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Reformsof Environmental Policies in the Presence of Cross-border Pollution and Public-Private Clean-up*

By

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Abstract

We construct a two-country model where pollution from production is transmitted across borders. Pollution abatement is undertaken by both private producers and the public sector. We characterize Nash optimal levels of the policy instruments in the two countries: emission taxes and funds allocated for public abatement activities. We examine the implications of a number of multilateral policy reforms. One of our findings is that the magnitude of the beneficial effect of a reform depends on the scope of the reform, and if it is restricted to a subset of policy instruments, then the efficacy of environmental policy reform can be greatly undermined.

Key Words: Cross-border pollution, Private pollution abatement, Public pollution abatement, multilateral policy reform.
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1 Introduction

It is now universally acknowledged that pollution knows no national geographical boundaries and excessive pollution generated in a country is likely to have serious adverse implications for the rest of the international community.[1] The acceptance of the above reality has led to several international conferences aimed at multilateral agreements to combat environmental degradation.[2]

Along side the above developments in the international policy making arena, a small theoretical literature has developed to analyze the implications of cross-border pollution and/or to examine the welfare implications of environmental policy reform (see, for example, Merrifield (1988), Copeland and Taylor (1995), Copeland (1994, 1996), Ludema and Wooton (1994, 1997), Beghin *et al* (1997), Turunen-Red and Woodland (1998, 2000), and Hatzipanayotou *et al* (2002)).

With the exception of Hatzipanayotou *et al* (2002), the rest of the emerging literature does not allow for the coexistence of abatements by both private and public sectors.[3] In reality, however, one observes the coexistence of private and public abatement activities. The share of public abatement expenditure in total abatement expenditure varies quite a lot from country to country and from one type of pollution to another. According to the OECD,[4] as far as abatement of water pollution in the early 1990s is concerned, the share of public expenditure in the total expenditure are 66% in the USA and the Netherlands and

[1]It is argued (see, for example, Yu, 2001) that cross-border pollution is an important reason why international environmental agreements have been taking place. Another reason is the concern for the so-called 'race to the bottom' in international environmental standards, *i.e.*, in a non-cooperative environment countries may resort to laxed environmental standards in order to pursue strategic economic objectives. For these reasons, effective environmental policies pursued by a country can be undermined by the lack of such policies in other countries. For example, Sterner and Kohlin (2003) found that most European countries have higher levels of pollution restrictions compared to the USA. Thus, there is a fear that European efforts at pollution control will not have the desired effects in the absence of similar efforts in the USA.

[2]For example, during the past two decades, these debates were the subject of a number of international fora for multilateral negotiations on concerted policy actions (e.g., Rio de Janiero 1992, Kyoto 1998, and Johannesburg 2001).

[3]There is a separate literature on public abatement of pollution in a somewhat different context (see, Khan (1995) and Chao and Yu (1999)).

[4]See OECD (1996).

only 12% in the UK. As for abatement of air pollution, whereas the share of public abatement in the Netherlands and the UK are 55% and 30% respectively, it is only 6% in the case of the USA. Given these figures, it is important that both types of abatements are taken into consideration in analyzing environmental policies. Hatzipanayotou *et al* (2002) allow for the coexistence of abatements by both private and public sectors in a North-South model in which pollution is only generated in the South and the North suffers from it because of cross-border pollution. They analyze the situation in which the North can influence pollution emission policies in the South by the strategic use of international transfers. The present paper extends that framework to a North-North (or, South-South) situation in which both countries are symmetric in the sense that they both create pollution, suffer from domestically and overseas generated pollution, and use the same set of instruments (non-cooperatively) to control pollution emission. The only common feature between the model in Hatzipanayotou *et al* (2002) and the present one is the coexistence of private and public abatement of pollution.

The existence of public abatement brings in an additional instrument at the disposal of the policy maker for combating pollution emission on top of the normal instruments such as an emission tax, *viz.* funds made available for public abatement activities. The existence of multiple instruments, *viz.* emission tax and funds made available for public abatement of pollution, in turn introduces two interesting issues. First, it raises the question as to how exactly the aforesaid funds are raised by the policy maker. Since there is considerable evidence that emission taxes are often earmarked for pollution activities by governments,[5] we assume that the government allocates a fraction of emission tax revenue for public sector abatement activities, and this fraction is a policy instrument available to the government.[6]

[5]For example, Brett and Keen (2000) note that, in the US, it is quite customary for environment taxes to be earmarked for specific environment related public expenditure. In particular, such tax proceeds are commonly paid into trust funds that finance various clean-up activities, or are spend on road and public transport networks.

[6]All our qualitative results except one will go through even if we assume that public abatement is funded from lump-sum taxation of the consumers. The exception will be noted in footnote 20.

The second implication of the existence of multiple environmental policy instruments is that it widens the scope of multilateral reforms of environmental policies. One of the objectives of the present paper is to consider a number of alternative multilateral environmental policy reform exercises depending on the scope of these reforms, *i.e.* we allow for the reform of emission taxes while the individual countries are free to adjust the other policy instrument. One of the interesting results of the paper is that the beneficial effects of reforms can be seriously undermined if the reforms are restricted to a subset of policy instruments. Recently, the Commission of the European Union (EU) has proposed an EU-wide increase in the minimum tax on energy. In this policy initiative, the EU however is, however, silent on the need for higher public abatement activities by member states which, as mentioned before, can constitute up to 66% of total (public and private) abatement expenditure in some member countries. In particular, the EU does not propose any restriction on how individual member states should use the extra tax revenue from higher energy taxes.[7] Our analysis suggests that the beneficial effects of such tighter environmental policies can be seriously compromised since the reform is restricted only to emission taxes and the use of extra emission tax revenue is left unrestricted.

Two points are to be noted. First, it is known in the literature that even in the absence of cross-border pollution, uncoordinated policy-making may lead to suboptimality.[8] Second, it is acknowledged that multilateral agreements often contain loopholes which can be exploited by opportunistic governments. In the context of multilateral agreements on trade policy reforms, Copeland (1990) showed that multilateral agreement with respect to a trade policy instrument may entice a government to move to a more costly trade policy instrument, though the latter will not completely offset the welfare improving effect of the former. Walz and Wellisch (1997) and Tsai (1999) carried out a similar analysis in the con-

[7]Since 1997 the Commission of the EU is pushing for a gradual rise in the EU-wide minimum tax rate on mineral oil products and an introduction, for the first time, of an EU-wide minimum tax on coal, natural gas and electricity. The revenue from these taxes could potentially be invested in public abatement activities and/or to be used to lower some of the already existing taxes.

