

Optimal Taxation and Transboundary Externalities - Are Endogenous World Market Prices Important?*

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Abstract

This paper concerns income and commodity taxation in a multi-jurisdictional 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 prices via public policy. In such a framework, a noncooperative Nash equilibrium does not only imply that the commodity tax on the externality-generating good is inefficiently low seen from the perspective of global well-being; it also means that the marginal income tax rate is inefficiently high, and that too much resources are spent on public goods. With the noncooperative Nash equilibrium as a starting point, we also consider the welfare effects of policy coordination with respect to taxation and public expenditures.

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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, suggesting that the incentives underlying decentralized policies are important to understand.

This paper concerns transboundary environmental problems in a framework with mixed taxation, where each national government faces a nonlinear income tax and linear commodity taxes. This provides a reasonably realistic description of the tax system facing many national governments, and implies that the use of distortionary taxes is a consequence of optimization; not of restrictions imposed on the choice set of the government. In addition, and contrary to earlier literature on environmental policy under mixed taxation, 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 commodity. The latter is interesting 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 paper takes this argument to its extreme by analyzing a world economy

comprising two large countries. Second, our approach integrates earlier literature on the so called 'leakage' phenomenon (see below) with the theory of income and commodity taxation, which makes it possible to compare large and small open economies with respect to the whole tax and expenditure structure; not just with respect to environmental policy.

The literature on fiscal policy in economies with transboundary environmental problems is relatively small by comparison with other literature on fiscal policy and environmental externalities¹. Earlier research on taxation and public expenditures in economies causing and/or suffering from transboundary externalities compares noncooperative and cooperative resource allocations from the perspective of environmental and/or other policies² as well as addresses issues such as labor mobility³, fiscal competition due to international trade⁴ and strategic aspects of environmental policy in economic federations⁵. However, none of the earlier 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 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 of this good will also decrease which, in turn, tends to increase the

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 e.g. van der Ploeg and de Zeeuw (1992) and Aronsson and Blomquist (2003).

³See Aronsson and Blomquist (2003).

⁴See Cremer and Gahvari (2004, 2005).

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

emissions abroad⁶. This suggests that, if the country is large in the sense that its government can significantly affect the world market prices, then it may have incentives to modify its fiscal policy accordingly. Our paper incorporates this mechanism into the theory of income and commodity taxation.

This paper is based on a two-country world economy with transboundary environmental damage (defined as a climate-problem), where the government in each country faces a mixed tax problem and provides a (national) public good. We also assume that both countries are large enough for their governments to be able to significantly affect the world market producer price of the externality-generating good via public policy. In addition, the countries behave as Nash competitors to one another, in the sense that the government in each country treats the policy variables of the other country as exogenous. The paper contributes to the literature in primarily two ways. The first is by characterizing the income and commodity tax structure as well as the provision of the public good in the resulting Nash equilibrium. This also means comparing the policy outcome with the policies that would be chosen by small open economies and the policies implicit in a cooperative equilibrium, respectively. We show that if the governments are able to affect the producer prices, then the resulting equilibrium does not only imply that the commodity tax on the externality-generating good is inefficiently low seen from the perspective of global well-being; it also means that the marginal income tax rate is inefficiently high, and that too much resources are spent on the public good. The second contribution is to analyze the welfare effects of policy coordination in a framework with endogenous producer prices, where the prereform resource allocation is given by the noncooperative Nash equilibrium. Our idea is to examine how marginal coordination with respect to the policy instruments can be used to improve the resource

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.

allocation. We show that several welfare improving reforms are possible. One such reform would be to simultaneously increase the commodity tax on the dirty good and the provision of the public good, whereas another is to increase both the marginal and average income tax rates.

To be able to focus on the tax structure, we disregard trade policy in what follows; an assumption which appears to be in line with the observed trend towards trade liberalization. In addition, instead of analyzing redistribution as part of the policy package decided upon by each national government, as in some earlier literature on mixed taxation, we follow Fuest and Huber (1997) and Aronsson and Sjögren (2004) by disregarding motives for using distortionary taxes that apply under perfect competition (such as asymmetric information). Therefore, the presence of market failures constitutes the only reason for using distortionary taxes in our paper. This does not reflect a belief that the self-selection motive for taxation is unimportant; only that it is well understood from earlier research, whereas the aspects of tax policy discussed here are not. Our results will, of course, also apply in a more general framework, where the individuals in each country are allowed to differ in terms of ability.

The outline of the study is as follows. In section 2, we present the model and the outcome of private optimization. Section 3 concerns optimal taxation and provision of the public good at the national level, whereas policy coordination is addressed in section 4. We summarize and discuss the results in section 5.

2 The Model

Consider an economy which consists of two jurisdictions - to be called 'countries' in what follows - which are denoted by superindices 1 and 2, respectively. The countries are identical in all important respects, and each country consists of identical consumers. For notational convenience, we normalize

the number of consumers in each country to one.

The preferences of the consumer living in country i are defined by the utility function $U^i = U(C^i, X^i, Z^i, G^i, E)$, for $i = 1, 2$, where C^i is an environmentally clean good, X^i an environmentally dirty good, Z^i leisure, G^i a public good and E environmental damage. We assume that C^i and X^i are normal goods. Leisure is defined as $Z^i = H - L^i$, where H is a time endowment and L^i the hours of work. The function $U(\cdot)$ is increasing in C^i , X^i , Z^i and G^i , decreasing in E and strictly quasiconcave. The environmental damage is caused by consumption of the dirty good (see below), and 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 . Since the dirty good is subject to international trade, both countries face the same producer price.

