \frac{\partial X^{i,j} / \partial B^{i,j}}{\alpha}. \end{aligned}$$

Therefore,

$$\frac{\partial P}{\partial G^i} - \sum_j MRS_{G,B}^{i,j} \frac{\partial P}{\partial B^{i,j}} = \frac{1}{\alpha} \sum_j \frac{\partial \tilde{X}^{i,j}}{\partial G^i}. \quad (\text{A.31})$$

Substituting equation (A31) into equation (A30), while using

$$\frac{\rho^i}{\gamma^i} = MRT_{C,G}^i - \frac{\partial S_x^i / \partial L^{i,l}}{\alpha \gamma^i \left(\partial F_G^i / \partial L_G^{i,l} \right)} \frac{\partial \mathcal{L}^i}{\partial P}$$

from equation (A7), gives the formula for public good provision in the proposition. ■

Proof of Proposition 6

The first part of the proposition follows by observing that the welfare effect is derived from the following welfare differential

$$dW^i = \sum_j \theta_G^{i,j} dL_G^{k,j} + \theta_\tau^i d\tau^k \quad (\text{A.32})$$

where $\partial P / \partial L_G^{k,j} > 0$ and $\partial P / \partial \tau^k > 0$, so

$$\theta_G^{i,j} = \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial L_G^{k,j}} > 0 \text{ (} < 0 \text{) if } \frac{\partial \mathcal{L}^i}{\partial P} > 0 \text{ (} < 0 \text{)}$$

$$\theta_\tau^i = \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial \tau^k} > 0 \text{ (} < 0 \text{) if } \frac{\partial \mathcal{L}^i}{\partial P} > 0 \text{ (} < 0 \text{)}.$$

Therefore, a simultaneous increase (decrease) in the production tax accompanied by a corresponding adjustment of the public production is welfare improving if $\partial \mathcal{L}^i / \partial P > 0$ (< 0).

In the second part, the corresponding welfare differential is

$$dW^i = \sum_j \theta_G^{i,j} dL_G^{k,j} + \theta_t^i dt^k \quad (\text{A.33})$$

where

$$\begin{aligned} \theta_t^i &= -\mu^i \sum_{j=l,k} \frac{\partial X^{k,j}}{\partial Q^k} + \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial t^k} \quad (\text{A.34}) \\ &= -\mu^i \left[1 + \frac{\sum_j \partial X^{k,j} / \partial Q^k}{\sum_n \partial S_x^n / \partial P - \sum_j \partial X^{k,j} / \partial Q^k} \right] \sum_j \frac{\partial X^{k,j}}{\partial Q^k} \\ &\quad + \frac{\gamma^i}{\beta^i} \left[\frac{\lambda^i L^{i,l} \hat{V}_Z^{i,h}}{\gamma^i} \frac{\partial \phi^i}{\partial P} + NX^i \right] \frac{\partial P}{\partial t^k}. \end{aligned}$$

Since the term within the square bracket in the second row of equation (A34) is between zero and one, $\partial \phi^i / \partial P \leq 0$ by assumption and $\partial P / \partial t^k < 0$, it follows that $\theta_t^i > 0$ if the net export (which can take any sign) is sufficiently small. The proof is then analogous to the proof of the first part of the proposition. ■

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II

Does Wage Bargaining Justify Environmental Policy Coordination?*

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Abstract

This paper analyzes the welfare consequences of coordinated tax reforms in an economy where a transboundary environmental externality and an international wage bargaining externality are operative at the same time. We assume that the wage in each country is decided upon in a bargain between trade-unions and firms, and the wage bargaining externality arises because the fall-back profit facing firms depends on the profit they can earn if moving production abroad. Using the noncooperative Nash equilibrium as a reference case, our results imply that the international wage bargaining externality may either reinforce or weaken the welfare gain of a coordinated increase in environmental taxation, depending on (among other things) how the reform affects the wage. For a special case, we also derive an exact condition under which a coordinated increase in the environmental tax leads to higher welfare.

Keywords: Environmental taxes, externalities, policy coordination, trade-unions

JEL Classification: H23, J51

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1 Introduction

In today's world, both economists and policy makers generally agree that transboundary environmental problems require international policy coordination, since uncoordinated actions taken by national governments are unlikely to give rise to an efficient resource allocation from the perspective of society as a whole. This is so because country-specific objectives and constraints can be expected to govern the policies decided upon by national governments, meaning that (the transboundary) part of the externality will remain uninternalized. At the same time, a full cooperative equilibrium may be beyond reach for a variety of reasons. It is, therefore, relevant to analyze the welfare consequences of partial policy coordination, where the purpose is to improve the resource allocation by comparison to the initial (uncoordinated) equilibrium. This is the topic of the present paper, which focuses on the role of trade-union wage formation in this particular context.

The bulk of earlier literature that analyzes tax and expenditure coordination assumes that the labor market is competitive. However, since the 1970s, many European countries have suffered from high unemployment rates, and it seems unlikely that full employment will be restored in the near future. As trade-unions are important actors in the European labor markets, it has been argued¹ that the wage bargaining structure may create an additional international externality. The argument is that the threat of moving production abroad may be used by firms during wage bargaining as a tool to moderate wage claims. A key factor determining the credibility of the firms' threat is the size of the potential profit they can obtain by moving production abroad. The larger the potential outside profit, the stronger will be the firms' bargaining position vis-a-vis the trade-unions, and the lower will be the wage. As a consequence, if the policies undertaken by the national government influences the profits of domestic firms, it will also give rise to an international externality. The intuition is, of course, that a national government is unlikely to consider how its policies affect the outcome of wage bargaining in other countries.

The purpose of the present paper is to analyze the welfare consequences of coordinated tax reforms in an economy where a transboundary environmental externality and the international wage bargaining externality are operative at

¹See Aronsson and Sjögren (2004b).

the same time. This is an interesting extension of the literature on environmental policy reforms because if the wage bargaining externality is non-negligible, previous studies have omitted a potentially important mechanism when they evaluate the welfare effects of such reforms. Our study is based on a multi-country economy, in which production gives rise to environmental damage and capital is mobile across countries. Each national government can use both distortionary taxes and lump-sum taxes to raise tax revenue, meaning that distortionary taxation will be used solely for externality correction. The tax instruments available to each national government are an emission tax (i.e. a tax on a dirty production factor), a capital tax and lump-sum taxes.

We start the analysis by characterizing the emission and capital taxes in a noncooperative Nash equilibrium, where each national government treats the policies decided upon by the other countries as exogenous. An interesting result here is that the wage bargaining externality may (itself) give rise to an incentive for tax competition. Then, we derive and characterize the welfare effects of coordinated increases in the emission and capital tax, respectively. The central question is whether the appearance of the wage bargaining externality reinforces, or weakens, the arguments for policy coordination. Using the noncooperative Nash equilibrium as a reference case, our results imply that the international wage bargaining externality may either reinforce or weaken the welfare gain of a coordinated increase in the emission tax depending on (among other things) how this reform affects the wage. For a special case where the consumers have quasi-linear utility functions and the production function is of Cobb-Douglas type, we also derive an exact condition under which a coordinated increase in the emission tax leads to higher welfare.

There is a relatively large literature dealing with different aspects of environmental policy coordination. One body of literature focuses on the incentives underlying the establishment of coalitions.² Another deals explicitly with the implementation of such arrangements by applying theories of optimal taxation or theories of policy reforms in the context of multi-country economies with transboundary environmental damage.³ Over the last decade, a number of studies have also emerged where fiscal and labor market distortions operate si-

²See, e.g. Mäler (1989), Barrett (1994) and Carraro (2003).

³See, e.g. van der Ploeg and de Zeeuw (1992), Aronsson and Löfgren (2000), Aronsson and Blomquist (2003) and Aronsson et al (2006).

multaneously with environmental externalities.⁴ However, most earlier research on economic policy, where environmental damage and labor market distortions jointly affect the policy outcome, abstracts from international spillover effects of environmental damage.⁵

Although the present paper is not primarily concerned with tax competition, it is, nevertheless, related to the literature dealing with taxation of labor and capital in economies with international capital mobility. Most studies in this area are based on the assumption that the labor markets are competitive.⁶ One exception is Koskela and Schöb (2002), who analyze the optimal use of labor and capital taxes in an open economy with union-firm wage bargaining. They show that capital should generally be taxed at a higher rate than labor, because labor supply is locally infinitely elastic in an economy with equilibrium unemployment. Another exception is Fuest and Huber (1999), who show that coordinated increases in the labor and capital tax rates may actually lead to lower welfare, if the economies are characterized by unemployment.

However, none of these studies have addressed the above mentioned wage bargaining externality. The main contribution of the present study is that it examines how the wage bargaining externality influences the welfare effects of coordinated increases in the emission tax and capital tax. Therefore, since the welfare effects of policy coordination associated with the environmental externality and the wage bargaining externality, respectively, may either reinforce or counterbalance each other, we are able to analyze under what circumstances countries are likely to gain from (and take part of) such policy coordination. In addition, there are few earlier studies dealing with international environmental policy in economies with imperfectly competitive labor markets, meaning that our study also contributes more generally by focusing on the role of the wage formation system in the context of environmental policy coordination.

The outline of the study is as follows. In Section 2, we present the basic model. Section 3 concerns the tax and expenditure policy that each country

⁴See, for example, Bovenberg and de Mooij (1994), Bovenberg and Goulder (1996) and Bovenberg and van der Ploeg (1998).

⁵Exceptions are Hoel (1997) and Aronsson et al (2006).

⁶The potential inefficiency associated with tax competition has been analyzed by e.g. Zodrow and Mieszkowski (1986) and Wildasin (1989), and it is argued that uncoordinated tax policies lead to inefficiently low tax rates (e.g. Bucovetsky and Wilson 1991). Therefore, tax policy coordination may be used to improve the resource allocation. For a survey of the welfare economics of tax coordination, see Keen (1993).

would implement in an uncoordinated equilibrium. In Section 4, we analyze the welfare effects of a coordinated increase in the emission tax and capital tax, respectively. The paper is summarized in Section 5.

2 The Model

In this section, we describe the behavior of consumers, firms and trade-unions as well as the equilibrium conditions characterizing the private sector. The public policy implemented by each national government in an uncoordinated equilibrium and the welfare effects of policy coordination are analyzed in Sections 3 and 4, respectively.

2.1 Consumers and Firms

Consider an economy comprising H identical countries. In each country, competitive firms produce a single output using three factors of production; labor, L , capital, K and energy, E . We assume that the use of energy has a detrimental effect on the environment in the sense of causing transboundary pollution. Since the production sector is competitive, each firm perceives that its actions do not influence the aggregate economy, meaning means that each firm treats prices and the environmental damage as exogenous. Given these characteristics, the number of firms in each country is, itself, not important and will be normalized to one.

The production function, $F(L, K, E)$, is increasing and strictly concave in each argument, and the inputs are complements in production in the sense that $F_{LK}, F_{LE}, F_{KE} > 0$. In addition, the production is characterized by decreasing returns to scale.⁷ Normalizing the price of output to one, the firm's profit is given by

$$\Pi = F(L, K, E) - wL - rK - tE \quad (1)$$

where w is the wage, r the interest rate and t an energy tax.⁸ The first order

⁷The reason for having decreasing returns to scale is that the labor market is dominated by trade unions. To be able to characterize the wage bargain between the unions and firms, the labor demand function must be well defined.

⁸We assume that the supply of energy is infinitely elastic. In addition, and without loss of generality, we normalize the marginal cost of producing energy to zero, meaning that the

conditions are $F_L(\cdot) = w$, $F_K(\cdot) = r$ and $F_E(\cdot) = t$, which implicitly define the factor demand functions

$$L = L(w, r, t), \quad K = K(w, r, t), \quad E = E(w, r, t) \quad (2)$$

and the profit function $\Pi(w, r, t)$.

Turning to the consumption side, there are three types of consumers; employed workers, unemployed workers and firm-owners. The consumers share a common utility function, which is written as

$$u(c) + v(Q) \quad (3)$$

where c is consumption and Q denotes environmental quality. The functions $u(\cdot)$ and $v(\cdot)$ are increasing and strictly concave in their respective argument. The total number of workers will be denoted by M , out of which $L \leq M$ are employed and $M - L$ unemployed. The number of firm-owners is normalized to one for notational convenience. Variables associated with consumer-types will be superindexed e (employed worker), u (unemployed worker) and f (firm-owner), respectively.

Each worker supplies one unit of labor inelastically. The reason for assuming fixed labor supply per worker is that the link between distortionary taxes, endogenous labor supply and wage formation in unionized economies has been analyzed thoroughly in earlier literature.⁹ Therefore, to be able to focus on the novel aspects of this paper in the simplest possible way, we disregard endogenous labor supply here.

Each (employed and unemployed) worker is endowed with a fixed and divisible capital asset, \bar{k} , which can be invested at home and/or abroad. Capital is taxed at source, meaning that the amount invested at home gives the net return $(1 - \theta)r$, while investments abroad generate the the net return $(1 - \theta^*)r^*$, in which r is the interest rate and θ the capital income tax rate. Variables indexed by "*" are non-domestic.

Equilibrium in the global capital market implies equalization of net capital returns, i.e.

$$(1 - \theta)r = (1 - \theta^*)r^*. \quad (4)$$

energy price paid by the final goods producer equals the energy tax.

⁹See e.g. Aronsson and Sjögren (2004a,b).

By using equation (4), the capital income (net of taxation) can be written as $y = (1 - \theta^*) r^* \bar{k}$, and the budget constraint facing each employed and unemployed worker, respectively, becomes

$$c^e = w + y - T^e \quad (5)$$

$$c^u = b + y \quad (6)$$

in which T^e is the lump-sum tax¹⁰ per employed worker, and b an unemployment benefit.

Let us finally turn to the firm-owner. To simplify the analysis, we assume that the firm-owner does not work; instead, he/she receives profit income, Π , and pays a lump-sum tax, T^f . This means that the firm-owner's consumption is given by $c^f = \Pi - T^f$.

The environmental quality is given by

$$Q = \bar{Q} - \sum_{i=1}^H E_i \quad (7)$$

where \bar{Q} is an exogenous measure of the potential environmental quality that would prevail in the absence of pollution. Since there are H countries in the economy, and pollution is transboundary, the actual environmental quality facing the residents in any country is equal to \bar{Q} minus the total energy use (i.e. the sum of emissions across countries). Therefore, since there is a one-to-one correspondence between energy use and emissions here, the terms "energy tax", "emission tax" and "environmental tax" will be used synonymously in what follows.

2.2 The Labor Market

We assume that all workers are trade-union members, and that wage formation is decentralized in the sense that each trade-union (i) is firm specific and (ii) treats the policy instruments of the government as exogenous. Therefore, in accordance with the treatment of the production sector above, we normalize the number of trade-unions to one. Following Oswald (1993), the objective

¹⁰When the labor supply is fixed, a proportional labor income tax is equivalent to a lump-sum tax. This is why we use the latter tax instrument.

function of the trade-union is assumed to coincide with the objective function of the member with median seniority. This means that the trade-union members are ranked according to (exogenous) seniority, and that the member with median seniority is the decisive voter. As long as the median voter is not at an immediate risk of becoming unemployed, the trade-union will be indifferent to the level of employment. Within our framework, this means that the median voter's objective is to maximize $u(c^e) + v(Q)$ subject to the employment restriction $L(w, r, t) \geq M/2$.

The wage formation part of the model is governed by the right-to-manage framework¹¹, meaning that the wage rate is determined in a bargain between the union and the firm. If no contract is signed, the median union member becomes unemployed, so that his/her fall-back utility is given by $u(c^u) + v(Q)$. The firm, on the other hand, has the option to move production abroad, in which case its fall-back profit is given by $\Pi(w^*, r^*, t^*) - q$, where q is a fixed moving cost. By using the short notations $u^e = u(c^e) + v(Q)$, $u^u = u(c^u) + v(Q)$, $\Pi = \Pi(w, r, t)$ and $\Pi^* = \Pi(w^*, r^*, t^*)$, and then defining $u^e - u^u$ and $\Pi - (\Pi^* - q)$ to be the union's and the firm's respective rents from bargaining, the outcome of the bargain will be the wage that maximizes the Nash product

$$\Omega = [u(w + y - T^e) - u(b + y)]^a [\Pi(w, r, t) - \Pi(w^*, r^*, t^*) + q]^{1-a} \quad (8)$$

where $a \in (0, 1)$ is the trade union's bargaining power vis-a-vis the firm. If $a = 0$, the firm unilaterally determines the wage, which is then pushed down to the market clearing level where $L(w, r, t) = M$. On the other hand, if $a = 1$ the union has monopoly power and pushes up the wage so that the employment restriction $L(w, r, t) = M/2$ will bind.