[8]See Ulph (1997) for a survey of the literature.

text of strategic environmental policies. Recently, Sturm (2001) has shown, in the context of strategic environmental policy literature, that the nature of imperfect competition and preferences, *inter alia*, are crucial for determining the effects of restricting the use of trade policy instruments. In this context, our paper is more in line with Copeland (1990) in that all the markets are perfectly competitive and the two instruments are aimed at the same distortion, *viz.* pollution distortion in our case and trade distortion in the case of Copeland (1990). However, in contrast to Copeland (1990) where the two trade instruments are imperfect substitutes and are chosen in two-stage game, our two environmental instruments (ie., the pollution tax and the fraction of pollution tax revenue allocated to the provision of the public sector pollution abatement) are close substitutes and are chosen by the government simultaneously.

The layout of the paper is as follows. Section 2 spells out the model. The non-cooperative optimal values of the policy instruments are characterized in section 3 which also carries out a simple comparative static exercise. In section 4, we consider the effects on individual country welfare and pollution levels of a number of multilateral policy reforms, where the initial levels of the instruments are at their Nash optimum levels. In this section we consider comprehensive as well as partial reforms of policy instruments. In section 5, we analyze the case where the initial levels of the policy instruments are at arbitrary levels and examine the effects of multilateral reforms that take the policy instruments towards their non-cooperative second-best levels. Finally, some concluding remarks are made in section 6.

2 The model

We consider a general equilibrium model with two countries –home and foreign– where pollution is generated as a by-product of production in both countries. It is assumed that residents of both countries suffer disutility from pollution generated by local producers and from pollution generated in the other country and transmitted across-borders.

Both countries produce, under perfectly competitive conditions, a number of goods which are freely traded in world markets. We assume that the two countries are small open economies in the goods markets so that they face exogenous commodity prices. Factors of production are internationally immobile and inelastically supplied. Factor markets are also perfectly competitive. In both countries, abatement of pollution is undertaken by both private producers and the public sector sequentially. First, private producers in the two countries carry out some abatement of pollution that they generate in response to emission taxes in the two countries at the rates t and t^* respectively.[9] The public sector of each country then abates some of the remaining pollution. The levels of public sector abatement in the two countries are denoted respectively by g and g^*. We discuss the determination of g and g^* later on. In both countries private producers and the public sector compete in equal terms in factor markets.

We proceed to develop the model for the home country; the model for the foreign country follows analogously. Let $v(= v^p + v^g)$ denote the vector of total factor endowments, where v^p and v^g are respectively the vectors of factors used in the production of the private goods and in the public abatement activities. The country's maximum value of production of private goods is denoted by a restricted gross domestic product, or restricted revenue function, $\bar{R}(p, t, v^p)$, defined as:

$$\bar{R}(p, t, v^p) = \max_{x,z}\{p'x - tz : (x, z) \in T(v^p)\},$$

where p is the vector of world commodity prices (exogenously given), $T(v^p)$ is the private sectors aggregate technology set,[10] x is the vector of net outputs, and z is the amount of pollution emission by the private sector (net of the amount abated by the private sector).[11,12]

[9] Henceforth, asterisks denote the variables and functions in the foreign country.

[10] The technology set includes pollution abatement technologies as well as production technologies, in various private sectors, *i.e.* the private sector carries out some abatement of pollution in response to the imposition of an emission tax.

[11] For simplicity, we consider only one type of pollution generated in one or more sectors.

[12] A prime ($'$) denotes a transposed vector or matrix.

Under the assumption of constant returns to scale in public abatement, the cost-minimization problem in the public sector yields a unit cost of abatement function $C^g_w(w)$, where w is the vector of factor prices and is given by

$$w = \bar{R}_{v^p}(p, t, v^p).$$

It is well known from the properties of the unit cost function that the demand for factors of production in the public sector, v^g, is equal to $C^g_w(w)g$ (e.g., see Abe, 1992). Therefore,

$$v^p = v - C^g_w(w)g = v - C^g_w(\bar{R}_{v^p}(p, t, v^p))g.$$

Solving the above equation for v^p, we get $v^p = v^p(p, t, g, v)$, and since p and v do not vary in our analysis, we define the restricted revenue function as

$$R(t, g) = \bar{R}(p, t, v^p(p, t, g, v)).$$

It is well known (e.g. Abe, 1992) that $-R_g[= -(\partial R/\partial g) = C^g(\omega)]$. For the rest of the analysis, for simplicity, we assume that $R_{gg} = 0$.[13] The $R(t, g)$ function is strictly convex in the emission tax rate (*i.e.* $R_{tt} > 0$), meaning that an increase in the emission tax rate lowers the amount of pollution emission by the private sector. It is also known (*e.g.* see Copeland, 1994 and Turunen-Red and Woodland, 1998) that:

$$z = -R_t(t, g). \tag{1}$$

Therefore, taking into account both private and public sector pollution abatement, the net emission of pollution, r, is defined as:

$$r = z - g = -R_t(t, g) - g. \tag{2}$$

[13] This assumption implies that changes in g which change factor supplies available to produce private goods, do not affect its unit cost of production. For example, in a conventional Heckscher-Ohlin model, factor prices are determined by commodity prices and are independent of changes in factor endowments. In such a case, when g changes, $C^g_g = -R_{gg} = 0$ (*e.g.* see Abe, 1992). It is to be noted that most of our results will go through when R_{gg} is not zero (the more general assumption is that $R_{gg} \leq 0$ (see Abe 1995 for the properties of the restricted revenue function when R_{gg} is negative). One of the results will be weakened in its absence and that will be taken up in footnote 24.