The consumer chooses C^i , X^i and L^i to maximize utility subject to the budget constraint,

$$w^i L^i - T(w^i L^i) - C^i - Q^i X^i = 0, \quad (1)$$

where $T(\cdot)$ is the income tax payment. Following Christiansen (1984), it will be convenient to solve the consumer's optimization problem in two stages. In the first stage, we maximize utility conditional on the hours of work. This problem is written

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

subject to

$$B^i = C^i + Q^i X^i$$

in which B^i is treated as a fixed post-tax income. The solution to this problem gives the conditional indirect utility function

$$V^i = V(Q^i, B^i, Z^i, G^i, E) \quad (2)$$

and the conditional demand functions

$$X^i = X(Q^i, B^i, Z^i, G^i, E) \quad (3)$$

$$C^i = C(Q^i, B^i, Z^i, G^i, E) \quad (4)$$

for $i = 1, 2$. These functions will be used in the optimal tax and expenditure problem to be discussed below. In the second stage, we can derive the hours of work by maximizing the conditional indirect utility function with respect to L^i subject to the budget constraint

$$B^i = w^i L^i - T(w^i L^i) \quad (5)$$

The first order condition is written

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

where $V_B^i = \partial V^i / \partial B^i$ and $V_Z^i = \partial V^i / \partial Z^i$, while $T_I^i = \partial T(I^i) / \partial I^i$ is the marginal income tax rate and $I^i = w^i L^i$ is the labor income.

The production side in each country consists of two private sectors, which are both competitive; sector c produces the clean good and sector d produces the dirty good. The government produces the public good. In each sector, labor (L_c^i , L_d^i and L_G^i , respectively) and a fixed factor (which is suppressed for notational convenience) are the only inputs in production. Labor is mobile between the domestic sectors, although it is immobile internationally⁷.

⁷This assumption simplifies the analysis considerably, as it implies that the transboundary externality is the only source of direct interaction. As such, this assumption makes it possible to analyze the policy incentives created by endogenous world market prices in an otherwise standard model for optimal taxation and externality-correction. Aronsson and Blomquist (2003) consider the consequences of labor mobility for mixed taxation and externality-correction, although the producer prices are exogenous in their model.

To simplify further, we assume that the fixed factors are owned by the government⁸.

The production function for the public good is given by $G^i = F_G(L_G^i)$, which is increasing and strictly concave in its argument. In each private sector, the firms are identical and we normalize the number of firms in each sector to one. The profit, i.e. the return on the fixed factor, in sector c and d , respectively, is given by

$$\Pi_c^i = F_c(L_c^i) - w^i L_c^i \quad (7)$$

$$\Pi_d^i = P F_d(L_d^i) - w^i L_d^i \quad (8)$$

The production functions, $F_c(\cdot)$ and $F_d(\cdot)$, are assumed to be increasing and strictly concave in their respective argument. As the workers are perfectly mobile between the public and private sectors, the wage rate will be the same in the equilibrium. The first order conditions for profit maximization are

$$\frac{\partial F_c(L_c^i)}{\partial L_c^i} - w^i = 0 \quad (9)$$

$$P \frac{\partial F_d(L_d^i)}{\partial L_d^i} - w^i = 0 \quad (10)$$

By using equations (9) and (10) together with the identity $L^i - L_G^i = L_c^i + L_d^i$, we can define w^i , L_c^i and L_d^i as functions of P and $L^i - L_G^i$. Therefore, substituting $L_c^i = L_c(L^i - L_G^i, P)$ and $L_d^i = L_d(L^i - L_G^i, P)$ into the production functions, we obtain the equilibrium supply functions

$$S_c^i = S_c(L^i - L_G^i, P) = F_c(L_c(L^i - L_G^i, P)) \quad (11)$$

$$S_d^i = S_d(L^i - L_G^i, P) = F_d(L_d(L^i - L_G^i, P)) \quad (12)$$

⁸An alternative would be to assume that the fixed factors are owned by the consumer and subject to taxation. Since the consumers are identical by assumption, this distinction is not important for the results.

Since the two private goods are subject to international trade, market equilibrium for the dirty good implies

$$\sum_{i=1}^2 S_d(L^i - L_G^i, P) \equiv \sum_{i=1}^2 X(P + t^i, B^i, Z^i, G^i, E) \quad (13)$$

As long as equation (13) is fulfilled, Walras' law implies that the market for the clean good is in equilibrium as well. Equation (13) implicitly defines the producer price of the dirty good as

$$P = P(B^i, L^i, L_G^i, t^i, B^k, L^k, L_G^k, t^k, E) \quad (14)$$

for $k \neq i$, where we have used $L^i = H - Z^i$ and $L^k = H - Z^k$ as well as suppressed the time endowment, H .

The environmental damage is determined by

$$E = \sum_{i=1}^2 X^i(P + t^i, B^i, Z^i, G^i, E) \quad (15)$$

which means that the environmental damage facing the residents in each country is given by the sum of the two countries' consumption of the dirty good.

Finally, the budget constraint facing the government in each country is given by

$$\Pi_c^i + \Pi_d^i + T(w^i L^i) + t^i X(P + t^i, B^i, Z^i, G^i, E) - w^i L_G^i = 0 \quad (16)$$

3 Public Policy at the National Level

It is convenient to begin by briefly considering two special cases of the model set out above; (i) a noncooperative Nash equilibrium with fixed producer prices (i.e. small open economies) and (ii) a cooperative equilibrium (a closed economy). Both these equilibrium concepts have been addressed in earlier research on environmental policy under mixed taxation⁹; let be that

⁹See Aronsson and Blomquist (2003).

the earlier research dealing with the cooperative equilibrium did not consider endogenous producer prices. The basic idea is to provide a reference case, which is (more or less) known from earlier research. Having done that, our main purpose is to analyze the income and commodity tax structure as well as the provision of the public good in the noncooperative Nash equilibrium with endogenous producer prices.

