Cross-border Pollution, Capital Mobility and Efficient Decentralized Environmental Policies

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Abstract
We construct a general equilibrium model of two regions with cross-border pollution and capital mobility. Within this framework, we examine the efficiency of decentralized (non-cooperative) policymaking when regions are small or large in capital markets. It is shown that when regions are small, the decentralized policymaking yields a Pareto efficient outcome, regardless of the environmental policy instruments that regions choose to control pollution. When regions are large, efficiency critically depends on the applied instrument of environmental policy.

Keywords: Cross-border Pollution, International Capital Mobility, Optimal Taxation

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1. Introduction

A dominant current policy debate is that in the presence of cross-border pollution, such as greenhouse gas emissions, decentralized policymaking can lead to socially inefficient outcomes. Related to this, countries engaging in international competition due to deeper economic integration in capital and commodity markets have incentive to relax environmental standards.

Oates and Schwab (1988), in a seminal contribution, challenge the “conventional wisdom” of race to the bottom in environmental policies as a result of non-cooperative policy behavior. In a model with many small jurisdictions and local pollution, decentralized policymaking can achieve efficient resource allocation, and if jurisdictional capital taxes are optimally chosen, then the local governments set emissions standards efficiently. Ogawa and Wildasin (2009), here on (OW) confirm the Oates and Schwab (1988) result of efficient resource allocation in the case of transboundary pollution. In their model regions are small and use, in a non-cooperative way, capital taxes to control pollution.¹

Our paper examines the efficiency of decentralized (non-cooperative) policymaking in the presence of international externalities, such as capital mobility and cross-border pollution. Along the lines of the aforementioned studies, pollution is related to supply of capital in a region. We raise the following consideration. Can decentralized environmental policymaking be efficient, when regions are large in capital markets and can influence the net return to capital? It is shown, that when regions use either capital or emission taxes to control pollution, then non-cooperative policymaking fails to achieve a Pareto efficient outcome. When regions use emission permits to control pollution, either intra-regionally or inter-regionally tradable, then non-cooperative policymaking leads to an efficient outcome. In the benchmark case where regions are small, non-cooperative policy making always lead to an efficient outcome, regardless of the applied environmental policy instrument. Thus, in this paper we show that the OW analysis holds also when emission taxes or emission permits, either intra-regionally or inter-regionally tradable, are used to control pollution. However, when regions are large then efficiency critically depends on the applied instrument of environmental policy. It is shown that when either intra-regionally

¹ Eichner and Runkel (2012), in a two period model of many jurisdictions and inter-regionally capital mobility, show how the elasticity of capital supply with respect to the net rate of return to capital can affect the decentralized policy equilibrium. Fell and Kaffine (2014) in a static model with many jurisdictions, capital mobility and inter-jurisdictional pollution show that in the presence of “capital retirement” the decentralized policy outcome generally differs from the solution of a centralized planner’s social welfare-maximizing problem.
or inter-regionally tradable emission permits are implemented for controlling pollution, then the Nash equilibrium outcome is a Pareto efficient outcome.

2. The Model
We consider a general equilibrium model of two regions, Home and Foreign. Both regions produce, consume and trade freely many goods. In each region prices of goods are assumed fixed. Capital is freely mobile inter-regionally, while all other factors of production are inter-regionally immobile; factor and commodity markets in both regions are perfectly competitive.

The production side of the two regions is represented by the Gross Domestic Product (GDP) function. For Home, this function is depicted by \( R(p, t, K) \) and captures the maximum value of production, at commodity prices \( p \) and the emission tax \( t \). The GDP function is written as \( R(t, K) \) where commodity prices are omitted since they are constant throughout the analysis. Similarly, Foreign’s GDP function is defined as \( R^*(t^*, K^*) \). \( K = \bar{K} + k \) is the amount of capital operating in Home, and \( k > 0 \) is the amount of Foreign capital operating in Home. \( \bar{K} (\bar{K}^*) \) denotes Home’s (Foreign's) capital endowment. Hereon, an (*) denotes Foreign’s variables. \( R_k (= \partial R / \partial K) \) denotes the marginal revenue product of capital. The production of goods generates pollution emission. The level of pollution \( z \) is given by \( z = -R_t (t, K) = aK \). We assume that \( R(t, K) \) is strictly concave in \( K \), i.e., \( R_{kk} < 0 \), and strictly convex in \( t \), i.e., while \( R_{tk} < 0 \). The latter assumption implies that a higher emission tax lowers the amount of pollution.\(^2\) Equivalently, \( R_k^*(t^*, K^*) \) denotes the marginal revenue product of capital in Foreign and \( z^* = -R_t^*(t^*, K^*) = aK^* \) denotes the level of Foreign generated pollution and \( R_{tk}^* < 0 \).