We also assume that $R_{tg} > 0$. In view of (1), we have $R_{tg} = -\partial z/\partial g$, and therefore this assumption states that an increase in the publicly provided pollution abatement reduces emission by the private sector. That is, we assume that the pollution abatement and the pollution good are substitutes in production.[14]

As for the public sector, we assume that the government finances the cost of publicly provided pollution abatement (*i.e.* $gC^g = -gR_g(t,g)$) by allocating a fraction, λ, of the revenue raised from emission taxes ($tz = -tR_t(t,g)$) for this purpose. The remaining $(1-\lambda)$ fraction of emission tax revenue is returned to the consumers in a lump-sum fashion.[15] Thus, the government's budget constraint is written as:

$$\lambda tz = -gR_g(t,g). \tag{3}$$

Turning to the demand side of the economy, utility, as previously noted, is adversely affected by both local net pollution, r, and foreign net pollution, r^*, transmitted across borders. Denoting by θ the rate of cross-border pollution into the home country or the spill-over parameter, welfare is adversely affected by the aggregate level of net pollution $\rho = r + \theta r^*$. The expenditure function $E(\rho, u)$ denotes the minimum expenditure required to achieve a given level of utility u at constant commodity prices p.[16] The partial derivative of the expenditure function with respect to u, E_u, denotes the reciprocal of the marginal utility of income. Since pollution adversely affects household utility, the partial derivative of the expenditure function with respect to ρ, E_ρ, is positive and denotes the households' *marginal willingness to pay for a reduction in pollution* (*e.g.* see Chao and Yu, 1999). That is, a

[14] In the two private good case, this occurs when the pollution abatement activity and the pollution generating activity are intensive in the same factor.

[15] For the justification for this specific rule for the funding of public abatement activities, see footnote 5. However, as noted in footnote 6, this assumption is made without loss of generality except in one case (see footnote 20). To be more specific, all but one of our results will go through if public abatement activities were funded entirely from lump-sum taxation of the consumers and the whole of the revenue from emission tax was returned to the consumers in a lump-sum fashion. The reason for this is that the instrument λ effectively acts as lump-sum taxation since the remaining fraction, as just noted, is returned to the consumers in a lump-sum fashion.

[16] For reasons previously noted, the constant commodity prices are omitted from the expenditure function. This formulation of aggregate (additive) level of net pollution, ρ, implicitly assumes that the two countries emit the same pollutant. One could easily generalize the formulation by expressing the expenditure function as $E(r, r^*, u)$. However, this is avoided in the paper as it creates unrewarding complications.

higher level of net pollution requires a higher level of spending on private goods to mitigate its detrimental effects so that a constant level of utility is maintained. The expenditure function is assumed strictly convex in ρ, *i.e.* $E_{\rho\rho} > 0$. That is, a higher level of net pollution raises the households' marginal willingness to pay for its reduction. It is also assumed that $E_{\rho u} > 0$, *i.e.* a higher level of utility increases the households' marginal willingness to pay for pollution abatement.

The budget constraint for the representative consumer requires that private spending $E(\rho, u)$ must equal factor incomes from the production of private goods $R(t, g)$ and that from public abatement activities $(-gR_g(t, g))$, plus the part of emission tax revenue that is returned to the consumers in a lump-sum fashion $((1-\lambda)tz)$. Using (3), the home country's budget constraint is written as:

$$E(\rho, u) = R(t, g) - gR_g(t, g) + (1-\lambda)tz. \tag{4}$$

The model for the foreign country is similarly developed. The equations for the foreign country are:

$$z^* = -R^*_{t^*}(t^*, g^*), \tag{5}$$

$$r^* = z^* - g^* = -R^*_{t^*}(t^*, g^*) - g^*, \tag{6}$$

$$\lambda^* t^* z^* = -g^* R^*_{g^*}(t^*, g^*), \tag{7}$$

$$E^*(\rho^*, u^*) = R^*(t^*, g^*) - g^* R^*_{g^*}(t^*, g^*) + (1-\lambda^*)t^* z^*, \tag{8}$$

where $\rho^* = r^* + \theta^* r$ and θ^* is the rate of cross-border pollution into the foreign country. Equations (1)-(8) constitute a system of eight equations in terms of the eight unknowns, namely $u, u^*, z, z^*, r, r^*, g$ and g^*. The model contains four policy instruments — two for each country, and these are: the emission tax rates (t, t^*) and the fractions (λ, λ^*) of emission tax revenue used to finance public abatement activities.

3 The Nash equilibrium

We begin this section by characterizing the Nash optimal levels of the policy parameters, and then carry out a comparative static exercise. For this end, we differentiate (1)-(8) to obtain the changes in the level of home and foreign country welfare as follows:[17]

$$\Delta du = A_t dt + A_{t^*} dt^* + A_\lambda d\lambda + A_{\lambda^*} d\lambda^*, \quad (9)$$

$$\Delta du^* = B_t dt + B_{t^*} dt^* + B_\lambda d\lambda + B_{\lambda^*} d\lambda^*, \quad (10)$$

where the various coefficients are defined in Appendix B.

Before explaining (9) and (10), we examine how the policy parameters affect the level of net emission in each country. Because of the assumed structural symmetry of the two countries, it suffices to examine the effects in the home country; the expression for the foreign country can be similarly obtained. Differentiating (1)-(3), we get:

$$(R_g - \lambda t R_{tg}) dr = tz(1 + R_{tg}) d\lambda + [(\lambda tr/g) R_{tt} + (\lambda z + g R_{gt})(1 + R_{tg})] dt. \quad (11)$$

Equation (11) indicates that an increase in λ, by increasing government revenue available for public abatement of pollution, unambiguously increases public abatement of pollution g and thus reduces local pollution. This increase in g in turn reduces private emission of pollution z, since $R_{tg} > 0$. On one hand, an increase in t reduces pollution emission by private producers. On the other hand, this reduction in pollution emission by private producers reduces the tax base for the provision of public abatement. The net effect of an increase in t on r is therefore *a priori* ambiguous. However, as it happens, the direct effect dominates the indirect effect via changes in tax revenue, and an increase in t unambiguously reduces net emission. Note that (1) and (3) alone determine the equilibrium values for g and z, and therefore r is independent of the policy parameters in the foreign country, *i.e.*

[17] Appendix A sets up the matrix system of changes in the variables of the model.

$dr/dt^* = dr/d\lambda^* = 0$. Similarly, for the foreign country, an increase in either λ^* or t^* reduces r^*. Furthermore, $dr^*/dt = dr^*/d\lambda = 0$.

Turning to the effects on the level of welfare in the home country ((9)), an increase in t, as noted before, unambiguously reduces net emission and thus, *ceteris paribus*, raises welfare. However, an increase in t reduces the representative consumer's lump-sum income by, for example, reducing pollution tax revenue for a given t. The net effect on welfare is therefore ambiguous.