3.1 Briefly on Two Special Cases

A noncooperative Nash equilibrium is commonly derived by assuming that each national government solves a domestic optimal tax and expenditure problem, in which it treats the policy instruments of the other country as exogenous. The cooperative equilibrium, on the other hand, is often based on the assumption that the economic policies in both countries are decided upon by a global social planner, who maximizes the sum of the two country-specific objectives (or, more generally, a weighted sum) subject to a resource constraint for the economy as a whole. The latter is, of course, equivalent to a closed economy, as it implies that the two countries are merged together into a single jurisdiction from the perspective of economic policy. Given the model set out above, the main difference between these resource allocations is that, in a noncooperative Nash equilibrium, each national government only internalizes the part of the domestically created externality that influences the domestic residents, whereas the cooperative resource allocation means that all externalities are internalized at the global level.

However, provided that the noncooperative Nash equilibrium is derived under the assumption of exogenous producer prices, these two resource allocations will, nevertheless, share some common characteristics with regards to the tax structure. To see this, let us define¹⁰

$$MWP_{E,B}^i = -\frac{\partial V^i/\partial E}{\partial V^i/\partial B^i}, \quad MRS_{G,B}^i = \frac{\partial V^i/\partial G}{\partial V^i/\partial B^i}, \quad MRT_{C,G}^i = \frac{\partial F_c^i/\partial L}{\partial F_G^i/\partial L}$$

¹⁰Note that $\partial V^i/\partial B^i = \partial U^i/\partial C^i$.

to be the marginal willingness to pay by the resident in country i for a small reduction in the environmental damage, the marginal rate of substitution between the public good and private income for the resident in country i and the marginal rate of transformation between the numeraire and the public good in country i , respectively.

Then, if the resource allocation is a noncooperative Nash equilibrium with exogenous producer prices, it is straight forward to show that

$$t^i = MWP_{E,B}^i, T_I^i = 0 \text{ and } MRS_{G,B}^i = MRT_{C,G}^i \text{ for } i = 1, 2 \quad (17)$$

This has been established by earlier research. If, on the other hand, the two countries are merged into a closed economy, *with either exogenous or endogenous producer prices*, we have

$$t^i = \sum_i MWP_{E,B}^i, T_I^i = 0 \text{ and } MRS_{G,B}^i = MRT_{C,G}^i \text{ for } i = 1, 2 \quad (18)$$

In summary, therefore, we have established the following result;

Proposition 1 *Within the given framework, if the resource allocation is a noncooperative Nash equilibrium based on exogenous producer prices, or a cooperative equilibrium based on either exogenous or endogenous producer prices, the commodity tax is used solely for externality-correction, whereas the marginal income tax rate is zero. Furthermore, both regimes imply that the public good obeys the Samuelson rule.*

These results will serve as a benchmark for the analyses to be carried out in the next subsection.

3.2 Noncooperative Nash Equilibrium with Endogenous Producer Prices

Next, let us characterize the tax and expenditure structure implicit in the noncooperative Nash equilibrium with endogenous producer prices. As men-

tioned above, each national government solves a domestic optimal tax and expenditure problem, which can be written as follows;

$$\underset{L^i, B^i, t^i, L_G^i, G^i, E}{Max} \quad Max \quad V(P + t^i, B^i, Z^i, G^i, E) \quad (19)$$

s.t.

$$B^i = S_c(L^i - L_G^i, P) + PS_d(L^i - L_G^i, P) + t^i X(P + t^i, B^i, Z^i, G^i, E) \quad (20)$$

$$G^i = F_G(L_G^i) \quad (21)$$

$$E = X(P + t^i, B^i, Z^i, G^i, E) + X(P + t^k, B^k, Z^k, G^k, E) \quad (22)$$

for $i = 1, 2$, and $k \neq i$, where k represents "the other country". In addition, note that the producer price of the dirty good is endogenous to the government and determined by equation (14). Equation (20) is the budget constraint facing the government, which is derived by using equation (16) together with the private budget constraint given by equation (5), the objective functions of the two representative firms, i.e. equations (7) and (8), and the time constraint $L^i = L_c^i + L_d^i + L_G^i$. Note that $T(\cdot)$ is a general income tax; it can be used to implement any desired combination of work hours and private income. It is, therefore, convenient to use L^i and B^i , instead of the parameters of $T(\cdot)$, as direct decision variables for the government. Therefore, the optimal tax and expenditure problem is written such that the income tax function is replaced by L^i and B^i . Equation (21) is the production function for the public good, whereas equation (22) summarizes the relationship between the externality and the aggregate consumption of the dirty good; its appearance as an explicit constraint means that E is treated as an additional (and artificial) decision variable. This formulation allows us to define a shadow price of E facing each national government, which will be convenient for purposes of interpretation of the optimal tax policy (see below).

The Lagrangean becomes

$$\begin{aligned}
\mathfrak{L}^i &= V(P + t^i, B^i, Z^i, G^i, E) + \lambda^i [F_G(L_G^i) - G^i] \\
&\quad + \gamma^i [S_c(L^i - L_G^i, P) + PS_d(L^i - L_G^i, P - B^i) \\
&\quad + t^i X(P + t^i, B^i, Z^i, G^i, E)] \\
&\quad + \mu^i [E - X(P + t^i, B^i, Z^i, G^i, E) - X(P + t^k, B^k, Z^k, G^k, E)]
\end{aligned}$$

for $i = 1, 2$ and $k \neq i$, where λ^i , γ^i and μ^i are Lagrange multipliers. The first order conditions are presented in the Appendix. Since the two countries are identical by assumption, we concentrate on the implications of a symmetric Nash equilibrium in what follows.