The first order condition for an interior solution with respect to the wage can be written as

$$\Omega_w = aw_c^e (\Pi - \Pi^* + q) - (1 - a) L(u^e - u^u) = 0 \quad (9)$$

where the second-order condition, $\Omega_{ww} < 0$, is assumed to be satisfied. Equation (9) implicitly defines the bargained wage as

$$w = w(T^e, b, y, r, t, \Pi^* - q). \quad (10)$$

¹¹See Oswald (1985).

For the analysis below, we observe that the bargained wage rate satisfies the following comparative static properties

$$\frac{\partial w}{\partial T^e} = \frac{au_{cc}^e(\Pi - \Pi^* + q) - (1 - a)Lu_c^e}{\Omega_{ww}} > 0 \quad (11)$$

$$\frac{\partial w}{\partial b} = -\frac{(1 - a)Lu_c^u}{\Omega_{ww}} > 0 \quad (12)$$

$$\frac{\partial w}{\partial y} = -\frac{au_{cc}^e(\Pi - \Pi^* + q) - (1 - a)L(u_c^e - u_c^u)}{\Omega_{ww}} \quad (13)$$

$$\frac{\partial w}{\partial \Pi^*} = \frac{au_c^e}{\Omega_{ww}} < 0. \quad (14)$$

Equations (11) and (12) are standard. Equation (13) shows that the wage response to an increase in the nonlabor income comprises two counteracting effects. First, the employed workers now have a higher total income, meaning that the union can reduce its wage claims. Second, as an increase in y also increases the income of the unemployed, the union can be more aggressive in its wage demands. The net effect of these two forces is ambiguous. Finally, equation (14) shows that an increase in the fall-back profit contributes to reduce the bargained wage; a property which will be important below.

3 Noncooperative Nash Equilibrium

We assume that the national government faces a utilitarian welfare function, which is given by

$$W = L[u(c^e) + v(Q)] + (M - L)[u(c^u) + v(Q)] + [u(c^f) + v(Q)]. \quad (15)$$

The government raises revenue via the lump-sum taxes paid by the employed workers and the firm-owner, respectively, the capital income tax and the emission tax. The revenue is used to finance an unemployment benefit. Therefore, the policy instruments are T^e , T^f , t , θ and b , and the government's budget constraint is written as

$$tE + \theta rK + LT^e + T^f - b(M - L) = 0. \quad (16)$$

Each national government also recognizes that the environmental quality is determined by equation (7). In addition, as the national governments are Nash competitors to one another, each national government treats the policies decided upon by the other countries (i.e. T^{*e} , T^{*f} , t^* , θ^* and b^*) as exogenous.

The Lagrangian corresponding to the government's decision-problem can be written as

$$\mathcal{L} = W + \gamma [tE + \theta rK + T^f + LT^e - b(M - L)] \quad (17)$$

where γ is the Lagrange multiplier associated with the budget constraint. The first order conditions are presented in the Appendix. Here, we concentrate on the implications of these conditions for optimal taxation.

To begin with, let us define the welfare gain of increased employment, i.e. marginal value that the national government attaches to an increase in the number of employed persons. By differentiating the Lagrangean in equation (17) with respect to L , using the private first order conditions and rearranging, we obtain

$$\Phi = (u^e - u^u) + \gamma(T^e + b). \quad (18)$$

Equation (18) decomposes the welfare effect of increased employment into two parts. First, each worker who becomes employed experiences a direct utility gain equal to $u^e - u^u > 0$. Second, the net effect on tax revenue if one additional worker goes from unemployment to employment is given by $T^e + b$. If the government aims to redistribute from the employed to the unemployed, meaning that $T^e + b > 0$, we have $\Phi > 0$.

We show in the Appendix that each national government implements the following emission and capital taxes in the noncooperative Nash equilibrium;

$$t = (M + 1) \frac{vQ}{\gamma} - \frac{\Phi}{\gamma} \frac{(\alpha^0 - \alpha^1 \beta^1 r)}{(1 - \alpha^1 \beta^0 r)} \quad (19)$$

$$\theta = \frac{\Phi}{\gamma} \frac{\alpha^0 \beta^0 - \beta^1}{(1 - \alpha^1 \beta^0 r)} \quad (20)$$

where

$$\alpha^0 = \frac{(L_t + \mu L_w \frac{\partial w}{\partial t})}{(E_t + \mu E_w \frac{\partial w}{\partial t})}, \quad \alpha^1 = \frac{(K_t + \mu K_w \frac{\partial w}{\partial t})}{(E_t + \mu E_w \frac{\partial w}{\partial t})}$$

$$\beta^0 = \frac{(E_r + \mu E_w \frac{\partial w}{\partial r})}{r (K_r + \mu K_w \frac{\partial w}{\partial r})}, \quad \beta^1 = \frac{(L_r + \mu L_w \frac{\partial w}{\partial r})}{r (K_r + \mu K_w \frac{\partial w}{\partial r})}$$

and $\mu = 1 / (1 - \partial w / \partial T^e)$.

The variable μ is interpretable in terms of wage compensation for increased taxation; if $\partial w / \partial T^e > 1$ (< 1), workers are "overcompensated" ("undercompensated") in terms of the wage response. Therefore, $1/\mu = 1 - \partial w / \partial T^e$ is the degree of undercompensation and, as a consequence, μ the inverse of the degree of undercompensation.

To interpret the tax policy summarized by equations (19) and (20), consider first the special case where the labor market is competitive. In a competitive labor market (where $L \equiv M$), one can show that the emission tax equals the marginal value that the (national) government attaches to reduced environmental damage, i.e. $t = (M + 1) v_Q / \gamma$, whereas the capital tax is equal to zero. The intuition is that the government can use lump-sum taxes to raise revenue, and it is able to equalize the marginal utility of consumption among consumers (meaning full implementation of the distributional objective implicit in the utilitarian welfare function). As a consequence, there will be no tax competition for mobile capital. In other words, the only corrective role of taxation that remains is correction for the environmental externality, which is accomplished by using the emission tax. In summary, this means that the emission tax is positive (and equal to the marginal value that the national government attaches to reduced environmental damage), and the capital tax is zero.

However, this basic intuition does not carry over to an economy with equilibrium unemployment, which is seen from equations (19) and (20). The reason is that the emission and capital taxes will, in this case, also serve as indirect instruments for influencing the employment. This is seen by the "extra term" in each tax formula, which is proportional to Φ . Therefore, these extra terms reflect an employment-motive for taxation, as a change in either the emission tax or capital tax affects the number of employed persons. Although this employment-motive can lead to either higher or lower taxes in general, one would expect the extra term in each tax formula to be negative, i.e. that the government tries to

boost employment by implementing a lower emission tax than would be motivated by pure domestic externality-correction and subsidizing capital. Note that this argument also implies that the appearance of equilibrium unemployment provides an incentive for at the government to compete for mobile capital (as an increase in the domestic capital stock contributes to increased domestic employment).

4 Policy Coordination

The uncoordinated equilibrium is globally inefficient for two reasons. The first inefficiency arises because each country implements emission tax policies solely on the basis of its own domestic objectives, i.e. it does not incorporate into its decision-problem that the domestic emissions (use of energy) causes environmental damage abroad. The second is due to the international wage bargaining externality. To see this more clearly, note from equation (10) that the profit abroad, Π^* , directly affects the domestic wage. The larger the outside profit, the stronger is the firm's bargaining position vis-a-vis the trade union, ceteris paribus, and the lower will be the wage, i.e. $\partial w / \partial \Pi^* < 0$. However, when each national government decides upon tax and expenditure policies, it does not take into account that the domestic profit also affects the fall-back profit for firms in other countries.

We consider policy coordination with respect to the energy and capital tax, respectively, which are the two corrective tax instruments that each national government has at its disposal. Since the countries are identical, the point of departure is a symmetric equilibrium where all countries have chosen the same tax and expenditure policies. This means that the resource allocation is the same in all countries; in particular, the capital stock used in the production in each country is fixed at $K = \bar{K} = M\bar{k}$ and the profits are equalized, so $\Pi = \Pi^*$. By using the first order conditions for the firm and the first order condition for the wage, where we normalize a to 0.5 for notational convenience¹², we obtain the following equation system

¹²This simplification shortens the relevant mathematical expressions. It is not important for the qualitative results.

$$0 = F_L(L, \bar{K}, E) - w \quad (21)$$

$$0 = F_E(L, \bar{K}, E) - t \quad (22)$$

$$0 = F_K(L, \bar{K}, E) - r \quad (23)$$

$$0 = u_c^e(w + y - T^e)q - L[u^e(w + y - T^e) - u^u(b + y)]. \quad (24)$$

Equations (21)-(24) imply a symmetric equilibrium in the sense that $L = L^*$, $E = E^*$, $w = w^*$ and $r = r^*$ become functions of $b = b^*$, $T^e = T^{e*}$, $t = t^*$ and $\theta = \theta^*$ (the latter via $y = y^*$).

Since the domestic policy has been optimally chosen conditional on the policies implemented by other countries, a coordinated infinitesimal increase in either the emission tax or the capital tax affects welfare only because a policy change in each country influences the welfare in other countries (via the two uninternalized international externalities). Throughout the paper, we assume that each national government adjusts the income tax paid by the firm-owner, T^f , to maintain budget balance.

Consider first the welfare effect of a coordinated increase in the emission tax accompanied by an adjustment of the income tax paid by the firm-owner. With the other policy instruments held constant, we may then write T^f as a function of the domestic and foreign emission taxes, i.e. $T^f = T(t, t^*)$. Differentiating the Lagrangian in equation (17) w.r.t. t and t^* , and using that $t = t^*$ in the symmetric equilibrium, we obtain

$$dW = \frac{\partial \mathcal{L}}{\partial t} dt + \frac{\partial \mathcal{L}}{\partial T^f} \left(\frac{\partial T^f}{\partial t} dt + \frac{\partial T^f}{\partial t^*} dt^* \right) + \frac{\partial \mathcal{L}}{\partial t^*} dt^* = \frac{\partial \mathcal{L}}{\partial t^*} dt^* \quad (25)$$

Note that the first order effects on domestic welfare following small changes in t and T^f are zero (i.e. $\partial \mathcal{L} / \partial t = \partial \mathcal{L} / \partial T^f = 0$). As a consequence, the only welfare effect that remains is due to increased emission taxation abroad, which is seen from the expression after the second equality. By using a similar argument, the cost benefit rule for a coordinated increase in the capital tax can be written as $dW = (\partial \mathcal{L} / \partial \theta^*) d\theta^*$.

To assess these welfare effects, consider the following Proposition;

Proposition 1. (i) *In the uncoordinated symmetric equilibrium, the welfare*

effect of a coordinated increase in the emission tax, accompanied by an adjustment of the income tax paid by the firm-owner to maintain budget balance for the government in each country, is given by

$$\frac{\partial W}{\partial t^*} = -(H-1)(M+1) \frac{dv}{dQ} \frac{dE^*}{dt^*} + \frac{\partial \mathcal{L}}{\partial w} \frac{\partial w}{\partial \Pi^*} \frac{d\Pi^*}{dt^*} \quad (26)$$

where

$$\frac{d\Pi^*}{dt^*} = \frac{\partial \Pi^*}{\partial w^*} \frac{\partial w^*}{\partial t^*} + \frac{\partial \Pi^*}{\partial r^*} \frac{\partial r^*}{\partial t^*} + \frac{\partial \Pi^*}{\partial t^*} \quad (27)$$

$$\frac{dE^*}{dt^*} = \frac{\partial E^*}{\partial w^*} \frac{\partial w^*}{\partial t^*} + \frac{\partial E^*}{\partial r^*} \frac{\partial r^*}{\partial t^*} + \frac{\partial E^*}{\partial t^*}. \quad (28)$$

(ii) The analogous cost benefit rule for the capital tax becomes

$$\frac{\partial W}{\partial \theta^*} = -(H-1)(M+1) \frac{dv}{dQ} \frac{dE^*}{d\theta^*} + \frac{\partial \mathcal{L}}{\partial w} \frac{\partial w}{\partial \Pi^*} \frac{d\Pi^*}{d\theta^*} \quad (29)$$

where

$$\frac{d\Pi^*}{d\theta^*} = \frac{\partial \Pi^*}{\partial w^*} \frac{\partial w^*}{\partial \theta^*} + \frac{\partial \Pi^*}{\partial r^*} \frac{\partial r^*}{\partial \theta^*} \quad (30)$$

$$\frac{dE^*}{d\theta^*} = \frac{\partial E^*}{\partial w^*} \frac{\partial w^*}{\partial \theta^*} + \frac{\partial E^*}{\partial r^*} \frac{\partial r^*}{\partial \theta^*} \quad (31)$$

Proof: See the Appendix.

Each cost benefit rule contains two parts, which correspond to the respective externality discussed above. Consider first the cost benefit rule for the emission tax. The first part of equation (26) shows that a coordinated infinitesimal increase in the emission tax changes the use of energy in each foreign country by dE^*/dt^* . There are $(H-1)$ foreign countries, implying that the total change in environmental quality due to increased energy taxation abroad is given by $-(H-1)dE^*/dt^*$. Therefore, since there are $(M+1)$ domestic consumers, each of whom experiences a utility change equal to dv/dQ , the total welfare change arising via this mechanism becomes $-(H-1)(M+1)(dv/dQ)(dE^*/dt^*)$. The intuition behind the first part of the cost benefit rule for the capital tax is analogous.

The second part of each cost benefit rule is due to the international wage bargaining externality. Note first that if the labor market were competitive, then this component would vanish (as a small change in the wage would have a zero first order welfare effect). However, in the presence of equilibrium unemployment, an additional (nonzero) welfare effect arises as a coordinated increase in the emission tax or capital tax influences the foreign profit, Π^* , and, therefore, the fall-back profit facing the domestic firm during the wage bargain. Since Π^* constitutes the fall-back profit for the domestic firms, the change in Π^* will influence the domestic wage, captured by $\partial w/\partial \Pi^*$.

The domestic welfare effect following a change in the wage, i.e. $\partial \mathcal{L}/\partial w$ in each cost benefit rule in the proposition, can be written as

$$\frac{\partial \mathcal{L}}{\partial w} = \frac{\Phi}{\gamma} \mu L_w + \left[t - (M + 1) \frac{v_Q}{\gamma} \right] \mu E_w + \theta \mu r K_w. \quad (32)$$

The first part of equation (32) is standard: it reflects the direct welfare cost of a higher wage in terms of lost employment. The second and third parts arise because $t \neq (M + 1) v_Q/\gamma$ and $\theta \neq 0$, since imperfect competition in the labor market means that the emission and capital tax policies governing the uncoordinated equilibrium typically deviate from the policies that would be implemented if the labor markets were competitive.¹³ As we argued above, although these components can be either positive or negative in general, intuition suggests that the tax policy in the uncoordinated equilibrium satisfies $t < (M + 1) v_Q/\gamma$ and $\theta < 0$, in which case the second and third terms in equation (32) tend to reduce the welfare cost of an increase in the wage. In other words, even if we were to base our interpretations on the assumption that $\partial \mathcal{L}/\partial w < 0$ (which appears to be reasonable in an economy with unemployment), the preexisting emission tax and capital tax policies may, nevertheless, offset part of the welfare gain that would otherwise arise from a decrease in the wage and, therefore, also reduce the absolute value of the second part of each cost benefit rule in the proposition.

Although the uncoordinated equilibrium is suboptimal from the perspective

¹³With competitive labor markets, where $L \equiv M$ in each country, the uncoordinated equilibrium would support a "national first best policy" in the sense that

$$t = (M + 1) v_Q/\gamma \text{ and } \theta = 0$$

in which case the second and third terms on the right hand side of equation (32) would be equal to zero.

of society as a whole, we cannot sign the cost benefit rules in Proposition 1 without further assumptions. However, what we can say is that if dE^*/dt^* and $d\Pi^*/dt^*$ have opposite signs - and if $\partial\mathcal{L}/\partial w < 0$ - then $\partial W/\partial t^*$ is signed, in which case it is possible to make a coordinated change of the emission tax such that welfare increases in all countries. If, on the other hand, dE^*/dt^* and $d\Pi^*/dt^*$ have the same sign, then $\partial W/\partial t^*$ is not signed. The condition under which the cost benefit rule for the capital tax can be signed is analogous.

4.1 A More Specific Model

To go further, we consider the special case of the model, where the utility function is quasi-linear and the production function is of Cobb-Douglas type. The utility facing an employed and unemployed worker, respectively, then becomes

$$u^e = w + y - T^e + v(Q) \quad (33)$$

$$u^u = b + y + v(Q). \quad (34)$$

The production function is given by

$$F(L, K, E) = L^{\rho_1} K^{\rho_2} E^{\rho_3} \quad (35)$$

where $0 < \rho_1, \rho_2, \rho_3$ and $\rho_1 + \rho_2 + \rho_3 < 1$. We begin by analyzing a coordinated increase in the emission tax and then continue with a coordinated increase in the capital tax. Throughout this section, our discussion is based on the assumption that $\partial\mathcal{L}/\partial w < 0$.