An increase in λ increases public abatement and therefore reduces pollution. However, it also has a negative income effect as it implies a lower lump-sum transfer (out of emission tax revenue) to the consumers. Therefore, the net effect of a change in λ on welfare in also ambiguous. An increase in t^* or in λ^* unambiguously improves home welfare via reduced cross-border pollution, *i.e.* by reducing emission in the foreign country. Finally, as shown by the expression A_θ, an increase in the rate of cross-border pollution into the home country reduces its welfare. The effects on welfare in the foreign country can be similarly explained.

Having explained the welfare equations, we can now characterize the non-cooperative Nash optimal levels of the policy instruments. That is, when the two countries choose respectively the levels of (t, λ) and(t^*, λ^*) simultaneously by maximizing their respective welfare, with each country treating the other's policy parameters as given. The first order conditions are given by:

$$\Delta(du/dt) = A_t = 0, \quad (12)$$

$$\Delta(du/d\lambda) = A_\lambda = 0, \quad (13)$$

$$\Delta(du^*/dt^*) = B_{t^*} = 0, \quad (14)$$

$$\Delta(du^*/d\lambda^*) = B_{\lambda^*} = 0. \quad (15)$$

Equations (12) to (15) give the best response functions and simultaneously determine the optimal (Nash) values of the policy instruments in the two countries. Manipulating the equilibrium conditions $A_t = A_\lambda = 0$, for the home country, and $B_{t^*} = B_{\lambda^*} = 0$ for the foreign country, we obtain the following optimality conditions:

$$t = E_\rho \quad = \quad -R_g, \tag{16}$$

$$t^* = E^*_{\rho^*} \quad = \quad -R^*_{g^*}. \tag{17}$$

Recognizing the fact that pollution is a 'public bad' and its abatement is a public good, it is interesting to note that the optimality conditions (16) and (17) combine the Samuelson rule for the optimal provision for public goods in a closed economy without distortionary taxes with the Pigouvian rule for environmental taxation. The first equality in the optimality conditions (16) and (17) gives the Pigouvian rule, *viz.* that the marginal willingness to pay for pollution abatement is equal to emission tax rate. The second equality gives the Samuelsonial rule, *viz.* that the marginal willingness to pay for a public good is equal to the marginal cost of producing it. Here, we are able to simultaneously satisfy the two rules because the instruments λ and λ^* to some degree function as lump-sum taxes for the financing of public abatement (see footnote 15).

We conclude this section by performing a simple comparative static exercise in order to highlight the working of our model. For this, we assume that one of the countries, *viz.* the foreign, is passive in the sense that it does not choose its policy instruments optimally, *i.e.* (17) does not apply and t^* and λ^* are exogenous. Under this assumption, we examine how a change in θ, the rate of cross-border pollution into the home country or the spill-over parameter, affects the Nash values of the country's policy instruments (t, λ). In other words, we examine how the best-response functions (12)-(15) respond to changes in the spill-over parameter, resulting in a new Nash equilibrium.

Differentiating the best response functions given by (12) and (13) and setting $dt^* =$

$d\lambda^* = 0$, we obtain:

$$A_{tt}dt + A_{t\lambda}d\lambda = -A_{t\theta}d\theta, \quad (18)$$

$$A_{\lambda t}dt + A_{\lambda\lambda}d\lambda = -A_{\lambda\theta}d\theta, \quad (19)$$

where the coefficients are defined in Appendix C. From (18) and (19) we obtain the following:

$$dt^o/d\theta = \Omega_1^{-1}[-A_{\lambda\lambda}A_{t\theta} + A_{t\lambda}A_{\lambda\theta}] = H_1 E_\rho(\eta - \zeta)r^*(\rho r)^{-1}, \quad (20)$$

$$d\lambda^o/d\theta = \Omega_1^{-1}[-A_{tt}A_{\lambda\theta} + A_{\lambda t}A_{t\theta}] = H_2 E_\rho(\eta - \zeta)r^*(\rho r)^{-1}, \quad (21)$$

where the coefficients are defined in Appendix D and η is the home country's marginal propensity to pay for pollution abatement, ζ is the elasticity of the marginal willingness to pay for pollution abatement with respect to the aggregate level of net pollution, and the superscript 'o' denotes the optimal levels of the policy instruments.

Observing (20) and (21), we note that the optimal values of both instruments increase with θ if and only if $\eta < \zeta$. Intuitively, an increase in θ exerts two effects on utility. First, an increase in θ reduces utility and therefore the marginal willingness to pay for pollution abatement, and this in turn lowers the optimal (Nash) values of the emission tax rate and of the fraction of emission tax revenue used for public sector abatement activities. We call this an *income effect* which is represented by the variable η defined above. Second, an increase in θ directly increases the marginal willingness to pay for pollution abatement and this raises the Nash values of t and λ. We call this the *direct effect*, represented by the variable ζ. If the *income effect* dominates the *direct effect*, then a higher θ reduces the Nash values for both t and λ.

Having characterized the optimal values of the policy instruments and having carried out a comparative static exercise, we now consider the issue of multilateral reforms of the policy instruments, starting from the point where these are set at their Nash optimal levels.

4 Multilateral policy reforms

In this section we analyze the welfare and environmental implications of multilateral policy reforms. We consider a number of scenarios depending on the scope of such reforms. In each case, however, we assume that the initial values of the policy instruments are at their Nash optimal levels so that it is only the international externalities of the policy instruments (via changes in cross-border pollution) that are present in the welfare equations. That is:

$$\Delta du = A_{t^*} dt^* + A_{\lambda^*} d\lambda^*, \tag{22}$$

$$\Delta du^* = B_t dt + B_\lambda d\lambda. \tag{23}$$

It will be convenient to express changes in welfare in terms of changes in emission levels. Totally differentiating (4) and using (1)-(3), it can be shown that, when the initial equilibrium is at the Nash optimum level,

$$E_u \; du = -\theta E_\rho dr^*, \tag{24}$$

and similarly, for the foreign country,

$$E^*_{u^*} \; du^* = -\theta^* E^*_{\rho^*} dr. \tag{25}$$

That is, changes in welfare in a country depend *only* on changes in the level of cross-border pollution into the country. In particular, an increase in net pollution in one country unambiguously reduces welfare in the other country via an increase in the level of cross-border pollution. Note that own-country pollution does not affect welfare as, at the Nash optimum, it is only the international externalities that matter.