Earlier research on environmental policy in the context of mixed taxation¹¹ shows that the shadow price of environmental damage over the shadow price of the government's budget constraint, μ^i/γ^i , plays an important role for the tax structure. We can interpret μ^i/γ^i as the marginal value of reduced environmental damage for country i measured in terms of its tax revenues. Consider Proposition 2;

Proposition 2 *In the symmetric noncooperative Nash equilibrium, where the producer price of the dirty good is endogenous to the national governments, the shadow price of environmental damage over the shadow price of the government's budget constraint can be written as (for $i = 1, 2$ and $k \neq i$)*

$$\frac{\mu^i}{\gamma^i} = MW P_{E,B}^i + t^i \frac{\partial X^k}{\partial E}$$

Proof: See the Appendix.

To interpret Proposition 2, recall first that the case with exogenous producer prices (briefly addressed in the previous subsection) means that $\mu^i/\gamma^i = MW P_{E,B}^i$. Therefore, relaxing the 'small open economy assumption' adds one additional term to the (domestic) marginal value of environmental quality; namely, $t^i(\partial X^k/\partial E)$. This effect arises because a domestically generated

¹¹See.e.g. Pirttilä and Tuomala (1997).

increase in E leads to a change in the consumption of the dirty good in the other country. The intuition is that, if a domestically generated increase in E causes an increase (a decrease) in X^k , so $\partial X^k/\partial E > 0$ (< 0), there is an incentive for the government in country i to try to influence X^k via public policy by reducing E more (less) than it would otherwise have done. As such, this implies that the government attaches a higher (lower) value to reduced environmental damage. However, if the utility function is weakly separable in E , meaning that $\partial X^k/\partial E = 0$, this additional effect vanishes and $\mu^i/\gamma^i = MWP_{E,B}^i$.

Let us now turn to the commodity tax structure. Does the endogeneity of the producer price of the dirty good only modify the commodity tax via the valuation of environmental damage, or does it imply other modifications as well in comparison with the previous subsection? To simplify the tax formulas as much as possible, let us use the short notations

$$\rho^i = \frac{\partial S_d^i}{\partial P} + \frac{\partial S_d^k}{\partial P} - \frac{\partial X^k}{\partial Q^k} > 0 \quad (23)$$

$$\phi^i = 1 + \frac{\partial X^k}{\partial Q^k} \frac{1}{\rho^i} \quad (24)$$

where $0 < \phi^i < 1$, since $\partial X^k/\partial Q^k < 0$ and $|\partial X^k/\partial Q^k| < \rho^i$. Consider Proposition 3;

Proposition 3 *In the symmetric¹² noncooperative Nash equilibrium, where the producer price of the dirty good is endogenous to the national govern-*

¹²If we were to relax the assumption that the equilibrium is symmetric, then each tax formula would also contain a terms of trade effect, so

$$t^i = \phi^i \frac{\mu^i}{\gamma^i} - \frac{NX^i}{\rho^i}$$

where NX^i is the net export of the dirty good. However, as we are considering a symmetric equilibrium, $NX^i = 0$, meaning that the terms of trade effect vanishes. This will be true for all policy formulas derived below.

ments, the commodity tax on the dirty good can be written as

$$t^i = \phi^i \frac{\mu^i}{\gamma^i}$$

Proof: See the Appendix.

By comparison with the small open economy, where $t^i = \mu^i/\gamma^i$, Proposition 3 implies that the commodity tax is scaled down by the variable $\phi^i \in (0, 1)$, so it falls short of the value attached to reduced environmental damage. Note also that this holds irrespective of whether or not the utility function is weakly separable in the environmental damage. If the consumption of the dirty good is a weakly decreasing function of the environmental damage, so $\partial X^i/\partial E \leq 0$ (which includes weak separability as a special case), our result means that $t^i < MWP_{E,B}^i$, indicating a policy where the commodity tax falls short of the consumer's marginal willingness to pay for environmental quality.

The intuition behind Proposition 3 is that each national government perceives to have the possibility of reducing the consumption of the dirty good in the other country. This can be accomplished by exercising influence over the world market producer price of the dirty good. By reducing its own commodity tax below μ^i/γ^i , the domestic demand for the dirty good increases in country i , which has a zero first order domestic welfare effect if measured conditional on P . On the other hand, a higher domestic demand in country i increases P , which leads to a higher consumer price in country k (conditional on t^k). The subsequent reduction of X^k increases welfare in country i .

Given the framework set out above, we saw in the previous subsection that a small open economy (which treats the producer price of the dirty good as exogenous) chooses a zero marginal income tax rate, meaning that the income tax is equivalent to a lump-sum tax. The interpretation is that consideration for the environment does not, in this case, motivate a modification of the income tax structure. Does this result carry over to a large

open economy with an endogenous producer price? To address this question, let us define

$$\varepsilon^i = -\frac{1}{\rho^i w^i} \frac{\partial X^k}{\partial Q^k} \frac{\partial S_d^i}{\partial L^i} > 0 \quad (25)$$

and consider Proposition 4;

Proposition 4 *In the symmetric noncooperative Nash equilibrium, where the producer price of the dirty good is endogenous to the national governments, the marginal income tax rate can be written as (for $i = 1, 2$ and $k \neq i$)*

$$T'(w^i L^i) = \varepsilon^i \frac{\mu^i}{\gamma^i}$$

Proof: See the Appendix.