4.1.1 A Coordinated Change in the Emission Tax

Before using the utility and production functions in equations (33)-(35) to evaluate the cost benefit rule for the emission tax, we start by examining how a change in the emission tax abroad affects the environmental damage and profit abroad, i.e. the derivatives dE^*/dt^* and $d\Pi^*/dt^*$. It turns out that the signs of these derivatives depend on the component $(T^e + b)/w$, which we will refer to as the "net tax revenue-wage ratio". Consider Lemma 1.

Lemma 1.

(i) If the net tax revenue-wage ratio satisfies $(T^e + b)/w < \rho_1$, then $dE^*/dt^* < 0$ and $d\Pi^*/dt^* > 0$.

(ii) If the net tax revenue-wage ratio satisfies $\rho_1 < (T^e + b)/w < \rho_1/(1 - \rho_3)$, then $dE^*/dt^* > 0$ and $d\Pi^*/dt^* > 0$.

(iii) If the net tax revenue-wage ratio satisfies $\rho_1/(1 - \rho_3) < (T^e + b)/w$, then $dE^*/dt^* < 0$ and $d\Pi^*/dt^* < 0$.

Proof: See the Appendix.

To interpret Lemma 1, we first need to evaluate how the wage rate responds to a coordinated increase in the emission tax. Differentiating equation system (21) - (24) w.r.t. $t = t^*$, we obtain

$$\frac{\partial w^*}{\partial t^*} = \frac{(w - T^e - b) F_{LE}}{\Psi} \quad (36)$$

where

$$\Psi = [(T^e + b)(1 - \rho_3) - \rho_1 w] \rho_3 L^{\rho_1} K^{\rho_2} E^{\rho_3 - 2}.$$

Equation (36) implies that the wage response is negative if $(T^e + b)/w < \rho_1/(1 - \rho_3)$. In this case, therefore, a coordinated increase in the emission tax leads to a lower wage. This means that the firms have the opportunity to substitute energy for labor in the production. Since relatively more labor will now be used in the production (at a lower cost than before the policy reform), there is room for an increase in the profit, which is what happens with a Cobb-Douglas production function. This explains part (i) of the lemma. Part (ii) is basically an extension of the argument underlying part (i) in the sense that, if the wage decreases in response to increased emission taxation, this wage reduction may be so large that the demand for energy actually increases. This happens if the net tax revenue-wage ratio satisfies $\rho_1 \leq (T^e + b)/w < \rho_1/(1 - \rho_3)$. Finally, part (iii) corresponds to the case where the wage response is positive, which happens when $\rho_1/(1 - \rho_3) < (T^e + b)/w$. As a consequence, both the use of energy in production and the profit will decrease.

Let us then turn to the implications in terms of the cost benefit rule for the emission tax. We have derived the following result;

Proposition 2. *Suppose that the economy has reached the uncoordinated symmetric equilibrium, that the consumers have a quasi-linear utility function, and that the production function is of Cobb-Douglas type. Consider the cost benefit rule for a coordinated increase in the emission tax in Proposition 1.*

(i) *If the net tax revenue-wage ratio satisfies $(T^e + b)/w < \rho_1$, a coordinated increase in the emission alleviates the preexisting environmental externality and the preexisting international wage bargaining externality. This leads to higher welfare.*

(ii) *If the net tax revenue-wage ratio satisfies $\rho_1 < (T^e + b)/w < \rho_1/(1 - \rho_3)$, a coordinated increase in the emission reinforces the preexisting environmental externality and alleviates the preexisting international wage bargaining externality. This renders the welfare effect ambiguous in sign.*

(iii) *If the net tax revenue-wage ratio satisfies $\rho_1/(1 - \rho_3) < (T^e + b)/w$, a coordinated increase in the emission tax alleviates the preexisting environmental externality and reinforces the preexisting international wage bargaining externality. This renders the welfare effect ambiguous in sign.*

Proposition 2 shows that the international wage bargaining externality may significantly influence the welfare effects of a coordinated increase in the emission tax. Part (i) of the proposition means that the welfare effect is unambiguously positive if the net tax revenue, $T^e + b$, is relatively small by comparison with the gross wage, w . In this case, therefore, the results are interpretable in terms of a "double dividend" of a coordinated increase in the emission tax, as such a reform alleviates both the environmental externality and the wage bargaining externality. Part (ii) implies that the higher emission tax induces the union to make large concessions in the wage bargain. In fact, the wage will be reduced so much that it causes an increase in the use of energy (as labor and energy are complements in terms of the production function). This means that the preexisting environmental externality is actually reinforced, although the reform contributes to alleviate the wage bargaining externality. Finally, part (iii) shows that if the net tax revenue is large enough relative to the gross wage, both the use of energy and the profit will decrease. The intuition is that a coordinated increase in the emission tax leads to a higher wage. Therefore, although the

reform contributes to alleviate the preexisting environmental externality, the preexisting wage bargaining externality becomes reinforced, which renders the welfare effect ambiguous.

In most real world economies, the net tax revenue-wage ratio is likely to satisfy the inequality in part (iii) of Proposition 2. The argument above then implies that the welfare effect of a coordinated environmental policy reform may not be so large (and it may even be negative).

4.1.2 A Coordinated Change of the Capital Income Tax

Let us now use the quasi-linear utility function and Cobb-Douglas production function to evaluate the cost benefit rule for the capital tax in Proposition 1. Consider the following result;

Proposition 3. *Suppose that the economy has reached the uncoordinated symmetric equilibrium, that the consumers have a quasi-linear utility function, and that the production function is of Cobb-Douglas type. It follows that a coordinated increase in the capital tax, while the income tax paid by the firm-owner is adjusted to maintain budget balance for the government in each country, leaves welfare unaffected (as a first order approximation).*

This result appears because the consumers have a quasi-linear utility function, in which case θ drops out from the first order condition for the wage. A coordinated change in θ will in this case neither affect the wage nor the allocation of capital between countries. As a consequence, the use of energy and the profit also remain unaffected, meaning that both parts of equation (29) are zero.

5 Summary

This paper analyzes the welfare effects of policy reforms designed to introduce coordination among countries. An uncoordinated equilibrium, where each country implements tax policy based solely on its own objectives and constraints, constitutes the reference case. We assume that the set of tax instruments facing the government in each country consists of an emission tax and a capital tax. The environmental damage is transboundary. In addition, firms and trade-unions bargain over the wage, which creates an inefficient labor market outcome

in the sense of equilibrium unemployment. The countries interact both via the transboundary externality and via the wage formation system. The latter interaction arises because the fall-back profit facing domestic firms during the wage bargain is the profit they can obtain if they move production abroad minus the cost associated with such a move. This creates an international wage bargaining externality.

We begin by characterizing the emission tax and capital tax policies in a noncooperative Nash equilibrium. Although the effects on the tax structure of imperfect competition in the labor market is ambiguous in general, we argue that each country is likely to implement lower taxes on emissions and capital than they would have done had the labor market been competitive.

Two policy reforms are then designed. First, a coordinated increase in the emission tax and, second, a coordinated increase in the capital tax. In both cases, a nondistortionary profit tax is adjusted to maintain budget balance for the government. Having characterized the cost benefit rule for each such reform, we consider a special case with a quasi-linear utility function and a Cobb-Douglas production function and show that the first reform is welfare improving if the ratio of the net tax revenue and the wage is smaller than the output elasticity of labor. If, on the other hand, the ratio of the net tax revenue and the wage is larger than the output elasticity of labor, the welfare effect is ambiguous. Therefore, even if a coordinated increase in the emission tax (most likely) alleviates the environmental externality, it may reinforce the international wage bargaining externality. We also show that, if the consumers have a quasi-linear utility function and the production function is of Cobb-Douglas type, the welfare effect of a coordinated increase in the capital tax is zero.

6 Appendix

The government's first order conditions are

$$\frac{\partial \mathcal{L}}{\partial b} = (M - L)(u_c^u - \gamma) + \frac{\partial \mathcal{L}}{\partial w} \frac{\partial w}{\partial b} = 0 \quad (\text{A.1})$$

$$\frac{\partial \mathcal{L}}{\partial T^f} = \gamma - u_c^f = 0 \quad (\text{A.2})$$

$$\frac{\partial \mathcal{L}}{\partial T^e} = (\gamma - u_c^e) L + \frac{\partial \mathcal{L}}{\partial w} \frac{\partial w}{\partial T^e} = 0 \quad (\text{A.3})$$

$$\begin{aligned} \frac{\partial \mathcal{L}}{\partial t} = 0 = & -(M + 1) v_Q E_t + (u^e - u^u) L_t + \frac{\partial \mathcal{L}}{\partial w} \frac{\partial w}{\partial t} \\ & + \gamma [tE_t + \theta r K_t + (T^e + b) L_t] \end{aligned} \quad (\text{A.4})$$

$$\frac{\partial \mathcal{L}}{\partial \theta} = \gamma r K + \frac{d\mathcal{L}}{dr} \frac{\partial r}{\partial \theta} + \frac{d\mathcal{L}}{dw} \frac{\partial w}{\partial r} \frac{\partial r}{\partial \theta} = 0 \quad (\text{A.5})$$

where

$$\begin{aligned} \frac{\partial \mathcal{L}}{\partial w} = & -(M + 1) v_Q E_w + (u^e - u^u) L_w + L(u_c^e - \gamma) \\ & + \gamma [tE_w + \theta r K_w + (T^e + b) L_w] \end{aligned} \quad (\text{A.6})$$

$$\begin{aligned} \frac{\partial \mathcal{L}}{\partial r} = & -(M + 1) v_Q E_r + (u^e - u^u) L_r - K\gamma \\ & + \gamma [tE_r + \theta K + \theta r K_r + (T^e + b) L_r]. \end{aligned} \quad (\text{A.7})$$

Equation (4) implies

$$r(\theta, \theta^*, r^*) = \frac{1 - \theta^*}{1 - \theta} r^* \quad (\text{A.8})$$

which, in turn, gives

$$\frac{\partial r}{\partial \theta} = \frac{r}{(1 - \theta)}. \quad (\text{A.9})$$

Combining (A.3), (A.4) and (A.6) and solving for t gives

$$t = (M + 1) \frac{v_Q}{\gamma} - \Phi \frac{\alpha^0}{\gamma} - \theta r \alpha^1. \quad (\text{A.10})$$

Similarly, combining equations (A.3), (A.5), (A.7) and (A.9), and solving for θ implies

$$\theta = \left[(M+1) \frac{v_Q}{\gamma} - t \right] \beta^0 - \Phi \frac{\beta^1}{\gamma}. \quad (\text{A.11})$$

Finally, combining equations (A.10) and (A.11), we obtain the tax formulas given by equations (19) and (20).

Proof of Proposition 1

Differentiating the Lagrangian w.r.t. t^* produces

$$\begin{aligned} \frac{\partial \mathcal{L}}{\partial t^*} = & -(H-1)(M+1) \frac{dv}{dQ} \frac{dE^*}{dt^*} + [Lu_c^e + (M-L)u_c^u](1-\theta^*)\bar{k} \frac{\partial r^*}{\partial t^*} + \frac{\partial \mathcal{L}}{\partial r} \frac{\partial r^*}{\partial t^*} \\ & + \frac{\partial \mathcal{L}}{\partial w} \left[\frac{\partial w}{\partial y} (1-\theta^*)\bar{k} \frac{\partial r^*}{\partial t^*} + \frac{\partial w}{\partial r} \frac{\partial r^*}{\partial t^*} + \frac{\partial w}{\partial \Pi^*} \left(\frac{\partial \Pi^*}{\partial w^*} \frac{\partial w^*}{\partial t^*} + \frac{\partial \Pi^*}{\partial r^*} \frac{\partial r^*}{\partial t^*} + \frac{\partial \Pi^*}{\partial t^*} \right) \right]. \end{aligned} \quad (\text{A.12})$$

By combining equation (A.12) with equations (A.1), (A.3), (A.5) and (A.9), and using that $K = M\bar{k} = L\bar{k} + (M-L)\bar{k}$ in the symmetric equilibrium, we can write the resulting expression as

$$\begin{aligned} \frac{\partial \mathcal{L}}{\partial t^*} = & -(H-1)(M+1) \frac{dv}{dQ} \frac{dE^*}{dt^*} + \frac{\partial \mathcal{L}}{\partial w} \frac{\partial w}{\partial \Pi^*} \left(\frac{\partial \Pi^*}{\partial w^*} \frac{\partial w^*}{\partial t^*} + \frac{\partial \Pi^*}{\partial r^*} \frac{\partial r^*}{\partial t^*} + \frac{\partial \Pi^*}{\partial t^*} \right) \\ & + \frac{\partial \mathcal{L}}{\partial w} \left(\frac{\partial w}{\partial T^e} - \frac{\partial w}{\partial b} + \frac{\partial w}{\partial y} \right) (1-\theta^*)\bar{k} \frac{\partial r^*}{\partial t^*}. \end{aligned} \quad (\text{A.13})$$

If we use the comparative statics derivatives in equations (11) - (13), one can see that the sum of the partial derivatives of the bargained wage inside the first parenthesis in the second row of equation (A.13) sum to zero, in which case we obtain equation (26). The derivation of equation (29) is analogous.

Proof of Lemma 1

To begin with, we need to evaluate dE^*/dt^* . Differentiating equation system (21) - (24) w.r.t. $t = t^*$, we obtain

$$\frac{dE^*}{dt^*} = -\frac{(T^e + b) - \rho_1 w}{\Psi} \quad (\text{A.14})$$

where

$$\Psi = [(T^e + b)(1 - \rho_3) - \rho_1 w] \rho_3 L^{\rho_1} K^{\rho_2} E^{\rho_3 - 2}. \quad (\text{A.15})$$

By inspection, it follows that $dE^*/dt^* < 0$ when $(T^e + b)/w < \rho_1$, $dE^*/dt^* > 0$ when $\rho_1 \leq (T^e + b)/w < \rho_1/(1 - \rho_3)$ and $dE^*/dt^* < 0$ when $\rho_1/(1 - \rho_3) < (T^e + b)/w$.

To evaluate $d\Pi^*/dt^*$, we first need to evaluate dw^*/dt^* and dr^*/dt^* . Differentiating equation system (21) - (24) w.r.t. $t = t^*$, we obtain

$$\frac{\partial w^*}{\partial t^*} = \frac{(w - T^e - b) F_{LE}}{\Psi} \quad (\text{A.16})$$

$$\frac{\partial r^*}{\partial t^*} = -\frac{(T^e + b) F_{KE}}{\Psi}. \quad (\text{A.17})$$

Substituting equations (A.16) and (A.17) into equation (27), using $\partial\Pi^*/\partial t^* = -E^*$ and that the production function is given by (35), we have

$$\frac{d\Pi^*}{dt^*} = -\frac{(1 - \rho_1 - \rho_2 - \rho_3) \rho_3 L^{\rho_1} K^{\rho_2} E^{\rho_3 - 1} (T + b)}{\Psi} \quad (\text{A.18})$$

By inspection, it follows that $\partial\Pi^*/\partial t^* > 0$ when $(T^e + b)/w < \rho_1/(1 - \rho_3)$ and $\partial\Pi^*/\partial t^* < 0$ when $(T^e + b)/w > \rho_1/(1 - \rho_3)$.

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III

Environmental Policy Negotiations, Transboundary Pollution and Lobby Groups in Small Open Economies

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Abstract

This paper analyzes the consequences of lobby group activity for policy outcomes in economies with transboundary pollution and international environmental policies. International environmental policies are characterized as pollution taxes determined in a negotiation between two countries and it is found, among other things, that the presence of local lobbying tends to reduce the level of pollution taxes. Furthermore, an increase in the environmental concern - here defined as an increase in the number of environmentalists - may reduce the pollution tax in both countries. It is also possible that increased environmental concern in one country reduces the pollution tax in the other country.

Keywords: transboundary pollution, lobbying, pollution tax, Nash bargain, international negotiations, environmental policy

JEL classification: D62, H21, H23, H70

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1 Introduction

When individuals are affected by political decisions, they have an incentive to try to influence the political outcome. One way of doing so is to participate in lobby groups, which exercise pressure on the incumbent governments. For example, 'green' lobby groups may exercise political pressure to increase pollution taxes, while industry lobby groups may try to reduce costs that are associated with pollution. The number of lobby groups and the extent to which they affect the political outcome may differ both between countries and over time.¹ Earlier literature on green lobbying and environmental policy has mainly focused on policies decided upon at the national level. Therefore, this paper analyzes consequences of lobby group activity for policy outcomes in economies with transboundary environmental problems and international environmental policies are analyzed.