We start with a benchmark case in which we examine the effects on the levels of individual national welfare and net pollution when the two countries decide to raise both instruments —emission tax rate and fraction of tax revenue allocated for public abatement. Since the two countries are symmetric in structure, we derive explicitly only the effects for the home country, and simply state the analogous effect for the foreign country.

4.1 Comprehensive reforms

In this reform programme, we consider a multilateral agreement which amounts to $dt > 0, d\lambda > 0, dt^* > 0$, and $d\lambda^* > 0$. Because of (24) and (25), it suffices to examine the effects on net pollution levels.

Using the optimality conditions (17), from (11) we obtain:

$$dr/dt = (R_g - \lambda t R_{tg})^{-1} K_2 < 0, \tag{26}$$

$$dr/d\lambda = (R_g - \lambda t R_{tg})^{-1} tz(1 + R_{tg}) < 0. \tag{27}$$

That is, the reform considered in this subsection unambiguously lowers net emission levels in both countries and therefore increases welfare in both countries. Formally, these results are stated as a proposition.

Proposition 1 *A multilateral increase of all policy instruments* (t, λ, t^* *and* λ^*) *from their Nash values raises national welfare and reduces net pollution in both countries.*

Intuitively, the Nash equilibrium is characterized by the well-known inefficiency of over-provision of a public bad. Therefore, any multilateral policy initiative that reduces this inefficiency improves welfare levels.

4.2 Partial reforms

In this subsection we consider the case where the multilateral negotiations are restricted to only one policy instrument, *viz.* emission taxes. Moreover, once agreements on emission taxes are made, we assume that the countries are free to adjust the other instrument, the fractions of emission tax revenue allocated to public abatement practices, *i.e.* λ and λ^*, to achieve selfish interests. We consider in turns two alternative rules for the national governments for adjusting the fraction of tax revenue allocated to public abatement activities: (i) public abatement neutrality, *i.e.* the two governments keep funds available for public abatement, evaluated at the initial level of emission, at the same level as before the reform, and (ii) optimality in adjustment, *i.e.* the two countries adjust optimally their other instrument (λ, λ^*).[18,19]

4.2.1 Public abatement neutrality

In the present case, we assume that having agreed multilaterally to increase emission taxes, the two countries adjust the values of the fractions of tax revenue allocated to public abatement so that total funds allocated for public abatement, *i.e.* λtz and $\lambda^* t^* z^*$ respectively for each country, remain constant at the initial levels of emission z and z^*.[20] That is, for a given dt and dt^*, the home and the foreign governments choose $d\lambda$ and $d\lambda$ respectively such that[21]

$$(\lambda dt + t d\lambda)z = 0, \quad \text{and} \quad (\lambda^* dt^* + t^* d\lambda^*)z^* = 0,$$

which can be simplified to:

$$d\lambda = -(\lambda/t)dt, \quad \text{and} \quad d\lambda^* = -(\lambda^*/t^*)dt^*, \tag{28}$$

where $dt > 0$ and $dt^* > 0$.

The effect of the above tax reform on net pollution in the two countries is calculated from (11) and its counterpart for the foreign country, as:

$$dr/dt = (\partial r/\partial t) + (\partial r/\partial \lambda)(d\lambda/dt) = (R_g - \lambda t R_{tg})^{-1} K_3 < 0, \tag{29}$$

$$dr^*/dt^* = (\partial r^*/\partial t^*) + (\partial r^*/\partial \lambda^*)(d\lambda^*/dt^*) = (R^*_{g^*} - \lambda^* t^* R^*_{t^* g^*})^{-1} K^*_3 < 0, \tag{30}$$

[18] This analysis is comparable to that of Copeland (1990) where he examines the strategic interactions in trade policies to implement a pre-determined level of protection. Here t and t^* are analogous to Copeland's negotiable trade instruments and λ and $\lambda^*$are analogous to his non-negotiable trade instruments. In the present case, the environmental policy instruments are used to maintain pollution emissions at their initial level in each country.

[19] Alternatively, we could consider a situation where the multilateral agreements are made on public abatement and countries are free to adjust emission taxes. The qualitative nature of the results will go through under this alternative scenario (see footnotes 21 and 23).

[20] This exercise is not meaningful when public abatement activities are financed by lump-sum taxation of the consumers. This is the exception mentioned in footnotes 6 and 15.

[21] Equivalently, one can consider the problem where for given $d\lambda$ and $d\lambda^*$, the home and the foreign governments choose dt and dt^* respectively so as to satisfy the following equations.

where $K_3 = (\lambda tr/g)R_{tt} + (1+R_{tg})gR_{gt} > 0$ and K_3^* is defined analogously. In (29) the terms $\partial r/\partial t$ and $\partial r/\partial\lambda$ are obtained from (11), and $d\lambda/dt$ is given by (28). Similarly, the terms $\partial r^*/\partial t^*$ and $\partial r^*/\partial\lambda^*$ can be obtained by considering the parallel equations for the foreign country. Equations (29) and (30) indicate that the present policy reform unambiguously reduces net emission levels in both countries, and therefore, because of (24) and (25), it increases welfare levels in both countries.[22] These results are formally stated as:

Proposition 2 *Consider a multilateral increase of the emission tax rates t and t^* from their Nash optimal levels, while the national governments adjust λ and λ^* to maintain the level of funds allocated for public sector abatement, at the initial equilibrium level of gross pollution in each country. This reform — which involves an increase in private sector abatement and a decrease in the public sector one — unambiguously improves welfare and reduces the level of net pollution in both countries.*

4.2.2 Optimality in adjustment

In this case, we assume that the two countries, upon agreeing to multilateral reforms of the emission tax rates t and t^*, adjust optimally their respective second instrument, λ and λ^*, the fraction of tax revenue used for public sector abatement activities. Specifically, we assume that the home country and the foreign country use the optimality conditions $A_\lambda = 0$ and $B_{\lambda^*} = 0$ respectively to adjust the second policy instrument.[23] This gives

$$dA_\lambda = 0 \implies d\lambda = -A_{\lambda\lambda}^{-1}A_{\lambda t}dt, \tag{31}$$

$$dB_{\lambda^*} = 0 \implies d\lambda^* = -B_{\lambda^*\lambda^*}^{-1}B_{\lambda^* t^*}dt^*, \tag{32}$$

[22] This is not to say that restricting the scope of a multilateral reform programme to a subset of instruments (leaving the countries to adjust the other instruments in an unrestricted fashion) has no cost. In fact, a partial reform of the types considered in this paper will always be less beneficial compared to a situation where the countries are not allowed to adjust the other instruments. What this results tells us is that the freedom to adjust other instrument according to the present rule will not eliminate *completely* the benefit of a reform of emission taxes alone.