Proposition 4 is a consequence of a more general result; if there are fewer policy instruments than variables to control, then the tax on the dirty good no longer constitutes a perfect environmental policy instrument. The intuition is that the government of country i cannot use t^i alone in order to exercise control over both X^i and X^k . Therefore, it will use other policy instruments as well - in this case the marginal income tax rate - for the explicit purpose of influencing the environmental damage.

The formula in Proposition 4 implies that the income tax serves as an 'indirect instrument' to increase the producer price of the dirty good, which is desirable for the national government as long as $\mu^i/\gamma^i > 0$. Clearly, one way to increase the producer price is to reduce the supply of the dirty good. This provides an incentive for the national government to choose a higher marginal income tax rate than it would otherwise have done, which leads to fewer hours of work and, therefore, less output. Note that this result is further strengthened if the utility function is weakly separable in the environmental damage; this case implies that μ^i/γ^i is always greater than zero in our framework, so $T'(w^i L^i) > 0$.

Let us finally consider the provision of the public good. Define

$$\psi^i = \frac{1}{\rho^i \partial F_G^i / \partial L_G^i} \frac{\partial X^k}{\partial Q^k} \frac{\partial S_d^i}{\partial L_G^i} > 0$$

where $\partial S_d^i / \partial L_G^i = -\partial S_d^i / \partial L^i < 0$, and consider Proposition 5;

Proposition 5 *In the symmetric noncooperative Nash equilibrium, where the producer price of the dirty good is endogenous to the national governments, the optimal provision of the public good satisfies (for $i = 1, 2$ and $k \neq i$)*

$$MRS_{G,B}^i = MRT_{C,G}^i - \psi^i \frac{\mu^i}{\gamma^i}$$

Proof: See the Appendix.

Proposition 5 implies overprovision of the public good relative to the Samuelson rule. The intuition is that, if the government increases production of the public good, employment in the private sector is crowded out. This reduces the supply of the dirty good and increases the producer price. Therefore, to be able to reap the additional benefit of a cleaner domestic environment (as a higher producer price reduces the consumption of the dirty good by the resident in the other country), the government produces more of the public good than it would otherwise have done.

4 Policy Coordination

The results derived in the previous section suggest that, if each national government is able to affect the producer prices, this does not only mean that the commodity tax on the externality-generating good is likely to be inefficiently low seen from the perspective of global well-being; it also implies that the marginal income tax rate is inefficiently high, and that too much resources are spent on public goods. An interesting question, therefore, is whether policy coordination can be designed in such a way, that welfare

increases in both countries? Here, we will not interpret the concept of 'cooperation' 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 in comparison with the initial equilibrium. We will not discuss the conditions under which such international agreements are likely to be formed; only the welfare consequences if they arise.

To simplify the analysis and be able to derive clear-cut results, we add the assumption that Z^i , G^i and E are all weakly separable from the other goods in the utility function, which implies that the conditional demand functions for C^i and X^i reduce to $C^i = C(Q^i, B^i)$ and $X^i = X(Q^i, B^i)$, respectively. Since we are considering a symmetric equilibrium, we only have to evaluate the effects for one country in order to say something about global welfare. Then, by observing that the national welfare equals the national Lagrangean in the noncooperative Nash equilibrium, i.e. $V^i = \mathfrak{L}^i$, an application of the envelope theorem gives

$$dV^i = \beta_1^i dL^k + \beta_2^i dL_G^k + \beta_3^i dt^k + \beta_4^i dB^k \quad (26)$$

for $k \neq i$, where

$$\begin{aligned} \beta_1^i &= \frac{\mu^i}{\gamma^i} \frac{\partial X^k}{\partial Q^k} \frac{\gamma^i}{\rho^i} \frac{\partial S_d^k}{\partial L^k} < 0 \\ \beta_2^i &= \frac{\mu^i}{\gamma^i} \frac{\partial X^k}{\partial Q^k} \frac{\gamma^i}{\rho^i} \frac{\partial S_d^k}{\partial L_G^k} > 0 \\ \beta_3^i &= -\frac{\mu^i}{\gamma^i} \frac{\gamma^i}{\rho^i} \left(\frac{\partial S_d^i}{\partial P} + \frac{\partial S_d^k}{\partial P} \right) \frac{\partial X^k}{\partial Q^k} > 0 \\ \beta_4^i &= -\frac{\mu^i}{\gamma^i} \frac{\gamma^i}{\rho^i} \left(\frac{\partial S_d^i}{\partial P} + \frac{\partial S_d^k}{\partial P} \right) \frac{\partial X^k}{\partial B^k} < 0 \end{aligned}$$

To interpret equation (26), recall that the noncooperative Nash equilibrium means that each national government has made an optimal policy choice on

a national basis. As a consequence, a small change in a domestic decision variable will have a zero first order domestic welfare effect. This explains why changes in L^k , L_G^k , t^k and B^k affect the welfare in country i , whereas changes in the corresponding domestic decision variables do not.