Previous studies suggest that green lobbying leads to a stricter environmental policy at the national level. For example, Fredriksson (1997) and Aidt (1998) show that more green lobbying may lead to higher pollution taxes in small open economies with local pollution.² Furthermore, Conconi (2003) introduces interactions between countries, such as trade and transboundary pollution, and examines how green lobbying affects policy outcomes. She shows that the impact of green lobbying depends crucially on the trade regime and on how lobby groups act together. A specific result is that one country's increase in pollution taxes, triggered by lobbying, improves the terms of trade in favor of the other country, which leads to an increase in that country's production and emissions. However, it is worth noting that Conconi (2003) does not consider consequences of environmental policies that are determined in a negotiation between countries, which will be the case in this paper. Moreover, Aidt (2005) finds that an increase in the influence from environmental lobby-groups may lead to lower pollution taxes. This result rests on the assumption that pollution is immobile and environmentalists care sufficiently about pollution that arises abroad. Specifically, when environmentalists are very concerned with pollution abroad, the lobby group is willing to accept more domestic pollution in return for less

¹See e.g. Conconi (2003) for a discussion on the importance of lobbying in real world politics.

²Fredriksson (1997) uses a lobby group model to study how a pollution tax is affected by movements in prices and lobbying.

pollution abroad. Accordingly, these two studies show that the standard intuition, where stronger environmental lobby groups improve the environmental quality, may not necessarily be correct.

In this paper, the standard lobby group model in Fredriksson (1997) is extended to include a negotiation between countries with respect to environmental policy, here defined as pollution taxes.³ Hence, the present paper does not focus on trade policies but instead on international environmental agreements. The present paper considers a global economy consisting of many small countries but, to simplify the analysis as much as possible, it is assumed that only two of them generate, and are affected by, transboundary pollution. These two countries coordinate their environmental policies (taxes) via a cooperative Nash bargain, while treating the world market prices as exogenous. Although the focus on a two-country agreement is a simplification and motivated by convenience, the model is interpretable in terms of the literature on 'bottom-up' agreements; see e.g. Buchner and Carraro (2005).⁴

The purpose of this paper is to bring together lobbying, transboundary environmental problems and international environmental policy. It follows earlier literature on lobbying and employs a standard menu auction model first applied in Grossman and Helpman (1994).⁵ The menu auction model is a suitable tool for analyzing situations where different lobby groups offer an incumbent government a menu of campaign contributions in return for a particular choice of policy. It should perhaps be emphasized that lobby activities are assumed to

³It can perhaps be argued that a negotiation over national policy instruments directly is an unrealistic assumption. However, this can - for example - be seen in economic federations such as the European Union. In such federations carbon dioxide targets are determined at the federal level although each member country chooses how to implement the targets. As for the present paper, the negotiation over national pollution taxes becomes equivalent to a negotiation over national target levels.

⁴With a bottom-up approach, each country has the freedom to sign agreements with other countries, bilaterally or multilaterally, without being constrained by a 'global' convention (by 'global' it is referred to e.g. the Kyoto protocol and other international agreements). The bottom-up approach most likely lead to more regional coalitions with stronger incentives to participate (see Buchner and Carraro (2005) for a more rigorous discussion of this topic). If some countries do not take part in the agreement but are affected by the transboundary pollution, the approach does not completely internalize the external effects. However, an assumption of all countries taking part in the agreement is not sufficient to guarantee a complete internalization.

⁵The model in Grossman and Helpman (1994) originates from a paper by Bernheim and Whinston (1986).

be strictly national, meaning that campaign contributions are offered to the domestic government⁶, and depend on domestic government policies⁷. Hence, the possibility of ‘cross-national’ lobbying is disregarded in this paper. Furthermore, each government is assumed to care only about the probability of re-election, which depends on a weighted sum of aggregate campaign contributions and domestic social welfare.

The negotiation between the countries is characterized as a Nash bargain with two possible outcomes facing each government. The preferred outcome to both governments is a signed contract that, by definition, renders a higher level of welfare than the no-contract outcome. If no contract is signed, each government obtains the ‘fall-back’ welfare level, which represents a non-cooperative Nash equilibrium, where each government treats the policy instruments of the other country as exogenous. Since each country benefits from signing a contract, the Nash bargain approach may be interpreted in terms of a ‘self-enforcing’ agreement.⁸ Moreover, it is also worth noting that, if the political process is considered as a repeated game, the bottom-up approach may increase the credibility of the contract because a country could face a punishment in the next round of negotiations.

The paper is organized as follows. Section 2 describes the model and its characteristics. Section 3 defines and explains the political process. The main results are presented in section 4, while section 5 summarizes and discusses the results.

2 The Model

Consider a global economy consisting of many small countries. Two of these countries, denoted by superindices 1 and 2, respectively, are identical in all important respects. Pollution in each of these two countries is assumed to affect

⁶There are studies where lobby groups in one country may offer contributions to the government in the other country; see e.g. Prat and Rustichini (2003) for the multiple agent - multiple principle approach. This approach is adopted by Fredriksson and Millimet (2007) who study pollution taxation, and by Aidt and Hwang (2008) who study internalization of ‘cross national’ externalities via labour standards.

⁷Grossman and Helpman (1995) extend their previous paper to allow for contribution schedules that are contingent on tax policies in both countries.

⁸There is an existing body of literature that deals with game theoretic aspects of policy cooperation, see e.g. Mäler (1989), Barrett (1994) and Carraro (2003).

not only the domestic residents, but also residents in the other country. Notice, however, that pollution is assumed to be transboundary only in a restricted way, as no other country is affected by the environmental damage generated by these two particular countries.⁹

Production in country i , $i = 1, 2$, takes place in two sectors; one produces a non-polluting good, c^i , that serves as a numeraire, while the other produces a polluting good, x^i . Both countries produce both types of goods. The numeraire good is produced with a linear technology that uses labor as the only input, whereas good x^i is produced with a constant returns to scale technology that uses labor and a sector-specific input in the production. The sector-specific input is assumed to be immobile and non-tradable. Furthermore, all markets are assumed to be competitive and the wage rate is normalized to one in both countries.

The government in country i has the possibility to levy a tax on the pollution associated with the production of good x^i . Free trade and the assumption of small open economies define the producer price of good x^i as $p^i = p^* - t^i$, where p^* is the world market consumer price on good x^i and t^i the corresponding pollution tax paid by the producers. The assumption of price taking economies implies that p^* is exogenous to each country/government. The revenue from the pollution tax in country i is given by $\tau^i = t^i x^i$ and is redistributed uniformly to all individuals.¹⁰ Profit maximization defines a profit function, $\Pi^i(p^i)$, and a supply function¹¹, $x_s^i(p^i)$, where the latter satisfies $\partial x_s^i / \partial p^i > 0$ and $\partial^2 x_s^i / \partial (p^i)^2 = 0$. Hotelling's lemma defines the supply of good x^i as

$$x_s^i(p^i) = \partial \Pi^i / \partial p^i \quad (1)$$

Each country consists of N^i citizens who receive labor income, l^i , and, for notational convenience, N^i is normalized to one. Some citizens are assumed to have a special interest in the environmental quality, while others receive profit

⁹It is, of course, possible to generalize the model to include more than two countries that are affected by environmental damage. However, given the objective of this paper it would complicate the analysis without providing any valuable insights (at least in the symmetric equilibrium, which is the main focus of the paper).

¹⁰The assumption of uniformly distributed revenues follows related literature, see e.g. Grossman and Helpman (1994) and Fredriksson (1997).

¹¹A linear supply function is used for computational reasons and follows Fredriksson (1997). An example of a production technology that implies a linear supply function is a Cobb-Douglas production function with an input elasticity equal to 0.5.

income from the production of x^i . The remaining agents (i.e. those who are neither environmentalists nor owners of the firm that produces x^i) are called workers. In what follows, these groups are denoted environmentalists, industrialists and workers, respectively (superindex E , I and W). By assumption, all citizens share a common quasilinear utility function for c^i and x^i , whereas environmentalists also derive disutility from pollution associated with the production of good x^i .¹² Hence, workers and industrialists have their utility functions defined as

$$U^{W,i} = c^{W,i} + u(x^{W,i}) \quad (2)$$

$$U^{I,i} = c^{I,i} + u(x^{I,i}) \quad (3)$$

while an environmentalist's utility becomes

$$U^{E,i} = c^{E,i} + u(x^{E,i}) - X \quad (4)$$

where X is the disutility experienced from both domestic and foreign pollution, defined as $X = x^i + x^j$ for $i \neq j$. Notice that $x^{k,i}$, $k = E, I, W$, is the fraction of x^i associated with each group of individuals and that the marginal disutility of pollution is normalized to one. It is assumed that *all* citizens receive income from both labor and redistributed tax revenues, while industrialists also receive profit income from the polluting sector.

Citizens with interests in the polluting sector are assumed to organize themselves into lobby groups. Environmentalists join the environmental lobby group and industrialists join the industry lobby group, while workers do not take part in any lobbying. Lobby group membership is exogenous in the model, meaning that *all* environmentalists and *all* industrialists are assumed to be members in their respective groups.¹³

Citizens use their income to finance the consumption of c^i and x^i . However, environmentalists and industrialists also support their interests by campaign contributions to the incumbent government. Campaign contributions in each country are assumed to depend only on the domestic pollution tax rate, i.e. $\Lambda^{E,i}(t^i)$ and $\Lambda^{I,i}(t^i)$. Other characteristics of the contribution schedules are

¹²The quasilinear utility function is appealing because it implies a simple demand structure and there are no income effects to be considered. A quasilinear utility function is also in line with related literature as e.g. Grossman and Helpman (1994).

¹³For a more general discussion of incentives associated with lobbying, see e.g. Olson (1965).

discussed in more detail later in the paper. It is assumed that the environmentalists recognize that a higher tax on pollution reduces production in the polluting sector, while industrialists recognize that a higher tax on pollution reduces profits. Given these characteristics, each citizen chooses c^i and x^i to maximize his/her utility subject to the budget constraint. The optimization problem facing environmentalists and industrialists can be written as

$$\max_{c^{E,i}, x^{E,i}} U^{E,i} = c^{E,i} + u^i(x^{E,i}) - [x^i + x^j] \quad (5)$$

$$s.t. \quad l^i + \tau^i = c^{E,i} + p^* x^{E,i} + \Lambda^{E,i} / \alpha^{E,i}$$

and

$$\max_{c^{I,i}, x^{I,i}} U^{I,i} = c^{I,i} + u^i(x^{I,i}) \quad (6)$$

$$s.t. \quad l^i + \tau^i + \Pi^i / \alpha^{I,i} = c^{I,i} + p^* x^{I,i} + \Lambda^{I,i} / \alpha^{I,i},$$

respectively, where $\alpha^{E,i}$ and $\alpha^{I,i}$ are the fractions of environmentalists and industrialists, respectively, in country i . As described above, workers are not lobby group members and do not give any campaign contributions. Hence, the optimization problem facing each worker is written as

$$\max_{c^{W,i}, x^{W,i}} U^{W,i} = c^{W,i} + u^i(x^{W,i}) \quad (7)$$

$$s.t. \quad l^i + \tau^i = c^i + p^* x^{W,i}$$

By defining $Y^{k,i}$ as each individual's net income after redistributed tax revenues (τ^i), profits (Π^i) and expenses for lobbying ($\Lambda^{k,i}$), the indirect utility functions for each type of individual can be written as

$$V^{E,i}(p^*, t^i, Y^{E,i}) = Y^{E,i} + u(x_d^{E,i}(p^*)) - p^* x_d^{E,i}(p^*) - X$$

$$V^{I,i}(p^*, t^i, Y^{I,i}) = Y^{I,i} + u(x_d^{I,i}(p^*)) - p^* x_d^{I,i}(p^*) \quad (8)$$

$$V^{W,i}(p^*, t^i, Y^{W,i}) = Y^{W,i} + u(x_d^{W,i}(p^*)) - p^* x_d^{W,i}(p^*)$$

where the demand for the polluting good, associated with each type of individual, $x_d^{k,i}(p^*)$, is the inverse of $\partial u(x^{k,i}) / \partial x^{k,i} = p^*$ and the difference $u(x_d^{k,i}(p^*)) - p^* x_d^{k,i}(p^*)$ is the consumer surplus derived from the two goods.

Each lobby group's utility is defined as the sum of its members' utilities. Hence, when omitting constant terms and in the absence of campaign contributions, the utilities of the environmental and industrial lobby groups become, respectively,

$$\Omega^{E,i}(t^i, t^j) = \alpha^{E,i} [\tau^i(t^i) - [x^i(p^i) + x^j(p^j)]] \quad (9)$$

$$\Omega^{I,i}(t^i) = \alpha^{I,i} \tau^i(t^i) + \Pi^i(p^i)$$

By adding all indirect utilities, the aggregate social welfare function in country i is defined as

$$\Omega^i(t^i, t^j) = \tau^i(t^i) + \Pi^i(p^i) - \alpha^{E,i} [x^i(p^i) + x^j(p^j)] \quad (10)$$

3 The Political Game

As mentioned in the introduction, the political process to determine the level of pollution taxes can be described as a two stage game. The first takes place at the national level between the government and the lobby groups, where each lobby group offers the incumbent government a contribution schedule that depends on the pollution tax rate, i.e. $\Lambda^{k,i}(t^i)$, $k = E, I$. The contribution schedule from each lobby group is assumed to be continuously differentiable and each lobby group treats the other lobby group's contribution schedule as exogenous. Following earlier literature (e.g. Grossman and Helpman (1994)), possible effects of direct political competition (political parties) and lobby groups that do not recognize that their contributions affect the likelihood of re-election of the incumbent government are disregarded.

In line with earlier comparable literature, it is assumed that the incumbent government uses contributions to finance campaign spending. The incumbent government realizes the relationship between campaign spending and the probability of re-election, and that the probability of re-election also depends on the aggregate welfare of society. Therefore, given that re-election is the single goal of the government, the incumbent government in each country maximizes a weighted sum of aggregate campaign contributions and aggregate social welfare. Hence, the government's objective function is defined as

$$W^i(t^i, t^j) = \sum_{k=E,I} \Lambda^{k,i}(t^i) + \lambda^i \Omega^i(t^i, t^j) \quad (11)$$

where $\lambda^i \geq 0$ is an exogenous weight attached to aggregate social welfare relative to campaign contributions.¹⁴

In the second stage, where the bargain between the two governments takes place, each government takes the contribution schedules into consideration and negotiates with the other country's government about the policy. Let $W^i = W^i(t^i, t^j)$ be the welfare each government obtains if it signs a contract, and \overline{W}^i the welfare obtained if no contract is signed (denoted 'fall-back'). The fall-back outcome is derived by assuming that each government behaves as a Nash competitor by choosing its policy conditional on the other country's policy, i.e. the outcome will be a non-cooperative Nash equilibrium. By defining $\Psi^i = W^i - \overline{W}^i$ and $\Psi^j = W^j - \overline{W}^j$ to be the rents from bargaining, the Nash bargain maximizes the product

$$\Gamma = \Psi^i \Psi^j \quad (12)$$

with respect to t^i and t^j (where both governments are assumed to have equal bargaining power). Given these characteristics, the first order condition for t^i becomes

$$\frac{\partial \Gamma}{\partial t^i} = \frac{\partial \Psi^i}{\partial t^i} \Psi^j + \frac{\partial \Psi^j}{\partial t^i} \Psi^i = 0 \quad (13)$$

3.1 The equilibrium

It is assumed that the environmental policy and the campaign contributions are determined as a subgame perfect Nash equilibrium of the game presented above. The characteristics of this subgame perfect Nash equilibrium is that each contribution schedule is feasible, that the chosen pollution taxes maximize the government's objective function and, given the contribution schedules of each lobby group, no other lobby group has an alternative strategy that yields a greater payoff than the equilibrium payoff. These characteristics follow the equilibrium properties derived in Grossman and Helpman (1994), Dixit (1996) and Fredriksson (1997), which are all based on the characterization of a subgame perfect Nash equilibrium in a menu auction model developed in Bernheim and

¹⁴Following the model as defined above, the government's problem should be introduced as a maximization of $\widehat{W}^i = \nu_1^i \sum_{k=E,I} \Lambda^{k,i} + \nu_2^i \left[\Omega^i - \sum_{k=E,I} \Lambda^{k,i} \right]$. However, this is equivalent to maximizing W^i (equation (11)) with $\lambda^i = \nu_2^i / (\nu_1^i - \nu_2^i)$, given that the government values a dollar in their campaign budget higher than a dollar in the hands of the public, i.e. given that $\nu_1^i > \nu_2^i$. This assumption is in line with related literature and must hold when lobbying exists.