[23] Alternatively, we could consider the scenario that the two countries, upon agreeing to multilateral reforms of public abatements λ and λ^*, adjust optimally their respective second instrument t and t^*. For this, the two countries will need to use the optimality conditions $A_t = 0$ and $B_{t^*} = 0$ respectively to adjust the second policy instrument. For the sake of brevity, we do not present the results for this scenario.

where $A_{\lambda\lambda}$ and $A_{t\lambda}$ are defined in appendix C and

$$\begin{aligned} B_{\lambda^*\lambda^*} &= -(R^*_{g^*} - \lambda^* t^* R^*_{t^*g^*})^{-1} K_1 [t^* z^* (1 + R^*_{t^*g^*})]^2 E^*_{\rho^*\rho^*} < 0, \\ B_{\lambda^* t^*} &= -(R^*_{g^*} - \lambda^* t^* R^*_{t^*g^*})^{-1} K_1 K^*_2 t^* z^* (1 + R^*_{t^*g^*}) E^*_{\rho^*\rho^*} < 0, \\ K_1 &= E_u (R_g - \lambda t R_{tg}) < 0, \\ K^*_2 &= t^*(1-\lambda^*) R^*_{t^*t^*} + (1 + R^*_{t^*g^*})(\lambda^* z^* + g^* R^*_{g^*t^*}) > 0. \end{aligned}$$

Substituting the above expressions in (11) and its foreign counterpart, we obtain:

$$\begin{aligned} dr/dt &= (\partial r/\partial t) + (\partial r/\partial \lambda)(d\lambda/dt) \\ &= (R_g - \lambda t R_{tg})^{-1} K_2 - (R_g - \lambda t R_{tg})^{-1} K_2 = 0, \end{aligned} \tag{33}$$

$$\begin{aligned} dr^*/dt^* &= (\partial r^*/\partial t^*) + (\partial r^*/\partial \lambda^*)(d\lambda^*/dt^*) \\ &= (R^*_{g^*} - \lambda^* t^* R^*_{t^*g^*})^{-1} K^*_2 - (R^*_{g^*} - \lambda^* t^* R^*_{t^*g^*})^{-1} K^*_2 = 0. \end{aligned} \tag{34}$$

Equations (33) and (34) (and (24) and (25)) indicate that, the present reform has no effect whatsoever on net emission and utility levels in either country. To see why this is the case, consider the effects for the home country (*i.e.* (33) and (24)). An increase in the tax rate reduces emission by the private sector (z), and thus exerts a negative impact on net emission (*i.e.* $\partial r/\partial t < 0$). From (31) it is clear that the adjustment is such that λ is reduced due to the increase in t. As a result, total funds available for public sector abatement activities are reduced on two counts: (i) a reduction in the tax base due to a reduction in z, and (ii) a reduction in funds allocated for public sector abatement due to a reduction in λ. These two effects reinforce each other and the level of public sector abatement goes down and thus raising net emission. The two opposing effects of the policy reform on net emission r cancel each other out.[24] That is, the ability of the countries to adjust an

[24] When R_{gg} is not necessarily equal to zero but is less than or equal to zero (see footnote 13), it can be derived that

$$\left[(1+R_{tg})^2 E_{\rho\rho} - R_{gg}\right] \Omega \frac{dr}{dt} = R_{tt} R_{gg} \left[-\frac{rt}{z} + g R_{gg} - \lambda t (1 + R_{tg})\right].$$

That is, $dr/dt < 0$ if $R_{gg} < 0$ and $dr/dt = 0$ if $R_{gg} = 0$. This result is explained below in footnote 25.

instrument not covered by multilateral agreements *completely* offsets the beneficial effect of increases in emission taxes. This is because at the optimum the two instruments are perfect substitutes in our model. On the benefit side, one unit extra abatement in either the private sector or the public one reduces emission by the same amount. On the cost side, at the optimum, the marginal cost of abatement in the public sector is equal to the marginal cost of abatement in the private sector (which, for profit maximizing firms, must be equal to the emission tax rate t: the marginal benefit of abatement in the private sector). Furthermore, since the marginal cost of abatement in the public sector is constant when $R_{gg} = 0$, the slopes of the marginal costs of abatement in private and the public sectors are the same and equal to zero. Therefore, a small increment away from the equilibrium does not have any effect on net pollution.[25]

These results are formally stated in the following proposition.

Proposition 3 *Consider a multilateral increase of the emission tax rates t and t^* from their Nash optimal levels, while the national governments adjust λ and λ^* optimally. This reform has no effect on the levels of national welfare and of net pollution.*

A policy implication of the above proposition is that if the scope of multilateral policy reform is limited in the sense it applies only to a subset of instruments — as it is often the case, and the individual countries are free to adjust the remaining instruments after the reforms, then the beneficial effects of such reforms can be seriously undermined.

5 Reform policy towards the second-best

In this section, unlike the previous one, we assume arbitrary initial values for the policy instruments $(t, \lambda, t^*, \lambda^*)$, and then we consider the reform exercises that take the values of all

[25] When $R_{gg} < 0$, the slope of marginal cost in the public sector is positive (note that $-R_g$ is the marginal cost in the public sector), but that in the private sector is still zero, and therefore the reduction in public abatement does not fully offset the increase in private abatement and there is a net reduction in emission (see footnote 22).