A reform will always consist of a change in (at least) two policy variables, because the government must balance the budget. Let us, therefore, use equation (26) to find possible pairwise changes in policy variables, which unambiguously increase welfare. Consider Proposition 6;

Proposition 6 *If the initial resource allocation is represented by the non-cooperative Nash equilibrium with endogenous producer prices, it is welfare improving to;*

- (i) increase the commodity tax, while the post-tax private income and total hours of work are held constant (via adjustments of the income tax), and use the additional tax revenues to increase the production of the public good.*
- (ii) reduce the total hours of work and simultaneously reduce the post-tax private income to keep the tax revenues unchanged.*
- (iii) reduce the post-tax private income (given the total hours of work and the commodity tax) and use the additional tax revenues to increase the production of the public good.*

Reform (i) means that $dB^k = dL^k = 0$, while $dt^k > 0$ and $dL_G^k > 0$, so $dV^i > 0$. The intuition for why a coordinated increase in the commodity tax increases welfare is straight forward; higher commodity taxation in country k reduces the environmental damage in country i and vice versa. However, note that we are only considering an infinitesimal change in the commodity tax in a noncooperative Nash equilibrium, meaning that this hypothetical reform does not increase the commodity tax all the way to the first best level; we are still in the second best where the consumer price of the dirty good is inefficiently low from the perspective of global well-being. To be more specific, since the public policy in the noncooperative Nash equilibrium is based

on domestic objectives (where each national government underestimates the full welfare effect of pushing up the producer price of the dirty good), additional marginal policy coordination leads to higher welfare if it increases the producer price. This is accomplished here as the countries agree to use the additional tax revenues to hire more labor in the public sector which, in turn, crowds out part of the employment in the private sector, implying that P and, therefore, Q^k will increase.

Reform (ii) means that $dt^k = dL_G^k = 0$, while $dB^k < 0$ and $dL^k < 0$. Effectively, this implies an increase in the marginal income tax rate (which reduces L^k), accompanied by an increase in the average income tax rate (which reduces B^k). A reduction of L^k has a negative effect on private sector output; as such, it contributes to increase P and, therefore, Q^k , which leads to higher welfare in country i . In addition, the associated decrease in B^k reduces the consumption of X^k (recall that X^k is a normal good), which also contributes to higher welfare in country i . Therefore, and somewhat surprisingly, although the marginal income tax rate is inefficiently high in the noncooperative Nash equilibrium, increasing the marginal income tax rate will, nevertheless, lead to higher welfare. The intuition is, again, that the prereform resource allocation is a noncooperative Nash equilibrium, where the consumer price of the dirty good is inefficiently low from the perspective of global well-being.

Finally, reform (iii) means $dt^k = dL^k = 0$, while $dB^k < 0$ and $dL_G^k > 0$. The interpretation is that a lower B^k (via a higher average income tax rate) tends to reduce X^k , which is welfare improving for country i . Note that this hypothetical reform also means that the marginal income tax rate is adjusted to keep L^k unchanged. The associated increase in the production of the public good also contributes to higher welfare, as it tends to increase the producer price of the dirty good. In other words, it is welfare improving to increase the provision of public good (conditional on the inefficiently low consumer price of the dirty good in the noncooperative Nash equilib-

rium), although the public good is already too large relative to the first best Samuelson rule.

5 Summary and Discussion

This paper characterizes the optimal income and commodity tax structure in a two-country economy. There are two private goods (produced and consumed in both countries); a clean and a dirty (externality-generating) good. The two commodities are subject to international trade, and we assume that the aggregate consumption of the dirty good (measured over both countries) gives rise to a transboundary environmental problem. Each national government is assumed to face a mixed tax problem, where the set of tax instruments consists of a nonlinear income tax and a linear commodity tax on the dirty good. Contrary to earlier literature in this area, we assume that the producer prices are endogenous to each national government; the idea is that each country is large in the sense that its government can significantly affect the world market producer prices via public policy. This is easily motivated because the environmental policy scene is to some extent characterized by large actors, where the price-taking assumption appears to be less realistic.

In order to highlight the importance of endogenous world market producer prices for externality-correction, our model disregards motives other than externality-correction for using distortionary taxation. As a consequence, if we were relax the assumption that the producer prices are endogenous, i.e. imposing fixed producer prices as in much of the earlier literature, we would find that the tax on the externality-generating good equals the marginal value that the national government attaches to the externality, and that the marginal income tax is equal to zero. We would also find that the provision of the public good satisfies the Samuelson rule. We show that none of these standard results apply, if the producer prices are treated as

endogenous by the national governments.

To be more specific, each national government sets the commodity tax below the marginal value it attaches to the externality. The intuition is that, if the producer price is endogenous, then each national government perceives to have an option of reducing the consumption of the dirty good in the other country. By reducing its own commodity tax below the domestic marginal value of the externality, the domestic demand for the dirty good increases which, in turn, increases the world market price of the dirty good. The subsequent decrease in foreign consumption increases the domestic welfare. Each national government also tries to reduce the domestic environmental damage by choosing a higher marginal income tax rate than it would otherwise have done; this tends to reduce the hours of work and, therefore, the output of the dirty good. In addition, each national government overprovides the public good relative to the Samuelson rule.

The final part of the paper addresses the welfare effects of policy coordination, where the noncooperative Nash equilibrium constitutes the prereform resource allocation. The purposes are to characterize the underlying cost benefit rule as well as discuss some of its implications for policy reforms. We exemplify by discussing three coordinated policy reforms, which lead to higher welfare; (i) a coordinated increase in the commodity tax accompanied by increased production of the public good, (ii) a coordinated increase in the marginal and average income tax rates, and (iii) a coordinated reduction in the post-tax private income accompanied by increased production of the public good. These policy reforms are welfare improving because, as long as the commodity tax on the dirty good is set below the first best level, it is welfare improving to increase the producer price of the dirty good. This is precisely what these reforms accomplish. The intuition is that the prereform resource allocation is a noncooperative Nash equilibrium, where the policies are based on domestic objectives. As a consequence, in the pre-reform equilibrium each national government underestimates the global welfare effect

of pushing up the producer price, which makes it welfare improving to coordinate policies.