Whinston (1986). These equilibrium properties imply, among other things, that

$$\partial\Lambda^{k,i}(t^i)/\partial t^i = \partial\Omega^{k,i}(t^i, t^j)/\partial t^i \text{ for } k = E, I \quad (14)$$

The intuition behind this property is that each lobby group sets its contribution schedule so that the change in the contributions, caused by a marginal change in the tax rate, is equal to the corresponding change in the lobby group's welfare. Hence, the property corresponds to the marginal willingness to pay for a change in the tax rate. The contribution schedules are said to be locally truthful around the equilibrium pollution tax rate.¹⁵ Throughout the paper, this equilibrium property is assumed to hold, meaning that equation (14) will be interpreted as a constraint in the optimization process.

4 The Environmental Policy Outcome

The main purpose of this section is to derive optimal pollution taxes and to study how exogenous changes in the number of lobby group members, as well as changes in the relative weight the government attaches to social welfare, affect the policy outcome. To simplify the analysis, the section begins with a benchmark case in which the policy is determined without any influence of lobbying. It then continues by incorporating lobbying into a symmetric framework where the countries are identical in all important respects, and changes are symmetric between the countries. Finally, the pollution taxes are derived and analyzed with differences between the two countries, meaning that the assumption of identical countries is relaxed.

Within the lobby group framework, a standard result when all individuals have their interests represented by lobby groups is that the policy outcome becomes socially efficient and replicates the first best. This result is a direct implication of an efficient equilibrium as presented in Bernheim and Winston (1986). The intuition is simply that the externality becomes completely internalized in this case. However given the specific setup of this paper, the externality is not completely internalized - even though all individuals have their interests represented by lobby groups (this is explained in more detail below). Accordingly, to simplify the analysis as much as possible, most of the results

¹⁵See e.g. Grossman and Helpman (1994) for a more rigorous discussion about this property.

are presented with the assumption that all citizens are lobby group members (i.e. either environmentalists or industrialists).

4.1 The benchmark case

In the absence of lobbying, the objective of each national government reduces to the measure of aggregate social welfare. By using $W^i = \lambda^i \Omega^i$, in equation (12), the optimal solution defines the pollution tax in country i as

$$t^i = \alpha^{E,i} + \alpha^{E,j} \quad (15)$$

where it is used that $\Psi^i = \Psi^j$ in a symmetric equilibrium with identical countries¹⁶.

This result is standard and implies that the optimal pollution tax in each country equals the sum of marginal social damage that this country generates. Given the model specification, the sum of marginal social damage is defined as the proportion of environmentalists in both countries.¹⁷

4.2 The symmetric equilibrium

The introduction of lobbying implies that each government maximizes the objective function defined by equation (11). Consider the case where all citizens are either environmentalists or industrialists, i.e. $\alpha^{E,i} + \alpha^{I,i} = 1$.

Proposition 1 *Within the given framework, a subgame perfect Nash equilibrium with symmetric countries implies that the pollution taxes are defined as*

$$t^i = \alpha^{E,i} + \alpha^{E,j} \frac{\lambda^j}{(1 + \lambda^i)}$$

where $\alpha^{E,i} = \alpha^{E,j}$, $\lambda^i = \lambda^j$ and $i \neq j$.

Proof. See the Appendix. ■

Compared with equation (15), the pollution tax in country i is lower than in the benchmark case. The intuition is that a government only receives contributions from domestic lobby groups and, therefore, attaches no weight to

¹⁶Without the assumption of identical countries, the pollution tax in country i equals $t^i = \alpha^{E,i} + \alpha^{E,j} \frac{\lambda^j \Psi^i}{\lambda^i \Psi^j}$.

¹⁷This result corresponds to a tax rate equal to the sum of marginal willingness to pay to avoid the pollution, i.e. $t^i = \sum_i MWP^i$, in related literature. A Benthamite approach, where a global planner determines the pollution taxes in both countries, also gives the same result.

the other country's environmentalists. The pollution tax reflects the weight the other country's government attaches to social welfare. The interpretation must be that the marginal social damage from pollution in country j has less impact on the pollution tax in country i . Accordingly, the introduction of lobbying implies that the pollution tax in country i is defined as a weighted sum of the marginal social damage in each country, and pollution taxes become lower with lobbying than without (i.e., the benchmark case). This result implies that although all citizens have their interests represented by lobby groups, the pollution tax does not replicate first best; the policy outcome does not completely internalize the externality.

4.2.1 Comparative statics in a symmetric equilibrium

It is reasonable to assume that the environmental concern and industrial lobbying may change within countries. It is also reasonable to assume that the weight the government attaches to lobbying may change. It is, for example, possible that a government's motive may change over time, which is interpreted as a change in the weight attached to contributions. Therefore, a relevant question would be to ask how the equilibrium pollution taxes are affected by changes in $\alpha^{E,i}$ and λ^i ?

Given that all citizens are either environmentalist or industrialists, it is sufficient to study changes in only one lobby group's member base, since the effect of the other lobby group becomes its mirror image. Moreover, to characterize a general change in either the environmental concern, or in the weight the governments attach to social welfare, in the two countries, it will be convenient to define $\alpha^E = \alpha^{E,i} + \alpha^{E,j}$ and $\lambda = \lambda^i + \lambda^j$. Consider the following proposition.

Proposition 2 *In a symmetric equilibrium, a general increase in the environmental concern or in the weight the governments attach to social welfare will lead to an increase in the pollution tax in both countries;*

$$\frac{dt^i}{d\alpha^E} = 1 + \frac{\lambda^j}{1 + \lambda^i} > 0$$

$$\frac{dt^i}{d\lambda} = \frac{\alpha^{E,j}}{(1 + \lambda^i)^2} > 0$$

for $\lambda^i = \lambda^j$ and $j \neq i$.

To prove Proposition 2, differentiate the pollution tax equation derived in Proposition 1 and solve for $dt^i/d\alpha^E$ and $dt^i/d\lambda$, respectively.

First, consider the general increase in the environmental concern (defined as more environmentalists in both countries). In Proposition 1, the pollution tax was defined as a weighted sum of marginal social damages in countries i and j . Hence, an increase in the number of environmentalists in both countries will undoubtedly increase this weighted sum. The reason is that more individuals in each country are negatively affected by pollution, and thus accept/want a higher tax on pollution.

To interpret the effect on t^i of increasing the weight attached to social welfare, note that a joint increase in λ^i and λ^j affects the pollution tax in country i via the preferences of country j 's environmentalists. When differentiating the pollution tax in Proposition 1 with respect to both λ^i and λ^j , it becomes obvious that an increase in λ^i tends to decrease the weight attached to the preferences in country j , while an increase in λ^j tends to increase this weight. Hence, the joint increase in λ^i and λ^j has both a positive and negative effect on the tax rate in country i . However, since the government in country i now attaches relatively less weight on lobbying contributions compared to social welfare, the net effect becomes positive. The government in country i attaches relatively more weight on the preferences of the environmentalists in country j . Notice that, as contributions become less important to the government, the pollution tax approaches the benchmark case. In the limit, when λ^i goes to infinity, the contributions becomes insignificant and aggregate social welfare is all that matters to the government.

4.3 Extensions

Although the assumption of symmetric countries gives intuitive results, it is partly motivated by analytical convenience. Allowing for asymmetries between the countries takes the analysis one step further. For example, the introduction of asymmetries makes it possible to analyze pollution taxes when countries differ with respect to their environmental concern (number of environmentalists), which certainly is a realistic scenario. As for the symmetric equilibrium, consider the case where all citizens are lobby group members, i.e. $\alpha^{E,i} + \alpha^{I,i} = 1$.

Proposition 3 *Within the given framework, a subgame perfect Nash equilib-*

rium with asymmetric countries implies pollution taxes defined by

$$t^i = \alpha^{E,i} + \alpha^{E,j} \frac{\lambda^j}{(1 + \lambda^i)} \frac{\Psi^i}{\Psi^j}$$

Proof. See the Appendix. ■

When the analysis is extended to allow for asymmetries, the tax rates change slightly. Compared with the symmetric equilibrium, the second part of the pollution tax equation is now multiplied by the quotient of rents (Ψ^i/Ψ^j). If the two countries are not identical, these rents may differ and the quotient may, therefore, deviate from unity. For example, countries may differ with respect to the proportion of environmentalists and/or industrialists as well as the weight that the government attaches to social welfare. Assume for a moment an exogenous change that only affects country i and increases the rent Ψ^i . In such a case (cet. par.), the quotient of rents becomes larger than one and thus works in the direction of increasing the pollution tax in country i . The interpretation is that country i becomes more eager to reach an agreement (has more to lose from a no-contract outcome or, alternatively, puts less pressure on country j) and, therefore, accepts a higher tax on pollution.

To conclude, the introduction of asymmetries between the two countries may either increase or decrease the pollution taxes, compared to the symmetric case, depending on the relative rents.

4.3.1 Symmetric changes in an asymmetric equilibrium

From Proposition 3 it is obvious that, to analyze changes in the number of environmentalists and the weight attached to social welfare, effects via the rents, Ψ^i , need to be considered. This, however, implies a slightly more complicated analysis since changes in exogenous variables in one country affect the other country's policy decision via the quotient of rents. Recall that, the assumption of symmetric countries actually implies that symmetric changes in both countries have equal effects on the rents - the rent effects become insignificant. Accordingly, the comparative statics in an asymmetric equilibrium must be solved as a simultaneous system of equations (tax equations), where exogenous changes may also affect the fall-back outcome.

Given an asymmetric equilibrium, the total effect on the pollution taxes from an increase in the fraction of environmentalists in both countries becomes

ambiguous. To see this, take as a starting point the pollution taxes defined in Proposition 3. By inspection, there are now effects via the quotient of rents, in addition to the positive effects derived in Proposition 2. These rent effects capture how a change in the number of environmentalists affects a country's incentives in the bargaining process (as described above). The total effect becomes ambiguous since the rents in each country, Ψ^i and Ψ^j , are affected so that they tend to increase, as well as decrease, the pollution tax. For instance, one of the rent effects (via Ψ^j) captures how an increase in the number of environmentalists in country j tends to decrease the pollution tax in country i since the rent Ψ^j increases. The interpretation of this particular effect is that country j becomes more eager to reach an agreement when $\alpha^{E,j}$ increases, and relaxes the pressure on country i in the bargaining process.

To conclude, given symmetric countries a general increase in the environmental concern increases the pollution tax. However, when allowing for asymmetries, the possibility that a general increase in environmental concern actually reduces the pollution tax cannot be excluded.

4.3.2 Asymmetric changes in a symmetric equilibrium

To develop the analysis further, it would be interesting to study the effects on the pollution taxes when the number of environmentalists changes in only one country. Therefore, consider the following proposition.

Proposition 4 *Starting with identical countries, an increase in the number of environmentalists in country i ($\alpha^{E,i}$) increases the pollution tax in that country (t^i), while it has an ambiguous effect on the other country's pollution tax (t^j).*

Proof. See the Appendix. ■

When the environmental concern increases in one country, it is natural that it affects the domestic pollution tax, but, through the bargaining, it must also be taken into account that it affects the pollution tax in the other country. Besides the positive effects derived in the case with symmetric changes, there is now an effect via the rent in country i . Since $\partial\Psi^i/\partial\alpha^{E,i} > 0$, this accentuates the positive impact on the tax rate. The intuition follows the previously discussed rent effects, which implies that country i becomes more eager to reach an agreement and hence increases its pollution tax.

The total 'cross-country' effect from an increase in $\alpha^{E,i}$ is indeterminate because, in addition to the effects that tend to increase t^j (corresponding to the effects in Proposition 2), there is a negative effect that tends to decrease the pollution tax t^j . The intuition behind this negative effect is that the increase in $\alpha^{E,i}$, and the corresponding reduction of pressure that country i puts on country j in the bargaining process, implies that country j tends to reduce its pollution tax. The government in country i becomes more eager to reach an agreement when the number of environmentalists increases, and therefore reduces its pressure on the other country. Therefore, if this effect is large enough an increase in the environmental concern in country i may actually reduce the pollution tax in country j .

The exogenous change in the fraction of environmentalists affects the welfare in both the bargaining outcome and the fall-back outcome. This implies that the assumption of the fall-back welfare is crucial for Proposition 4. So far in the paper, it has been assumed that the fall-back welfare may be affected by exogenous changes in country characteristics. However, let us change the setup for a moment and make an assumption of a fixed fall-back welfare. This could, for example, be the case if a supranational organization decides the environmental policy if no contract is signed. In such a case, $\partial\Psi^i/\partial\alpha^{E,i}$ becomes negative and turns the rent effects discussed in Proposition 4 in the opposite direction. The intuition is that, since more individuals are negatively affected by pollution, the increased number of environmentalists decreases the aggregate social welfare *cet.par.* which decreases the rent. Recall the case of a 'flexible' fall-back welfare in which more environmentalists reduced the aggregate social welfare to a larger extent in the fall-back case, implying a positive effect on the rent. Hence, an increase in one country's environmental concern has a corresponding impact on the tax rates as in the flexible 'fall-back' case, yet with completely opposite 'rent effects'. These opposite rent effects imply that the 'cross country' effect is now unambiguously positive, while the 'home country' effect is ambiguous. The intuition behind these results is analogous to Proposition 4.

4.4 Pollution taxes with workers included

Although the assumption of $\alpha^{E,i} + \alpha^{I,i} = 1$ implies pollution taxes that differ from the first best, it is reasonable to assume that some citizens are not lobby group members. In this section, the pollution taxes are derived given

the assumption that $(\alpha^{E,i} + \alpha^{I,i}) < 1$ (as defined in section 2.1).¹⁸ However, note that differences between countries are still allowed for, i.e. an asymmetric equilibrium. Define that

$$\beta^i = \frac{(1 + \lambda^i) \delta^i}{[\alpha^{E,i} + \alpha^{I,i} + \lambda^i] (1 + \delta^i) - (1 + \lambda^i)} \quad (16)$$

where $\delta^i = [dx^i/dt^i] [t^i/x^i]$ is the tax elasticity of total pollution in country i . By inspection, it can be found that $\beta^i > 0$ if total pollution is decreasing in the tax rate, i.e. if $\delta^i < 0$, and if $\alpha^{E,i} + \alpha^{I,i} < 1$. This shows that, given an asymmetric equilibrium where lobby groups employ campaign contributions that fulfil the criterion for a subgame perfect Nash equilibrium, and if pollution taxes are determined in a Nash bargain between two countries, the outcome will be tax rates defined as

$$t^i = \left[\alpha^{E,i} + \alpha^{E,j} \frac{\lambda^j}{(1 + \lambda^i)} \frac{\Psi^i}{\Psi^j} \right] \beta^i \quad (17)$$

Therefore, the pollution tax in country i depends on lobby group membership, the governments' weights attached to aggregate social welfare and the tax elasticity of pollution in country i . Moreover, the pollution taxes are unambiguously positive in equilibrium, given that total pollution is decreasing in the tax rate, i.e. the tax elasticity of pollution is negative. When compared to the pollution tax derived in Proposition 3, it becomes obvious that the previously derived tax formula now is multiplied by β^i . Hence, an increase in β^i tends to increase the tax rates and vice versa. This means that the pollution tax now depends on the tax elasticity of pollution, δ^i . Differentiation of equation (16) gives that β^i is decreasing in δ^i , which implies that the tax rate tends to increase (via β^i) the more sensitive pollution is to changes in the tax rate (δ^i more negative). The intuition behind this result is that, although the positive welfare effect to environmentalists increases, the negative tax revenue effect through the lost tax base dominates and hence tends to decrease the tax rate.

Finally, it is worth noting that the only difference compared with the tax rates derived in Proposition 3 is that not all citizens are lobby group members. Accordingly, when the number of lobby group members increases, the pollution tax approaches that in Proposition 3. If all citizens are lobby group members, Proposition 3 becomes completely replicated ($\beta^i = 1$).

¹⁸This result is referred to as the 'general case' in the Appendix.

5 Summary and Discussion

The purpose of this paper has been to derive pollution taxes in the context of lobbying and transboundary pollution. In the specific setup, pollution in one country is assumed to affect not only residents in that country but also residents in another country. A standard lobby group model is used to characterize the influence from environmental and industrial lobbying on an incumbent government. The framework is then extended to incorporate environmental policies determined in a negotiation between the two countries affected by pollution.