policy instruments towards the second-best levels. In particular, we consider the following reform program:

$$dt = -b_1[t - t^o(t, t^*, \lambda, \lambda^*)] \quad \text{and} \quad d\lambda = -b_2[\lambda - \lambda^o(t, t^*, \lambda, \lambda^*)] \tag{35}$$

$$dt^* = -b_1^*[t^* - t^{*o}(t, t^*, \lambda, \lambda^*)] \quad \text{and} \quad d\lambda^* = -b_2^*[\lambda^* - \lambda^{*o}(t, t^*, \lambda, \lambda^*)], \tag{36}$$

where $b_1,\ b_2,\ b_1^*$ and b_2^* are positive scalars, and $(t^o, \lambda^o, t^{o*},\ \lambda^{o*})$ represent the shadow values of the policy instruments obtained from (12) and (13) for the home country, and from (14) and (15) for the foreign country,[26] and defined as

$$\lambda^0(t, t^*, \lambda, \lambda^*) = \frac{g[E_\rho + (E_\rho - t)R_{tg}]}{tz}, \tag{37}$$

$$t^0(t, t^*, \lambda, \lambda^*) = E_\rho + \frac{(\lambda t R_{tt} - \lambda z - gR_{tg})(E_\rho + R_g)}{R_g R_{tt} - (\lambda t + gR_{gt})R_{tg}}, \tag{38}$$

$$\lambda^{*o}(t, t^*, \lambda, \lambda^*) = \frac{g^*[E_{\rho^*}^* + (E_{\rho^*}^* - t^*)R_{t^*g^*}^*]}{t^* z^*}, \tag{39}$$

$$t^{*o}(t, t^*, \lambda, \lambda^*) = E_{\rho^*}^* + \frac{(\lambda^* t^* R_{t^*t^*}^* - \lambda^* z^* - g^* R_{t^*g^*}^*)(E_{\rho^*}^* + R_{g^*}^*)}{R_{g^*} R_{t^*t^*}^* - (\lambda^* t^* + g^* R_{g^*t^*}^*)R_{t^*g^*}^*}. \tag{40}$$

The above reform program requires that the values of the policy instruments are raised (lowered) if their initial levels are lower (higher) than the respective second-best levels.

Using (3), (12)-(15) and (37)-(40), we obtain from (9) and (10):

$$\Delta\ du = -c_1(t - t^o)\ dt - c_2(\lambda - \lambda^o)\ d\lambda + A_{t^*}\ dt^* + A_{\lambda^*}\ d\lambda^*, \tag{41}$$

$$\Delta\ du^* = -c_1^*(t^* - t^{*o})\ dt^* - c_2^*(\lambda^* - \lambda^{*o})\ d\lambda^* + B_t\ dt + B_\lambda\ d\lambda, \tag{42}$$

where

$$c_1 = (R_g R_{tt} - (\lambda t + gR_{gt})R_{gt})K_1^* > 0, \quad c_2 = -(K_1^*(tz)^2)/g > 0,$$

$$c_1^* = (R_{g^*}^* R_{t^*t^*}^* - (\lambda^* t^* + g^* R_{g^*t^*}^*)R_{g^*t^*}^*)K_1 > 0, \quad c_2^* = -(K_1(t^* z^*)^2)/g^* > 0.$$

[26]This concept of shadow values is used extensively in the literature (see, for example, Copeland (1994), Neary (1995) and Turunen-Red and Woodland (1998)).

Substituting (35) and (36) into (41) and (42), the induced welfare changes are given by:[27]

$$du = b_1c_1(t-t^o)^2 + b_2c_2(\lambda-\lambda^o)^2 + A_{t^*}dt^* + A_{\lambda^*}d\lambda^*, \tag{43}$$

$$du^* = b_1^*c_1^*(t^*-t^{*o})^2 + b_2^*c_2^*(\lambda^*-\lambda^{*o})^2 + B_tdt + B_\lambda d\lambda. \tag{44}$$

The above equations clearly indicate that the effects of reforms of own policy instruments — given by the first two terms in (43) and (44)— are positive. In contrast, since A_{t^*}, A_{λ^*}, B_λ and B_t are unambiguously positive, the international externality effects — given by the last two terms in (43) and (44)— are ambiguous. This is because the reform rules do not make any specific directional recommendation. However, sufficient conditions for these effects to be positive are that initial values the policy instruments are below their second-best levels, *i.e.* $t^o \geq t$ and $\lambda^o \geq \lambda$, $t^{*o} \geq t^*$, $\lambda^{*o} \geq \lambda^*$. Formally,

Proposition 4 *In the presence of cross-border pollution, a multilateral reform of environmental policy instruments towards the second-best is strictly Pareto improving if the initial values of the policy instruments are below their second-best levels.*

We conclude this section by noting that Copeland (1994) also considered environmental policy reforms towards the second best for a small open economy with both trade and pollution distortions but without any international externality and public abatement. He found that equiproportional reforms of pollution taxes towards the second best, in the presence or absence of tariffs, is always welfare improving.[28,29] In contrast, we consider a two-country model with international externality and public abatement of pollution, in which we

[27] It is to be noted that $(t-t^o), (\lambda-\lambda^o), (t^*-t^{*o})$ and $(\lambda^*-\lambda^{*o})$ are called the shadow premia of the policy instruments (see, for example, Neary (1995)).

[28] Contrary to Copeland (1994) where interactions among multiple trade and pollution distortions provide the key ingredient, in the present two-country model it is cross-border pollution that drives the results.

[29] Turunen-Red and Woodland (1998) consider concertina and proportional reforms (as opposed to reforms towards the second best) in a very general setup with many countries, endogenous terms of trade, and transboundary pollution, albeit not with public abatement. They derive conditions under which the tax reforms are potentially Pareto improving, *i.e.* strictly Pareto improving in the presence of international transfers.

have two different types environmental policies present simultaneously. In this context, we show that in the presence of international externalities reforms towards the second best of either one type or both types of environmental policies may not increase welfare in either of the two countries. Note that the dependence of welfare in one country on policy instruments of the other country (the last two terms in equations (43) and (44)) makes the welfare effects of multilateral policy reforms ambiguous. The first two positive terms in the two equations reflect the positive impact of the reforms on own-country welfare.

6 Conclusion

Undisputably, the problem of pollution is a global one and its reduction requires a global approach. Pollution generated in one country often has far reaching implications for other countries. With these in mind, the international community has been very active in recent years organizing international meetings such as in Kyoto and Johannesburg to come up with commitments by individual countries to reduce pollution emission.

These developments in the policy arena have been accompanied by academic research on the subject and there is now a small theoretical literature that analyses the implications of multilateral reforms of environmental policies. However, with one exception, this literature does not acknowledge the fact that often the private and the public sectors complement each other in abating pollution.