6 Appendix

First Order Conditions

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

$$\frac{\partial \mathcal{L}^i}{\partial L^i} = -V_Z^i + \gamma^i \left(-t^i \frac{\partial X^i}{\partial Z^i} + w^i \right) + \mu^i \frac{\partial X^i}{\partial Z^i} + \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial L^i} = 0 \quad (\text{A.2})$$

$$\frac{\partial \mathcal{L}^i}{\partial t^i} = -X^i V_B^i + \gamma^i \left(t^i \frac{\partial X^i}{\partial Q^i} + X^i \right) - \mu^i \frac{\partial X^i}{\partial Q^i} + \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial t^i} = 0 \quad (\text{A.3})$$

$$\frac{\partial \mathcal{L}^i}{\partial L_G^i} = \lambda^i \frac{\partial F_G^i}{\partial L_G^i} - \gamma^i \frac{\partial F_c^i}{\partial L_c^i} + \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial L_G^i} = 0 \quad (\text{A.4})$$

$$\frac{\partial \mathcal{L}^i}{\partial G^i} = V_G^i - \lambda^i + \gamma^i t^i \frac{\partial X^i}{\partial G^i} - \mu^i \frac{\partial X^i}{\partial G^i} + \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial G^i} = 0 \quad (\text{A.5})$$

$$\frac{\partial \mathcal{L}^i}{\partial E} = V_E^i + \gamma^i t^i \frac{\partial X^i}{\partial E} + \mu^i \left(1 - \frac{\partial X^i}{\partial E} - \frac{\partial X^k}{\partial E} \right) + \frac{\partial \mathcal{L}^i}{\partial P} \frac{\partial P}{\partial E} = 0 \quad (\text{A.6})$$

for $k \neq i$, where $V_B^i = \partial V^i / \partial B^i$, $V_Z^i = \partial V^i / \partial Z^i$, $V_G^i = \partial V^i / \partial G^i$ and $V_E^i = \partial V^i / \partial E$. To derive equations (A.2) and (A.4), we have used the time constraint $L^i = L_c^i + L_d^i + L_G^i$. Note also that

$$\frac{\partial \mathcal{L}^i}{\partial P} = -X^i V_B^i + \gamma^i \left(t^i \frac{\partial X_d^i}{\partial Q^i} + X^i \right) - \mu^i \left(\frac{\partial X^i}{\partial Q^i} + \frac{\partial X^k}{\partial Q^k} \right) \quad (\text{A.7})$$

in which we have used that the net export of the dirty good is zero in the symmetric equilibrium.

Proof of Proposition 3

Let us substitute (A.7) into (A.1) and (A.3), divide by γ^i and rearrange the resulting expression. This gives

$$\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \times \begin{bmatrix} \frac{V_B^i}{\gamma^i} \\ t^i \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \end{bmatrix} \quad (\text{A.8})$$

where

$$\begin{aligned}
a_{11} &= \left(1 - X^i \frac{\partial P}{\partial B^i}\right), & a_{12} &= \left(\frac{\partial X^i}{\partial B^i} + \frac{\partial X^i}{\partial Q^i} \frac{\partial P}{\partial B^i}\right) \\
a_{21} &= -\left(X^i + X^i \frac{\partial P}{\partial t^i}\right), & a_{22} &= \left(\frac{\partial X^i}{\partial Q^i} + \frac{\partial X^i}{\partial Q^i} \frac{\partial P}{\partial t^i}\right) \\
b_1 &= \frac{\mu^i}{\gamma^i} \left(\frac{\partial X^i}{\partial B^i} + \frac{\partial X^i}{\partial Q^i} \frac{\partial P}{\partial B^i} + \frac{\partial X^k}{\partial Q^k} \frac{\partial P}{\partial B^i}\right) + \left(1 - X^i \frac{\partial P}{\partial B^i}\right) \\
b_2 &= \frac{\mu^i}{\gamma^i} \left(\frac{\partial X^i}{\partial Q^i} + \frac{\partial X^i}{\partial Q^i} \frac{\partial P}{\partial t^i} + \frac{\partial X^k}{\partial Q^k} \frac{\partial P}{\partial t^i}\right) - \left(X^i \frac{\partial P}{\partial t^i} + X^i\right)
\end{aligned}$$

for $k \neq i$. By using Cramer's rule to solve for t^i and V_B^i/γ^i , we obtain

$$t^i = \frac{\mu^i}{\gamma^i} + \frac{\mu^i}{\gamma^i} \frac{\partial X^k / \partial Q^k}{|H|} \left(\frac{\partial P}{\partial t^i} + \frac{\partial P}{\partial B^i} X^i\right) \quad (\text{A.9})$$

$$\frac{V_B^i}{\gamma^i} = 1 + \frac{\mu^i}{\gamma^i} \left(\frac{\partial X^i}{\partial Q^i} \frac{\partial P}{\partial B^i} - \frac{\partial X^i}{\partial B^i} \frac{\partial P}{\partial t^i}\right) \frac{\partial X^k}{\partial Q^k} \frac{1}{|H|} \quad (\text{A.10})$$

where

$$|H| = \left(1 + \frac{\partial P}{\partial t^i}\right) \frac{\partial \tilde{X}^i}{\partial Q^i}$$

Recall that the producer price is implicitly defined by equation (13). Differentiating equation (13), we obtain

$$\frac{\partial P}{\partial t^i} = \frac{\partial X^i / \partial Q^i}{\alpha} \quad (\text{A.11})$$

$$\frac{\partial P}{\partial B^i} = \frac{\partial X^i / \partial B^i}{\alpha} \quad (\text{A.12})$$

$$\frac{\partial P}{\partial t^i} + \frac{\partial P}{\partial B^i} X^i = \frac{\partial \tilde{X}^i / \partial Q^i}{\alpha} \quad (\text{A.13})$$

where

$$\alpha = \frac{\partial S_d^i}{\partial P_d} + \frac{\partial S_d^k}{\partial P_d} - \frac{\partial X_d^i}{\partial Q_d^i} - \frac{\partial X_d^k}{\partial Q_d^k} > 0$$