It is found that the assumption of local lobbying, implying that the domestic government puts no weight on the preferences of the other country's environmentalists, tends to reduce the pollution tax. The intuition is that a government has no incentive to satisfy the preferences of lobby group members in the other country. Note, however, that it will still be a bargaining outcome where each country considers the other country. Second, a general increase in the environmental concern and in the weight the governments attach to social welfare, respectively, tends to increase the pollution tax in a symmetric equilibrium. The intuition for the first part is that more people experience disutility from pollution, which increases the willingness to pay for reduced pollution levels and hence increases the tax on pollution. The second part is explained by the fact that when a government increases the relative weight attached to social welfare, it increases the weight attached to environmentalists' preferences in the other country.

The model also shows that an increase in the number of environmentalists in just one country may reduce the other country's tax on pollution in a symmetric equilibrium. The intuition behind this result is that a government tends to accept a higher tax on pollution when the number of environmentalists in that country increases, which implies that the other country tends to reduce its tax on pollution.

Allowing for asymmetries between the two countries gives rise to interesting consequences. For example, it is possible that a general increase in the environmental concern reduces the taxes on pollution. The driving force behind this result follows the same intuition as in the symmetric equilibrium when the number of environmentalists in just one country increases. That is, a government becomes more eager to reach an agreement when the number of environmen-

talists increases in that country, which leads to reduced pressure on the other country to implement a high tax on pollution.

The main implication of this paper is that it is not always correct that an increase in the environmental concern increases the pollution taxes. This is an interesting finding since it seems to correspond to results in Conconi (2003). However, it is important to emphasize that the result in the present paper arises strictly from the bargaining process and does not rest on the assumption of trade between the two countries, i.e. it is not a terms of trade effect as in Conconi (2003). Hence, the point to be made here is that, although due to completely different mechanisms than other studies, the present model gives rise to the counterintuitive possibility that an increase in the environmental concern increases the pollution taxes.

A possible extension of the present paper would be to change the setup slightly and allow for transboundary pollution in a more 'unrestricted' way. This is possible in our specific framework, although it would require a considerably more complicated analysis of the comparative statics. Another possible extension is to moderate the bargaining process in a more sophisticated manner (e.g. by endogenous participation). In addition, it would also be possible to extend the model to include 'cross-national' lobbying as discussed in the introduction. However as indicated, these extensions are left for future research.

A Appendix

In the Appendix, subindices denote partial derivatives, e.g. $\Psi_{\alpha^{E,i}}^i = \partial\Psi^i/\partial\alpha^{E,i}$ and $\Gamma_{t^i t^j} = \partial^2\Gamma/\partial(t^j)^2$.

A.1 Pollution taxes

The general case The ‘general case’ refers to the model defined in sections 2 and 3, i.e. the complete model without any simplifying assumptions. Section 4.4 follows from, and discusses, this ‘general case’.

To derive the pollution taxes, first define

$$\beta^i = \frac{\delta^i}{[\alpha^{E,i} + \alpha^{I,i} + \lambda^i] (1 + \delta^i) - (1 + \lambda^i)} \quad (\text{A.1})$$

where $\delta^i = [dx^i/dt^i] [t^i/x^i]$ is the tax elasticity of total pollution in country i . By substituting for $\Psi_{t^i}^i$ and $\Psi_{t^i}^j$ into the first order condition for an optimal pollution tax (equation (13)), simple rearrangement yields the following tax equation

$$t^i = \left[\alpha^{E,i} (1 + \lambda^i) + \lambda^j \alpha^{E,j} \frac{\Psi^i}{\Psi^j} \right] \beta^i \quad (\text{A.2})$$

Proof of Proposition 1 The assumptions of symmetry and $\alpha^{E,i} + \alpha^{I,i} = 1$ imply that $\Psi^i = \Psi^j$ and $\beta^i = 1/(1 + \lambda^i)$, respectively. By substituting this into equation (A.2), the following is obtained

$$t^i = \alpha^{E,i} + \alpha^{E,j} \frac{\lambda^j}{(1 + \lambda^i)} \quad (\text{A.3})$$

Proof of Proposition 3 The assumption that $\alpha^{E,i} + \alpha^{I,i} = 1$ implies that $\beta^i = 1/(1 + \lambda^i)$. By substituting this into equation (A.2), the following is obtained

$$t^i = \alpha^{E,i} + \alpha^{E,j} \frac{\lambda^j}{(1 + \lambda^i)} \frac{\Psi^i}{\Psi^j} \quad (\text{A.4})$$

A.2 Proof of Proposition 4

A simultaneous system of the tax equations can be written as

$$\begin{bmatrix} \Gamma_{t^i t^i} & \Gamma_{t^i t^j} \\ \Gamma_{t^j t^i} & \Gamma_{t^j t^j} \end{bmatrix} \begin{bmatrix} \frac{dt^i}{d\alpha^{E,i}}, \frac{dt^i}{d\lambda^i} \\ \frac{dt^j}{d\alpha^{E,i}}, \frac{dt^j}{d\lambda^i} \end{bmatrix} = \begin{bmatrix} -\Gamma_{t^i \alpha^{E,i}}, -\Gamma_{t^i \lambda^i} \\ -\Gamma_{t^j \alpha^{E,i}}, -\Gamma_{t^j \lambda^i} \end{bmatrix} \quad (\text{A.5})$$

The determinant of the first matrix on the left can be written as $|H| = z^i (2\Gamma_{t^i t^j} + z^i) > 0$, where $z^i = (1 + \lambda^i) x_p^i \Psi^j$. It can be shown that, by using the first order condition for the maximization of the Nash product (see equation (13)), $\Gamma_{t^i t^j} = \Gamma_{t^j t^i} > 0$. Moreover, the second order conditions for a maximum imply that $\Gamma_{t^i t^i}, \Gamma_{t^j t^j} < 0$.

The 'home country' effect Starting with equation (A.5), Cramer's rule gives that

$$\frac{dt^i}{d\alpha^{E,i}} = \frac{-\Gamma_{t^i \alpha^{E,i}} \Gamma_{t^j t^j} + \Gamma_{t^j \alpha^{E,i}} \Gamma_{t^i t^j}}{|H|} \quad (\text{A.6})$$

Since $|H| > 0$, the numerator determines the sign of $dt^i/d\alpha^{E,i}$. Starting with symmetric countries, the numerator of equation (A.6) can be re-written as

$$[z^i + \lambda^j \alpha^{E,j} x_p^i \Psi_{\alpha^{E,i}}^i] z^j + [z^i + \lambda^i x_p^j \Psi^j] \Gamma_{t^i t^j} > 0 \quad (\text{A.7})$$

implying that $dt^i/d\alpha^{E,i} > 0$.

The 'cross-country' effect Starting with equation (A.5), Cramer's rule gives that

$$\frac{dt^i}{d\alpha^{E,j}} = \frac{-\Gamma_{t^i \alpha^{E,j}} \Gamma_{t^j t^j} + \Gamma_{t^j \alpha^{E,j}} \Gamma_{t^i t^j}}{|H|} \quad (\text{A.8})$$

Since $|H| > 0$, the numerator determines the sign of $dt^i/d\alpha^{E,i}$. Starting with symmetric countries, the numerator of equation (A.8) can be re-written as

$$[-\lambda^j \alpha^{E,j} x_p^i \Psi_{\alpha^{E,j}}^j + \lambda^j x_p^i \Psi^i] z^j + [z^j + \lambda^j x_p^i \Psi^i] \Gamma_{t^i t^j} \geq 0 \quad (\text{A.9})$$

implying that $dt^i/d\alpha^{E,i} \geq 0$.

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IV

Environmental Policy, Decentralized Leadership and Horizontal Commitment Power

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Abstract

This paper analyzes environmental policy in a decentralized economic federation comprising two countries, where a federal government decides upon environmental targets (maximum allowable emissions) for each country, which are implemented by the national governments. Both national governments have commitment power vis-à-vis the federal government, whereas one of the national governments (the horizontal Stackelberg leader) also has commitment power vis-à-vis the other country (the horizontal follower). The results show how the horizontal and vertical commitment power affect the horizontal leader's use of income and production taxes, which are the tax instruments available at the national level.

Keywords: environmental policy, optimal taxation, economic federation, horizontal commitment power

JEL Classification: D62, H21, H23, H70

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1 Introduction

Many environmental problems are transboundary in the sense that the environmental damage created by the production and/or consumption in one specific country does not only affect the well-being of domestic residents; it also influences the well-being of residents in other countries. In this case, therefore, environmental policies determined by individual countries without any cooperation are not likely to fully internalize externalities, as national policies are typically governed by domestic objectives and constraints. There is a growing literature dealing with optimal tax policy in the presence of transboundary environmental damage. However, this literature typically focuses on tax and expenditure policies designed to implement non-cooperative and cooperative resource allocations, or welfare effects of policy coordination, without paying much attention to the institutional structure within which the public policy is decided upon.¹ In a European context, much of the environmental policy is determined within the European Union (EU), where the supranational level typically decides upon maximum allowable emissions for the member countries - referred to as 'environmental targets' in what follows - which are implemented by the national governments. For instance, EU decides upon targets for green house gases (via the so-called burden sharing agreement) as well as targets for many other pollutants such as sulfur dioxide and lead, which the members implement via taxation and/or other policies.² Therefore, a fiscal-federalism-like approach may provide insights of relevance for understanding environmental policy. The present paper considers an economic federation with transboundary effects of environmental damage across the member countries and focuses on the incentives characterizing tax policy at the national level - described more thoroughly below.

In the literature on optimal taxation in economic federations, EU is often used to exemplify an economic federation with decentralized leadership - here meant to imply that the national level of government acts as first mover (has commitment power) vis-à-vis the federal government.³ This is so for at least

¹See, e.g. Mäler (1989), Carraro (2003), van der Ploeg and de Zeeuw (1992) and Aronsson and Blomquist (2003).

²See Council Directive 1999/30/EC for a complete report of limit values for concentrations of sulphur dioxide, nitrogen dioxide and nitrogen oxides, particulate matter and lead in the ambient air.

³See e.g. Silva and Caplan (1997), Caplan and Silva (1999) and Aronsson et al. (2006b).

two reasons. First, the EU is still in a developing phase, meaning that member countries may already have made commitments to policies based on their national objectives. Second, the member state governments are represented in the Council of Ministers, which suggests that individual member countries may have a significant influence over union policy.⁴

In addition, the member countries may also differ with respect to horizontal commitment power, here meant to imply that a particular member country might act as first mover in horizontal space vis-à-vis the others. For instance, large countries such as Germany - most likely - has more potential to act strategically against other countries than, say, Luxemburg or Sweden. The reason is basically that such large countries have greater influence on the economic development within the federation than smaller countries. In the present paper, this is interpreted so that one member country acts as a horizontal Stackelberg leader, whereas the other members act as horizontal followers. Stackelberg leadership is often recognized in monopoly, or oligopoly, contexts, and modeled so that the leader - who is assumed to have commitment power - moves first and then the follower move sequentially. The reason for commitment power typically refers to size (or market power), but possibly varies with the context of interest.⁵

To my knowledge, there are no earlier studies dealing with environmental policy in an economic federation characterized by decentralized leadership, where one of the member countries also exercises horizontal commitment power vis-à-vis other members. Therefore, the purpose of the present paper is to analyze the incentives underlying optimal national tax policies in an economic federation with decentralized leadership, where one of the countries acts as a Stackelberg leader in horizontal space. Accordingly, although all member countries act as first movers vis-à-vis the federal government (vertical space), one of them also acts as a first mover toward the others (horizontal space).

There are relatively few earlier studies dealing with environmental policy in

⁴In the EU, the Commission has the power to initiate environmental legislation. However to become EU law, each proposal has to pass the Council of Ministers, which consists of representatives from each member country, suggesting that the member state governments have a strong position in the decision process.

⁵See e.g. Higgins (1996) for a brief discussion about which oligopolist would be the leader. For empirical discussions of Stackelberg leadership across countries, see e.g. Altshuler and Goodspeed (2002) and Ruiz and Gerard (2008).

economic federations with decentralized leadership. Silva and Caplan (1997), and Caplan and Silva (1999) address environmental policy (emission taxes and abatement policy) in an economic federation comprising a federal government and two lower-level governments. In their framework, each level of government controls one policy variable and, depending on which level makes credible commitments, the economic federation is interpreted either as centralized or decentralized. In Caplan and Silva (1999), one of the main findings refers to the distribution of policy instruments between the levels of government. It is shown - given model specific assumptions - that it is socially desirable to give regional governments the tax (price) instrument, while giving the central government a quantity instrument. This result applies for decentralized as well as centralized economic federations and follows from the central government's ability of choosing the regional environmental damage levels as it wishes. As a consequence, for a decentralized economic federation, the lower level government has no better option than internalizing the transboundary environmental damage it generates. Aronsson et al. (2006b) also consider an economic federation comprising two lower level governments - referred to as countries - and a federal government. In their framework, the federal government decides upon an emission target for each country (i.e. a maximum allowable emission), which is implemented by tax policy at the national level. Each national government faces a mixed tax problem, where the set of tax instruments contains a nonlinear income tax and linear commodity taxes.⁶ In addition, it is assumed that the national governments are first movers vis-à-vis the federal government, which is meant to imply that the emission targets are conditioned on the national tax policies. Their results show that the decentralized leadership creates incentives for each country to influence the emission targets decided upon by the federal government. This implies that each country implements commodity taxes that do not satisfy the so-called additivity property, and that the marginal labor income tax is, in part, also used to relax the emission target.

The present paper follows Aronsson et al. (2006b) in the sense that the federal government decides upon emission targets, which are to be implemented by the national governments. As mentioned above, the main contribution here is to

⁶Other studies dealing with mixed taxation in economies with environmental externalities are e.g. Pirttilä and Tuomala (1997) and Aronsson and Blomquist (2003). However, these studies do not consider a federal decision structure with several levels of government.

add the horizontal leader-follower dimension to their framework. To simplify the analysis, the transboundary environmental damage constitutes the only direct channel of interaction between the countries, meaning that other forms of direct interactions - such as international trade and factor mobility - are disregarded. In addition, to be able to focus on environmental policy, i.e. externality correction and the incentive to affect the emission targets, redistributive motives for using distortionary taxation that may also apply in a competitive economy (such as asymmetric information) are disregarded.⁷ For analytical convenience, the federation comprises two countries; the country with horizontal commitment power is defined as the horizontal Stackelberg leader, whereas the other is the horizontal follower. As indicated above, the access to horizontal commitment power will create incentives for the horizontal Stackelberg leader to try to influence the other country and, thereby, affect the emission targets. Given the set of tax instruments - a production tax on an environmentally bad input and a non-linear labor income tax - each national government is assumed to maximize the domestic social welfare.

The paper is organized as follows. Section 2 presents the model and derives the outcome of private, as well as federal government, optimization. Section 3 characterizes the behavior of the federal and the national governments. Finally, the optimal tax policy implemented by the horizontal Stackelberg leader is presented in section 4, while the paper is concluded in section 5.

2 The model

Consider an economic federation comprising two countries, which differ with respect to their ability of commitment. Country 1 - to be called the horizontal Stackelberg leader - acts as first mover vis-à-vis both the federal government and the other country. In contrast, country 2 - to be called the horizontal follower - acts as first mover only vis-à-vis the federal government.⁸

The decision making structure within the federation is as follows. First, the horizontal Stackelberg leader chooses its policy while anticipating, and incorporating into its decision problem, how the horizontal follower, the federal

⁷This approach is in line with Fuest and Huber (1997) and Aronsson and Sjögren (2004a, 2004b).

⁸The number of member countries has been normalized to two - additional horizontal followers would not affect the qualitative results.

government and the domestic private sector respond to its policy. Second, the horizontal follower chooses its policy, taking as given the policies decided by the horizontal Stackelberg leader, while anticipating the federal government's and the domestic private sectors' response to its policy. Third, the federal government chooses maximum allowable emissions (environmental targets) for the countries. These targets are conditioned on the national tax policy, while anticipating the behavioral responses by the private sector in each country. Finally, the private sector makes its choices conditional on the domestic public policy. However, when solving for the optimal tax policy, it is convenient to start backwards, i.e. with the private sector, the federal government and so on.

2.1 Consumers

Each member country is made up of identical consumers, the number of which is normalized to one. The preferences of the consumer in country i ($i = 1, 2$) are defined by the utility function

$$U^i = u(c^i, x^i, z^i) - \phi(E) \quad (1)$$

where c^i is the consumption of a good produced by a clean technology, x^i the consumption of a good produced by a dirty technology and z^i leisure. Leisure is defined as $z^i = H - l^i$, where H is a fixed time endowment and l^i the hours of work. The variable E is the environmental damage and is treated as exogenous by the consumer. The function $u(\cdot)$ is assumed to be increasing in each argument and strictly concave, while $\phi(\cdot)$ is increasing and strictly convex in the environmental damage.