Motivated by such deficiencies in the literature, we develop a two-country model where production generated pollution is emitted across borders, and pollution abatement is undertaken both by private and public sectors of each country. An important feature of the present model, not widely used in the relevant literature despite the existence of substantial empirical evidence, is that part of the emission tax revenue is earmarked to finance the public sector pollution abatement. The analysis characterizes the Nash optimal rates of the policy instruments in each country (*viz.*, the emission tax rate and the fraction of emission tax revenue allocated to public abatement), and examines the environmental and welfare implications of several multilateral policy reforms.

The policy implication emerging from the analysis is that multilateral policy reforms can raise national welfare and reduce net pollution in both countries. However, the beneficial effects of such reforms can be undermined if the reforms are restricted to a subset of policy instruments, *i.e.* while a country agrees to tighten one of instruments multilaterally, it is free to adjust the other instruments for selfish motives. Furthermore, in the presence of international spill-over of pollution, a move towards the non-cooperative optimal level of the instruments may not always be welfare improving.

Appendix A: The Matrix System of Changes in Variables

Total differentiation of (2) to (7) yields the following system of equations:

$$\begin{bmatrix} E_u & 0 & [E_\rho-(1-\lambda)t] & \theta E_\rho & -E_\rho & -\theta E_\rho \\ 0 & E^*_{u^*} & \theta^* E^*_{\rho^*} & [E^*_{\rho^*}-(1-\lambda^*)t^*] & -\theta^* E^*_{\rho^*} & -E^*_{\rho^*} \\ 0 & 0 & 1 & 0 & R_{tg} & 0 \\ 0 & 0 & 0 & 1 & 0 & R^*_{t^*g^*} \\ 0 & 0 & \lambda t & 0 & R_g & 0 \\ 0 & 0 & 0 & \lambda^* t^* & 0 & R^*_{g^*} \end{bmatrix} \begin{bmatrix} du \\ du^* \\ dz \\ dz^* \\ dg \\ dg^* \end{bmatrix} =$$

$$\begin{bmatrix} -tz \\ 0 \\ 0 \\ 0 \\ -tz \\ 0 \end{bmatrix} d\lambda + \begin{bmatrix} 0 \\ -t^*z^* \\ 0 \\ 0 \\ 0 \\ -t^*z^* \end{bmatrix} d\lambda^* + \begin{bmatrix} -(\lambda z + gR_{gt}) \\ 0 \\ -R_{tt} \\ 0 \\ -(\lambda z + gR_{gt}) \\ 0 \end{bmatrix} dt$$

$$+ \begin{bmatrix} 0 \\ -(\lambda^* z^* + g^* R^*_{g^*t^*}) \\ 0 \\ -R^*_{t^*t^*} \\ 0 \\ -(\lambda^* z^* + g^* R^*_{g^*t^*}) \end{bmatrix} dt^* + \begin{bmatrix} -r^* E_\rho \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} d\theta + \begin{bmatrix} 0 \\ -rE^*_{\rho^*} \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} d\theta^*$$

Appendix B: The Coefficients in Equations (9) and (10)

$$\begin{aligned} \Delta &= E_u E^*_{u^*}(R_g - \lambda t R_{tg})(R^*_{g^*} - \lambda^* t^* R^*_{t^*g^*}) > 0, \\ A_t &= K^*_1\{(\lambda t R_{tt} - \lambda z - gR_{gt})(E_\rho + R_g) + [R_g R_{tt} - (\lambda z + gR_{gt})R_{tg}](E_\rho - t)\}, \\ A_{t^*} &= -E^*_{u^*}(R_g - \lambda t R_{tg})[(\lambda^* t^* r^*/g^*)R^*_{t^*t^*} + (1 + R^*_{t^*g^*})(\lambda^* z^* + g^* R^*_{g^*t^*})]\theta E_\rho > 0, \\ A_\lambda &= -K^*_1 tz[(E_\rho + R_g) + (E_\rho - t)R_{tg}], \\ A_{\lambda^*} &= -E^*_{u^*}(R_g - \lambda t R_{tg})t^* z^*(1 + R^*_{t^*g^*})\theta E_\rho > 0, \\ K^*_1 &= E^*_{u^*}(R^*_{g^*} - \lambda^* t^* R^*_{t^*g^*}) < 0. \end{aligned}$$

$B_{t^*}, B_{\lambda^*}, B_t, B_\lambda$ and K_1 are similarly defined.

Appendix C: The coefficients in equations (18) and (19).

Using (16) we have:[30]

$$
\begin{aligned}
A_{tt} &= -K_1^*(R_g - \lambda t R_{tg})^{-1}[(R_g - \lambda t R_{tg})^2 R_{tt} + K_2^2 E_{\rho\rho}] < 0, \\
A_{t\lambda} &= A_{\lambda t} = -K_1^* K_2 (R_g - \lambda t R_{tg})^{-1} tz(1 + R_{tg}) E_{\rho\rho} < 0, \\
A_{t\theta} &= K_1^* K_2 r^* (E_\rho E_{\rho u} E_u^{-1} - E_{\rho\rho}), \\
A_{\lambda\lambda} &= -K_1^*(R_g - \lambda t R_{tg})^{-1}[tz(1 + R_{tg})]^2 E_{\rho\rho} < 0, \\
A_{\lambda\theta} &= K_1^* tz(1 + R_{tg}) r^* (E_\rho E_{\rho u} E_u^{-1} - E_{\rho\rho}), \\
K_2 &= t(1 - \lambda) R_{tt} + (1 + R_{tg})(\lambda z + g R_{gt}) > 0.
\end{aligned}
$$

Appendix D: The coefficients in equations (20) and (21).

$$
\begin{aligned}
\Omega_1 &= [K_1^* tz(1 + R_{tg})]^2 R_{tt} E_{\rho\rho} > 0, \\
H_1 &= [K_1^*(R_g - \lambda t R_{tg})(1 + R_{tg}) R_{tt}]^{-1} K_2 r^* R_{tg} < 0, \\
H_2 &= [tz(1 + R_{tg}) E_{\rho\rho}]^{-1} r^* (R_g - \lambda t R_{tg}) < 0, \\
\eta &= E_{\rho u}(\rho / E_u) > 0, \quad \text{and} \qquad \zeta = E_{\rho\rho}(\rho / E_\rho) > 0,
\end{aligned}
$$

[30]Since all our analysis are around the Nash equilibrium, these coefficients are defined at that equilibrium.

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