Substitute equation (A.13) into equation (A.9), use the definition of $|H|$ and observe that

$$1 + \frac{\partial P}{\partial t^i} = \frac{\rho^i}{\alpha} \quad (\text{A.14})$$

where

$$\rho^i = \alpha + \frac{\partial X^i}{\partial Q^i} > 0$$

This implies

$$t^i = \left(1 + \frac{\partial X^k}{\partial Q^k} \frac{1}{\rho^i}\right) \frac{\mu^i}{\gamma^i} \quad (\text{A.15})$$

which is the tax formula in Proposition 3. Note that by substituting equations (A.12) and (A.13) into equation (A.10) gives $V_B^i/\gamma^i = 1$. ■

Proof of Proposition 2

Let us first combine equations (A.3) and (A.7). Then, use equation (A.14) to obtain

$$\frac{\partial \mathcal{L}^i}{\partial P} = -\mu^i \frac{\partial X^k}{\partial Q^k} \frac{\alpha}{\rho^i} > 0 \quad (\text{A.16})$$

Next, substitute $V_E^i = -V_B^i MWP_{E,B}^i$ and equations (A.15) and (A.16) into equation (A.6). Divide the resulting expression with γ^i

$$0 = -MWP^i + \frac{\mu^i}{\gamma^i} \frac{\partial X^k}{\partial Q^k} \frac{1}{\rho^i} \frac{\partial X^i}{\partial E} + \frac{\mu^i}{\gamma^i} \left(1 - \frac{\partial X^k}{\partial E}\right) - \frac{\mu^i}{\gamma^i} \frac{\partial X^k}{\partial Q^k} \frac{\alpha}{\rho^i} \frac{\partial P}{\partial E} \quad (\text{A.17})$$

where we have used that $V_B^i = \gamma^i$. To evaluate $\partial P/\partial E$, we differentiate equation (13) to obtain

$$\frac{\partial P}{\partial E} = \frac{1}{\alpha} \left(\frac{\partial X_d^i}{\partial E} + \frac{\partial X_d^k}{\partial E} \right) \quad (\text{A.18})$$

Substituting equation (A.18) into equation (A.17) gives

$$0 = -MWP^i + \frac{\mu^i}{\gamma^i} - \left(\frac{\mu^i}{\gamma^i} + \frac{\mu^i}{\gamma^i} \frac{\partial X^k}{\partial Q^k} \frac{1}{\rho^i} \right) \frac{\partial X^k}{\partial E} \quad (\text{A.19})$$

Since the expression within parenthesis equals t^i , we can rearrange equation (A.19) to the formula in Proposition 2. ■

Proof of Proposition 4

Substitute equations (A.15) and (A.16) into equations (A.1) and (A.2)

$$0 = V_B^i + \gamma^i \left(\frac{\mu^i \partial X^k}{\gamma^i \partial Q^k} \frac{1}{\rho^i} \frac{\partial X^i}{\partial B^i} - 1 \right) - \mu^i \frac{\partial X^k}{\partial Q^k} \frac{\alpha}{\rho^i} \frac{\partial P}{\partial B^i} \quad (\text{A.20})$$

$$0 = -V_Z^i + \gamma^i \left(\frac{\mu^i \partial X^k}{\gamma^i \partial Q^k} \frac{1}{\rho^i} \frac{\partial X^i}{\partial L^i} + w^i \right) - \mu^i \frac{\partial X^k}{\partial Q^k} \frac{\alpha}{\rho^i} \frac{\partial P}{\partial L^i} \quad (\text{A.21})$$

Use equation (A.12) to substitute for $\partial P/\partial B^i$. In addition, use that $\partial P/\partial L^i$ is given by

$$\frac{\partial P}{\partial L^i} = -\frac{1}{\alpha} \left(\frac{\partial S_d^i}{\partial L^i} - \frac{\partial X^i}{\partial L^i} \right) \quad (\text{A.22})$$

We can then multiply equation (A.20) by w^i and add the resulting expression to equation (A.21). This gives

$$0 = T_I^i w^i V_B^i + \mu^i \frac{\partial X^k}{\partial Q^k} \frac{1}{\rho^i} \frac{\partial S_d^i}{\partial L^i} \quad (\text{A.23})$$

where we have used $V_B^i w^i T_I^i = V_B^i w^i - V_Z^i$. Since $V_B^i = \gamma^i$, we can rearrange equation (A.23) to obtain the formula in Proposition 4. ■

Proof of Proposition 5

By differentiating equation (13) with respect to L_G^i and G^i , we obtain

$$\frac{\partial P}{\partial L_G^i} = \frac{\partial S_d^i / \partial L^i}{\alpha} > 0 \quad (\text{A.24})$$

$$\frac{\partial P}{\partial G^i} = \frac{\partial X^i / \partial G^i}{\alpha} \quad (\text{A.25})$$

Substituting equations (A.15), (A.16) and (A.25) into equation (A.5) and rearranging gives

$$MRS_{G,B}^i = \frac{\lambda^i}{\gamma^i} \quad (\text{A.26})$$

where we have used $V_B^i = \gamma^i$ and $MRS_{G,B}^i = V_G^i / V_B^i$. Next, substitute equations (A.16) and (A.24) into equation (A.4). Rearranging the resulting expression gives

$$\frac{\lambda^i}{\gamma^i} = MRT_{C,G}^i - \psi^i \frac{\mu^i}{\gamma^i} \quad (\text{A.27})$$

Combining equations (A.26) and (A.27) gives the formula in Proposition 5. ■

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