The consumer's budget constraint is given by

$$w^i l^i - T^i(w^i l^i) = c^i + p x^i \quad (2)$$

where w^i is the gross wage rate and $T^i(w^i l^i)$ is the income tax paid to the national government. The price of good x^i is denoted by p , while good c^i is a numeraire good. Good x is assumed to be traded on a world market, which is meant to imply that its price is treated as exogenous by the federal and national governments as well as by the private agents.

The optimal tax problem will be defined in terms of a conditional indirect utility function and conditional demand functions. Therefore, it is convenient

to solve each consumer's optimization problem in two stages (following Christiansen (1984)). In the first stage, c^i and x^i are chosen conditional on z^i and the budget constraint $I^i = c^i + px^i$, where I^i is the consumer's net income. This gives the conditional demand functions for the two goods, $x^i = x(I^i, z^i, p)$ and $c^i = c(I^i, z^i, p)$, as well as the conditional indirect utility function

$$V^i = V(I^i, z^i, p, E) = v(I^i, z^i, p) - \phi(E). \quad (3)$$

In the second stage, the hours of work are chosen to maximize the conditional indirect utility function subject to the budget constraint $I^i = w^i l^i - T^i(w^i l^i)$. The first order condition is written

$$\frac{\partial v^i}{\partial I^i} w^i (1 - \tau^i) = \frac{\partial v^i}{\partial z^i} \quad (4)$$

where $v^i = v(I^i, z^i)$, and where $\tau^i = \partial T^i(w^i l^i) / \partial (w^i l^i)$ is the marginal income tax rate.

2.2 Production

Turning to the production part of the model, each country is made up of two competitive production sectors which produce goods c and x , respectively. Within each sector, all firms are identical and their number normalized to one. In both sectors, labor and a sector specific input are used in the production, while the production of good x^i also requires the use of an environmentally bad input, b^i .⁹ The use of bad input causes emissions that are transboundary. Therefore, the aggregate environmental damage in each country, E , is defined as

$$E = b^1 + b^2. \quad (5)$$

The profits in sectors c and x are given by

$$\pi_c^i = f_c^i(l_c^i) - w^i l_c^i \quad (6)$$

$$\pi_x^i = p f_x^i(l_x^i, b^i) - w^i l_x^i - t^i b^i \quad (7)$$

⁹The sector specific production factor - introduced to avoid fixed wages - will be suppressed for notational convenience throughout the paper. It is implicitly assumed that the sector specific factor is owned by the domestic government.

where t^i is the production tax on the ‘bad’ input, and where subindices indicate production sectors.^{10,11} The production functions, $f_c^i(\cdot)$ and $f_x^i(\cdot)$, are increasing and strictly concave in their respective arguments, and characterized by decreasing returns to scale. Moreover, it is assumed that the supply of the bad input is completely elastic, meaning that the price of the bad input is independent of changes in the demand. Therefore, it will be convenient to normalize the producer price of the bad input to zero. This assumption follows related literature (see e.g. Aronsson et al. (2006a)) and implies that the unit cost of the bad input in sector x equals the production tax. It is also assumed that labor is immobile between countries but completely mobile between sectors, meaning that the wage in each country will be the same in both sectors. The first order conditions for profit maximization can be written as

$$\frac{\partial f_c^i(l_c^i)}{\partial l_c^i} - w^i = 0 \tag{8}$$

$$p \frac{\partial f_x^i(l_x^i, b^i)}{\partial l_x^i} - w^i = 0 \tag{9}$$

$$p \frac{\partial f_x^i(l_x^i, b^i)}{\partial b^i} - t^i = 0. \tag{10}$$

By combining equations (8)-(10) with the labor market condition of $l^i \equiv l_x^i + l_c^i$, the equilibrium levels of w^i , l_x^i , l_c^i and b^i can be written as functions of t^i and l^i , i.e.

$$w^i = w^i(t^i, l^i) \tag{11}$$

$$l_x^i = l_x^i(t^i, l^i) \tag{12}$$

$$l_c^i = l_c^i(t^i, l^i) \tag{13}$$

$$b^i = b^i(t^i, l^i) \tag{14}$$

where the fixed consumer price, p , is suppressed for notational convenience¹².

¹⁰Since there are no consumption taxes, the producer price equals the consumer price.

¹¹See Cremer and Gahvari (2001) for a discussion about the choice between a consumption tax and a production tax, and its implications for the results.

¹²The fixed consumer price, p , will be suppressed in what follows.

3 Public Policies

This section begins with a characterization of the federal government's problem. It then continues with the decision problem facing the horizontal follower, as well as the decision problem facing the horizontal Stackelberg leader.

3.1 The federal government

The federal government maximizes the aggregate welfare of the federation by choosing targets, e^i , for the emissions arising from the use of the bad input in the two member countries.¹³ To solve this problem, note that the federal government recognizes the relationship between environmental damage and the bad input, as defined by equation (5). In addition, the federal government is assumed to recognize the equilibrium function for the bad input, i.e. it behaves as if each national government uses its production tax to control the bad input. This 'extra' assumption is needed to introduce a trade-off between environmental quality and production from the perspective of the federal government that is consistent with the behavior of the private sector (see below). Besides, the assumption that the production tax is used to control the use of bad input is reasonable in the sense that it can be considered as the most direct policy instrument available. Accordingly, when determining the emission targets, the federal government uses $t^i = t^i(b^i, l^i)$, which is the inverse of equation (14). Notice also that from the federal government's point of view, the production tax is, in this respect, conditioned on the hours of work, l^i .

When the federal government solves its decision problem, it recognizes that the national governments' budget constraints must be satisfied. The national government taxes profits, labor and the bad input to finance an exogenously given revenue requirement, G^i , meaning that the budget constraint facing the government in country i is written

$$\pi_c^i + \pi_x^i + T^i(w^i l^i) + t^i b^i = G^i. \quad (15)$$

By combining equation (15) with $I^i = w^i l^i - T^i(w^i l^i)$, and equations (6) and (7), as well as with the identity $l^i \equiv l_c^i + l_x^i$, each national government's budget

¹³Note that, since the environmental damage is linear in the bad input, e^i equals the use of bad input.

constraint can be rewritten as

$$I^i = pf_x^i(l_x^i, b^i) + f_c^i(l^i - l_x^i) - G^i. \quad (16)$$

The federal government then maximizes the sum of utilities over both countries and the optimal-target problem can, therefore, be written as

$$\max_{e^i} W = \sum_{i=1}^2 [v(I^i, z^i) - \phi(E)] \quad (17)$$

s.t.

$$E = b^1 + b^2 \quad (18)$$

$$t^i = t^i(b^i, l^i). \quad (19)$$

where I^i and l_x^i are given by equations (16) and (12), respectively, and where it is assumed that the environmental targets are binding, meaning that $b^i = e^i$. By substituting equations (16), (18) and (19) into equation (17), the federal government's choice of environmental targets give the following first order conditions

$$e^1 : \frac{\partial f_x^1}{\partial b^1} = MW P_1^{E,I} + MW P_2^{E,I} \frac{\partial V^2 / \partial I^2}{\partial V^1 / \partial I^1} \quad (20)$$

$$e^2 : \frac{\partial f_x^2}{\partial b^2} = MW P_1^{E,I} \frac{\partial V^1 / \partial I^1}{\partial V^2 / \partial I^2} + MW P_2^{E,I} \quad (21)$$

where $MW P_i^{E,I} = -(\partial V^i / \partial E) / (\partial V^i / \partial I^i)$ is the marginal willingness to pay by the citizen in country i for a small reduction in E . These first order conditions imply that the value of the marginal product of the bad input should equal the sum of the marginal willingness to pay for reduced environmental damage, adjusted for differences in the marginal utility of income between the two countries. These adjustments arise because the federal government does not have any policy instruments available for redistribution of income between countries. That is, if the federal government were able to equalize the marginal utility of income among countries, the right hand side of equations (20) and (21) would reduce to $MW P_1^{E,I} + MW P_2^{E,I}$.

In order to explain how the quotient of marginal utilities of income influences the federal government's optimal choices, consider the case when $\partial V^2 / \partial I^2 > \partial V^1 / \partial I^1$, which is here interpreted to imply that the citizen in country 2 has

a lower income than the citizen in country 1. By comparison with the case of equally distributed income, the right hand side of equation (20) will now *increase*, which suggests that the environmental target imposed on country 1 reflects a higher weight on country 2's marginal willingness to pay for reduced environmental damage. In other words, the use of bad input in country 1 must be reduced, relative to the case with equally distributed incomes, so that the value of the marginal product of the bad input compensates for the change on the right hand side of equation (20). As for the target defined by equation (21), it has a completely analogous interpretation, meaning that country 2 is allowed to use more of the bad input relative to the case with equally distributed incomes. The implication of these results is that the environmental targets reflect the federal government's desire to equalize the marginal utilities of income across countries - here achieved by tightening the environmental constraint for the country with higher income, while loosening it for the country with lower income. Moreover, equations (20) and (21) implicitly define the environmental targets as functions of l^1 and l^2 , so that the federal government's reaction functions can be written as

$$e^i = e^i(l^1, l^2) \quad \forall i = 1, 2. \quad (22)$$

3.2 The horizontal follower

The horizontal follower chooses a production tax and an income tax schedule to maximize the conditional indirect utility function specified in equation (3), subject to equations (5), (16) and (22). Besides, since country 2 is the horizontal follower, the hours of work in the other country, l^1 , are treated exogenous. Following previous studies, and since $T^2(\cdot)$ is a general labor income tax that can be used to implement any desired combination of consumption and hours of work, it has become common practice to use l^2 and I^2 as direct decision variables instead of the parameters of the income tax function. The Lagrangean corresponding to the government's problem becomes

$$\begin{aligned} \mathcal{L} = & v^2 - \phi(b^1 + b^2) + \gamma [f_x^2(l_x^2, b^2) + f_c^2(l^2 - l_x^2) - G^2 - I^2] \quad (23) \\ & + \beta_1^2 [e^1(l^1, l^2) - b^1] + \beta_2^2 [e^2(l^1, l^2) - b^2] \end{aligned}$$

where l_x^2 and b^2 are defined by equations (12) and (14), and where β_1^2 and β_2^2 are Lagrange multipliers associated with the foreign and domestic environmental

target constraints, respectively. By using the first order condition for I^2 , and since the wage rates are equalized between the production sectors, the first order conditions for l^2 and t^2 can be written as

$$l^2 : -\frac{\partial v^2}{\partial z^2} + \frac{\partial v^2}{\partial I^2} \left[\frac{\partial f_c^2}{\partial l_c^2} + \frac{\partial f_x^2}{\partial b^2} \frac{\partial b^2}{\partial l^2} \right] - \frac{\partial \phi}{\partial E} \frac{\partial b^2}{\partial l^2} \quad (24)$$

$$+ \beta_1 \frac{\partial e^1}{\partial l^2} + \beta_2 \left[\frac{\partial e^2}{\partial l^2} - \frac{\partial b^2}{\partial l^2} \right] = 0$$

$$t^2 : \frac{\partial f_x^2}{\partial b^2} \frac{\partial v^2}{\partial I^2} - \frac{\partial \phi}{\partial E} - \beta_2 = 0 \quad (25)$$

These first order conditions implicitly define l^2 and t^2 as functions of the horizontal Stackelberg leader's choice of hours of work, i.e. $l^2 = l^2(l^1)$ and $t^2 = t^2(l^1)$.

Assuming that the environmental target constraints are binding, equations (24) and (25) show that l^1 influences l^2 and t^2 both via $e^i(l^1, l^2)$ (via the damage function ϕ) and via the first derivative of $e^i(\cdot)$ with respect to l^2 , i.e. $\partial e^i / \partial l^2$. This means that the first order conditions can be written as the general functions

$$\Delta \left[t^2, l^2, \frac{\partial e^2(l^1, l^2)}{\partial l^2}, \frac{\partial e^1(l^1, l^2)}{\partial l^2}, e^1(l^1, l^2), e^2(l^1, l^2) \right] = 0 \quad (26)$$

$$\Psi [t^2, l^2, e^1(l^1, l^2), e^2(l^1, l^2)] = 0. \quad (27)$$

By solving for the l^2 and t^2 that do not appear in either $e^i(\cdot)$ or $\partial e^i(\cdot) / \partial l^2$ (i.e. the first two terms within the square brackets), equations (26) and (27) can be rewritten as

$$l^2 = \delta \left(\frac{\partial e^2(l^1, l^2)}{\partial l^2}, \frac{\partial e^1(l^1, l^2)}{\partial l^2}, e^1(l^1, l^2), e^2(l^1, l^2) \right) \quad (28)$$

$$t^2 = \psi \left(\frac{\partial e^2(l^1, l^2)}{\partial l^2}, \frac{\partial e^1(l^1, l^2)}{\partial l^2}, e^1(l^1, l^2), e^2(l^1, l^2) \right) \quad (29)$$

Equations (28) and (29) are convenient for interpretational reasons in what follows, and will be referred to as the horizontal follower's *implicit* reaction functions.

3.3 The horizontal Stackelberg leader

The horizontal Stackelberg leader acts strategically vis-à-vis both the federal government (vertical leadership) and the other member country (horizontal leadership). The objective of the horizontal Stackelberg leader is to implement a policy mix that maximizes the conditional indirect utility function, V^1 , in equation (3). The horizontal Stackelberg leader takes into account that the use of the bad input in each country is determined by equation (22), here defined as $E^i = e^i(l^1, l^2)$. The horizontal Stackelberg leader also recognizes the implicit reaction function for l^2 , equation (28). However, the horizontal Stackelberg leader does not need to consider that l^1 and t^1 influence t^2 as shown in equation (29). The reason is that, although the horizontal Stackelberg leader may influence the production tax, t^2 , it only affects $b^2(\cdot)$ which, in the end, must be determined by the environmental target level. Therefore, a constraint reflecting horizontal leadership via t^2 would become redundant in this specific setup, meaning that the horizontal Stackelberg leader only needs to consider the implicit reaction function for l^2 (equation (28)).

The discussion above implies that the Lagrangean associated with the horizontal Stackelberg leader's decision problem can be written as

$$\begin{aligned} \mathcal{L} = & v^1 - \phi(E^1 + E^2) + \gamma [f_x^1(l_x^1, b^1) + f_c^1(l^1 - l_x^1) - G^1 - I^1] \\ & + \beta_1 [e^1 - E^1] + \beta_2 [e^2 - E^2] + \mu_1 [E^1 - b^1] \\ & + \lambda_l \left[l^2 - \delta \left(\frac{\partial e^2(l^1, l^2)}{\partial l^2}, \frac{\partial e^1(l^1, l^2)}{\partial l^2}, E^1, E^2 \right) \right] \end{aligned} \quad (30)$$

where $v^1 = v(I^1, z^1)$. The Lagrange multipliers associated with each constraint, respectively, are γ , β_1 , β_2 , μ_1 and λ_l . The last constraint is the implicit reaction function of the follower, equation (28), for which it has been used that $E^i = e^i(l^1, l^2)$. Since the Lagrangean is defined in terms of explicit constraints to reflect the strategic leadership, E^1 , E^2 and l^2 are treated as additional decision variables. It should be noted that this, perhaps unusual, way of defining the Lagrangean is for interpretational convenience, although it could have been

written slightly more compact. The first order conditions become

$$l^1 : -\frac{\partial v^1}{\partial z^1} + \gamma \left[\frac{\partial f_c^1}{\partial l_c^1} + \frac{\partial f_x^1}{\partial b^1} \frac{\partial b^1}{\partial l^1} \right] - \lambda_l \frac{\partial \delta}{\partial l^1} + \beta_1 \frac{\partial e^1}{\partial l^1} + \beta_2 \frac{\partial e^2}{\partial l^1} - \mu_1 \frac{\partial b^1}{\partial l^1} = 0, \quad (31)$$

$$t^1 : \gamma \frac{\partial f_x^1}{\partial b^1} \frac{\partial b^1}{\partial t^1} - \mu \frac{\partial b^1}{\partial t^1} = 0, \quad (32)$$

$$I^1 : \frac{\partial v^1}{\partial I^1} - \gamma = 0, \quad (33)$$

$$E^1 : -\frac{\partial \phi}{\partial E^1} - \lambda_l \frac{\partial \delta}{\partial E^1} - \beta_1 + \mu_1 = 0, \quad (34)$$

$$E^2 : -\frac{\partial \phi}{\partial E^2} - \lambda_l \frac{\partial \delta}{\partial E^2} - \beta_2 = 0, \quad (35)$$

$$l^2 : \lambda_l \left(1 - \frac{\partial \delta}{\partial l^2} \right) + \beta_1 \frac{\partial e^1}{\partial l^2} + \beta_2 \frac{\partial e^2}{\partial l^2} = 0, \quad (36)$$

where

$$\frac{\partial \delta}{\partial l^i} = \frac{\partial \delta}{\partial e_{l^2}^1} \frac{\partial^2 e^1}{\partial l^2 \partial l^i} + \frac{\partial \delta}{\partial e_{l^2}^2} \frac{\partial^2 e^2}{\partial l^2 \partial l^i} \quad (37)$$

and where $e_{l^2}^i = \partial e^i(l^1, l^2) / \partial l^2$. Conditional on the implicit reaction function of the follower, as defined by the last constraint in the Lagrangean, it is obvious that the choice of l^1 and l^2 partly works via the mechanisms defined by equation (37). Equation (37) describes how the hours of work in country i influences the function δ via the marginal target effects of the followers use of l^2 , i.e. via $\partial e^i / \partial l^2$.

4 Tax Policy

This section characterizes the tax policy implemented by the horizontal Stackelberg leader, which is implicitly defined by equations (31) - (36). To clarify the incentive structure facing the horizontal Stackelberg leader, the analysis begins with a benchmark case that disregards the federal government. The analysis then continues with the decentralized economic federation as described above.

4.1 Special case: No federal government

In the case of no federal level, each country is assumed to act as described earlier, meaning that country 1 is the horizontal Stackelberg leader and country 2 the horizontal follower. The horizontal follower's first order conditions, equations (24) and (25), are modified because the constraints associated with β_1^2 and β_2^2 in the horizontal follower's Lagrangean are now redundant. In addition, without the binding environmental target constraints, the horizontal Stackelberg leader has to consider its influence on $b^2(\cdot)$, since this is no longer determined by the federal government's constraint. In other words, the reaction functions for both l^2 and t^2 must be considered in the horizontal Stackelberg leader's decision problem. Since the reaction functions of the horizontal follower are derived from equations (24) and (25), country 1 influences country 2 via the damage function $\phi(b^1 + b^2)$. This, in turn, implies that the horizontal follower's reaction functions now can be written as $l^2 = l^2(b^1)$ and $t^2 = t^2(b^1)$. That is, the horizontal Stackelberg leader's use of the bad input has a direct effect on the horizontal follower via the environmental damage. The Lagrangean corresponding to this problem for the horizontal Stackelberg leader is shown in the Appendix. The horizontal Stackelberg leader's optimal policy is summarized in the following proposition.

Proposition 1 *In the absence of a federal government, the horizontal Stackelberg leader's optimal production tax is defined as*

$$t^1 = MW P_1^{E,I} + MW P_1^{E,I} \left[\frac{\partial b^2}{\partial t^2} \frac{\partial t^2}{\partial b^1} + \frac{\partial b^2}{\partial l^2} \frac{\partial l^2}{\partial b^1} \right]$$

whereas the optimal marginal income tax rate equals zero, i.e. $\tau^1(\cdot) = 0$.

Proof: See the Appendix.

Let us begin by interpreting the policy rule for the production tax, t^1 . The first term on the right hand side, which is standard, is the marginal willingness to pay by the citizen in country 1 for a reduction in domestically generated damage. However, since the citizen in country 1 is also affected by the use of the bad input in country 2, there is an incentive for the national government to use its horizontal commitment power to change the behavior of the horizontal follower. This is captured by the terms within the square bracket and works via the reaction functions. Specifically, according to equations (24) and (25), if β_1

and β_2 are set to zero, the horizontal Stackelberg leader's use of the bad input influences the marginal environmental damage experienced by the horizontal follower. This, in turn, affects the follower's optimal policy and therefore also the use of the bad input. The production tax in Proposition 1 therefore not only reflects the marginal willingness to pay for reduced environmental damage, but also captures a desire to reduce the use of bad input in the other country.¹⁴

To explain why the marginal income tax rate is zero, observe that the horizontal Stackelberg leader controls the other country's choice of bad input via the production tax. This implies that the horizontal Stackelberg leader does not have to use the marginal income tax rate for externality correction (the marginal income tax does not improve the possibility to correct for the externality). This result can be interpreted as an analog to the additivity property in Sandmo (1975), which basically states that a correction should be made using the most 'direct' policy instrument available. In this case, the marginal income tax only affects the use of bad input indirectly via the hours of work, meaning that the most direct instrument is the production tax. Accordingly, the production tax works as a perfect instrument for externality correction, while the income tax is used solely for revenue collection.

4.2 The decentralized economic federation

Let us now return to the federal structure in which each member country has to comply with the environmental target levels chosen by the federal government. In this case, the horizontal Stackelberg leader considers both the horizontal leadership vis-à-vis the other country and the vertical leadership vis-à-vis the federal government. In addition, the environmental targets imposed by the federal government must also be fulfilled. For analytical convenience, define $\eta = 1 / (1 - \frac{\partial \delta}{\partial l^2})$ and consider the following proposition.

Proposition 2 *In an economic federation with decentralized leadership, where the horizontal commitment power differs between countries, the production tax imposed by the horizontal Stackelberg leader is given by*

$$t^1 = MWP_1^{E,I} + \frac{\beta_1}{\gamma} - \frac{\eta}{\gamma} \left[\beta_1 \frac{\partial e^1}{\partial l^2} + \beta_2 \frac{\partial e^2}{\partial l^2} \right] \frac{\partial \delta}{\partial E^1}.$$

¹⁴Observe that, in a noncooperative Nash equilibrium the production tax would equal the marginal willingness to pay by the *domestic* consumer for reduced environmental damage, i.e. the terms inside square brackets are zero and $t^1 = MWP_1^{E,I}$.

This tax formula is derived by combining equations (32) - (34) and (36) with equation (10). The first term on the right hand side is the marginal willingness to pay for reduced environmental damage by the citizen in country 1. The second term arises because country 1 has to comply with the environmental target imposed by the federal government. Specifically, with a binding target constraint, the horizontal Stackelberg leader is forced to attach a higher value on the environment than it would otherwise have done, provided that the welfare is increasing in the domestic environmental target level, i.e. provided that $\beta_1/\gamma > 0$.

The third part of the tax formula is associated with the horizontal commitment power. According to equations (20) and (21), each country's environmental target is defined so that the value of the marginal product of the bad input in that country should reflect the marginal willingness to pay for reduced environmental damage in both countries. Hence, the target levels are influenced by l^2 because this affects the marginal product of the bad input, which, in turn, affects the environmental target levels.¹⁵ These horizontal mechanisms work via the function δ as defined in the Lagrangean, equation (30).¹⁶

Let us now turn to the optimal marginal income tax rate.

Proposition 3 *In an economic federation with decentralized leadership, where the horizontal commitment power differs between countries, the marginal income tax rate implemented by the horizontal Stackelberg leader is characterized by*

$$\tau^1(\cdot) = -\frac{1}{w\gamma} \left[\beta_1 \frac{\partial e^1}{\partial l^1} + \beta_2 \frac{\partial e^2}{\partial l^1} + \eta \left(\beta_1 \frac{\partial e^1}{\partial l^2} + \beta_2 \frac{\partial e^2}{\partial l^2} \right) \frac{\partial \delta}{\partial l^1} \right].$$

The tax formula in Proposition 3 is derived by combining the horizontal Stackelberg leader's first order conditions with equation (4). Since the marginal income tax rate now differs from zero (recall the zero marginal income tax rate in Proposition 1), Proposition 3 suggests that the marginal income tax should be used for externality correction. All terms on the right hand side of the tax formula arise because the horizontal Stackelberg leader wants to influence the

¹⁵ According to the complete first order conditions for the environmental targets (equilibrium conditions have been used in equations (20) and (21)), there are, however, additional effects arising from a change in the hours of work. This makes the total effect on the use of the bad input ambiguous.

¹⁶ The implicit assumption behind these mechanisms is that the environmental target must be equal to the use of the bad input, which is influenced by the production tax rate.

environmental targets. The first two terms inside the square bracket show that the horizontal Stackelberg leader uses the vertical leadership to control both countries' environmental targets. That is, the horizontal Stackelberg leader uses that the domestic choice of hours of work has a direct effect on the environmental targets imposed by the federal government. The explanation for the effect on the domestic target is that the hours of work, l^1 , affect the value of the marginal product of the bad input which, in turn, changes the environmental target. Recall that the environmental targets are determined by equations (20) and (21).

The remaining terms in the tax formula reflect that the horizontal Stackelberg leader uses the horizontal commitment power to change the hours of work chosen by the citizen in the other country, l^2 , via the function δ (defined by equation (37)), which, in turn, affects both countries' target levels. That is, it shows an 'indirect' effect on the target levels via l^2 . These mechanisms arise from the assumption of horizontal commitment power but, it is important to recall that it is not a strictly horizontal mechanism. The reason is that the horizontal Stackelberg leader influences the target levels which, in turn, affect the hours of work in country 2. In the end, this will influence both countries' target levels, meaning that the horizontal leadership works through the environmental targets, i.e. indirectly via the vertical leadership.

Finally, notice that the mechanisms working via δ are similar to the mechanisms associated with the horizontal commitment power in the production tax formula in Proposition 2. However, the difference is that the marginal income tax rate has a direct effect on the hours of work, l^1 , which influences the horizontal follower's choice of l^2 via the function δ .

4.2.1 Special case: The horizontal follower treats e^1 and e^2 as exogenous

So far, the horizontal follower has been assumed to act as a leader toward the federal government. However, it is perhaps equally natural to assume that the horizontal follower is a follower in *all* respects, i.e. treating the environmental targets, e^1 and e^2 , as exogenous. In such a setup, the Lagrangean associated

with the problem facing the horizontal follower is written

$$\begin{aligned} \mathcal{L} = & v^2 - \phi(\bar{e}^1 + \bar{e}^2) + \gamma [f_x^2(l_x^2, b^2) + f_c^2(l^2 - l_x^2) - G^2 - I^2] \quad (38) \\ & + \xi [\bar{e}^2 - b^2], \end{aligned}$$

where a 'bar' indicates that the variable is treated as exogenous. The first order conditions corresponding to this problem are shown in the Appendix. By comparison with equations (24) and (25), the solution to this problem implies first order conditions for the horizontal follower that do not reflect any marginal environmental damage - there are no effects via the function ϕ . Therefore, the reaction functions facing the horizontal Stackelberg leader can now be defined as $l^2 = l^2(E^2)$ and $t^2 = t^2(E^2)$. By using these functions in the horizontal Stackelberg leader's problem, the following result can be derived.¹⁷

Corollary 1 *If the horizontal follower acts as a Nash competitor also toward the federal government, the optimal production tax formula for the horizontal Stackelberg leader reduces to*

$$t^1 = MW P_1^{E,I} + \frac{\beta_1}{\gamma}.$$

Proof: See the Appendix.

Since the horizontal follower in this scenario acts as a Nash competitor toward the federal level, the horizontal Stackelberg leader's motive for using the production tax to affect the target function no longer exists. This implies that the horizontal Stackelberg leader's production tax equals the domestic marginal willingness to pay for reduced environmental damage, although adjusted to account for the other country's experienced disutility, which is reflected by β_1/γ . The interpretation in this case is, therefore, that the horizontal commitment power does not give any effective channels through which it is possible to change the behavior of the other member country.

Turning to marginal income taxation when the horizontal follower acts as a Nash competitor towards the federal government, the following result is derived.

Corollary 2 *If the horizontal follower acts as a Nash competitor toward the federal government, the optimal marginal income tax rate implemented by the*

¹⁷The notation follows the previous cases where $e^i = E^i$.

horizontal Stackelberg leader reduces to

$$\tau^1(\cdot) = -\frac{1}{w\gamma} \left[\beta_1 \frac{\partial e^1}{\partial l^1} + \beta_2 \frac{\partial e^2}{\partial l^1} \right].$$

Proof: See the Appendix.

In the case where the horizontal follower acted as a leader toward the federal level (Proposition 3), the horizontal Stackelberg leader had the opportunity to influence l^2 via the mechanisms defined by the implicit reaction function. However, without the horizontal follower's vertical leadership, the horizontal Stackelberg leader has no effective channels (other than via the vertical leadership) through which it may influence country 2 since l^2 only depends on E^2 . This means that the marginal income tax rate now only reflects the horizontal Stackelberg leader's vertical leadership vis-à-vis the federal government. Still, the leadership is used to influence its own environmental target levels, as well as the follower's.

5 Summary and discussion

This paper analyzes environmental policies in a decentralized economic federation where the federal government decides upon national environmental targets (maximum allowable emissions). Although the environmental targets are to be implemented at the national level, it is assumed that the national governments are first movers vis-à-vis the federal government, which gives the economic federation its decentralized structure. Furthermore, it is argued that member countries within the economic federation differ with respect to their horizontal commitment power, which has been interpreted to mean that one member country, the horizontal Stackelberg leader, acts as first mover vis-à-vis the other member country, the horizontal follower.

Given the framework, this paper focuses on the incentives underlying the tax policy implemented by the horizontal Stackelberg leader. The results show that, in addition to the more or less standard result that environmental taxation should reflect marginal willingness to pay for reduced environmental damage, the horizontal Stackelberg leader has an incentive to influence the environmental targets imposed by the federal government. These mechanisms are interpreted as a desire to relax the domestic environmental target, while tightening the

other member's target constraint. This is reflected in both the production tax and the marginal income tax rate. However, it is important to emphasize that the incentives for influencing the environmental targets not only apply directly vis-à-vis the federal government, but also indirectly via the horizontal commitment power vis-à-vis the other country. It is also important to point out that these results presuppose that all member countries act as first movers vis-à-vis the federal government. Without that assumption, there will be no strategic incentives associated with the horizontal commitment power.

Furthermore, this paper has focused on the horizontal interactions arising from transboundary environmental damage, meaning that other possible interactions have been disregarded. Another possible source of horizontal interaction related to the environmental damage is that the price of the good produced by using the bad input is endogenous. An endogenous price would give rise to basically three additional mechanisms to consider for the horizontal Stackelberg leader. First, if the horizontal Stackelberg leader is a net exporter, it would try to improve its own welfare by increasing the market price. Second, since the price level would influence the environmental targets, mechanisms corresponding to those discussed for the hours of work would arise via the target functions. Third, and perhaps most relevant, price changes would have direct effects on the horizontal follower's choice of input. For example, if the horizontal Stackelberg leader has the ability to reduce the price of the good produced with bad input, the lower price level 'forces' the horizontal follower to use less of the bad input, which, in turn, improves the horizontal Stackelberg leader's welfare.

As for future research, it would be interesting to model more complex horizontal, as well as vertical, interactions to further clarify important mechanisms that may arise in economic federations. It would also be interesting to introduce negotiations in the political process regarding environmental policy at the federal level. However as indicated, this is left for future research.

A Appendix

The Appendix will serve as a guide for deriving Proposition 1, Corollary 1 and Corollary 2.

A.1 Proposition 1

In this case, the Lagrangean can be defined as

$$\begin{aligned} \mathcal{L} = & v^1 - \phi(E^1 + E^2) + \gamma [f_x^1(l_x^1, b^1) + f_c^1(l^1 - l_x^1) - G^1 - I^1] \\ & + \mu_1 [E^1 - b^1] + \mu_2 [E^2 - b^2] \\ & + \lambda_l [l^2 - l^2(b^1)] + \lambda_t [t^2 - t^2(b^1)]. \end{aligned}$$

To derive Proposition (1), differentiate this Lagrangean with respect to l^1 , t^1 , I^1 , E^1 , E^2 , l^2 and t^2 . Thereafter, combine these first order conditions with the first order condition for the use of bad input in the production sector, equation (10). To derive the marginal income tax rate, combine the first order conditions for l^1 , t^1 and I^1 with the first order condition for l^1 in the private sector, equation (4).

A.2 Corollary 1 and 2

The first order conditions corresponding to the Lagrangean defined by equation (38) are

$$\begin{aligned} l^2 & : -\frac{\partial v^2}{\partial z^2} + \gamma \left[\frac{\partial f_c^2}{\partial l_c^2} + \frac{\partial f_x^2}{\partial b^2} \frac{\partial b^2}{\partial l^2} \right] - \xi \frac{\partial b^2}{\partial l^2} = 0, \\ t^2 & : \gamma \frac{\partial f_x^2}{\partial b^2} \frac{\partial b^2}{\partial t^2} - \xi \frac{\partial b^2}{\partial t^2} = 0, \\ I^2 & : \frac{\partial v^2}{\partial I^2} - \gamma = 0, \\ \xi & : \bar{e}^2 - b^2 = 0 \end{aligned}$$

With an analogous notation as in the previous setup, the horizontal Stackelberg leader's first order condition for E^1 , equation (34), reduces to $-\partial\phi/\partial E - \beta_1 + \mu_1 = 0$. This implies that the combination of the horizontal Stackelberg leader's

first order conditions for t^1 , I^1 and E^1 with the first order condition for the use of bad input in the production sector, equation (10), give Corollary 1. To derive Corollary 2, combine the first order conditions above with equation (4).

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