Production generated pollution is transmitted across countries, affecting negatively the utility of residents in both. Overall pollution in Home (\( \rho \)) and in Foreign (\( \rho^* \)) consists of pollution locally generated and of pollution transmitted across borders from the other country. With \( 0 \leq \beta \leq 1 \), we denote the rates of cross-border pollution transmitted from Foreign to Home and vice-versa. For simplicity, we assume that production pollution is related with the use of

\(^2\) A higher emission tax reduces production and production generated pollution.
capital employed in each country, such that one unit of production generates $z = aK$ units of pollution in Home and $z^* = aK^*$ in Foreign. Thus, we define:

$$
\rho = z + \beta z^*, \quad \rho^* = z^* + \beta z.
$$

(1)

$$
d\rho = \alpha(1 - \beta)dK, \quad d\rho^* = -\alpha(1 - \beta)dK.
$$

(2)

Each country comprises identical individuals whose utility is adversely affected by pollution. Home’s demand side is represented by the minimum expenditure function, $E(\rho, u)$, capturing a representative individual’s minimum expenditure on goods required to attain a given level of utility, $u$, at the constant commodity prices, omitted from the analysis, and overall pollution in the country, $\rho$. The partial derivatives $E_u = \partial E / \partial u$ and $E_\rho = \partial E / \partial \rho$, respectively, give the reciprocal of the marginal utility of income normalized to equal to one i.e., $E_u = 1$, and the household’s marginal willingness to pay for reduction in pollution or marginal environmental damage. $E_\rho$ is positive since pollution is a public bad. Similarly, Foreign’s minimum expenditure function is given by $E^*(\rho^*, u^*)$.

Equilibrium in capital market requires that the net of tax returns on capital are the same between regions:

$$
R_k(t, K) - \tau = R'_{k^*}(t^*, K^*) - \tau^* = r,
$$

(3)

where $\tau$ ($\tau^*$) denotes the domestic (foreign) capital tax rate.

Each region’s income-expenditure identity requires that spending on goods equals income from production plus emission tax revenues, plus net payments to their capital located abroad. Thus the income expenditure identity for each region can be written as follows:

$$
E(\rho, u) = R(t, K) + tz - (R_k - \tau)k,
$$

(4)

$$
E^*(\rho^*, u^*) = R'(t^*, K^*) + t^*z^* + (R_k - \tau)k,
$$

(5)
where, \( k > 0 \) is the amount of Foreign’s capital operating in Home. Without loss of generality Home (Foreign) is designated as the capital importing (exporting) region

3. Welfare Effects of Emission and Capital Taxes

Differentiating equations (1)-(5) (see Appendix) we obtain the welfare effects of changes in emission and capital taxes as follows,

\[
\begin{align*}
\dot{u} &= \left[ -kR_{K'K}^* + E_\rho a(1 - \beta) - t a - \tau \right] R_{K'} H^{-1} dt + \left[ kR_{K'K} - E_\rho a(1 - \beta) + t a + \tau \right] H^{-1} d\tau \\
&\quad + \left[ -E_\rho a(1 - \beta) + t a + \tau - kR_{KK} \right] R_{K'} H^{-1} dt^* + \left[ E_\rho a(1 - \beta) - t a - \tau + kR_{KK} \right] H^{-1} d\tau^*
\end{align*}
\]

(6)

\[
\begin{align*}
\dot{u}^* &= \left[ kR_{KK} + E_\rho a(1 - \beta) - t^* a - \tau^* \right] R_{K'} H^{-1} dt^* + \left[ -kR_{KK} - E_\rho a(1 - \beta) + t^* a + \tau^* \right] H^{-1} d\tau^*
\end{align*}
\]

(7)

where \( H = R_{KK} + R_{K'K} < 0 \). Equations (6) and (7) indicate that an increase in emission and capital taxes affect welfare through changes in payments to mobile capital (pecuniary externality) and also through changes in the overall pollution level in each region (non-pecuniary externality).

3.1 Efficiency of capital taxes

First, we examine the case where pollution taxes are zero i.e., \( t = 0, \ t^* = 0 \), and the government uses only capital taxes.

3.1.1 Small Regions

The small regions case it can be easily reproduced in the current framework by setting \( R_{K}(K) - \tau = r \) where the net rate of return to capital i.e., \( r \), is fixed (i.e., regions cannot affect the net rate of return to capital). For completeness of our analysis we reproduce here the OW result. With fixed net rate of return to capital, we can obtain Nash equilibrium capital tax rates by setting the modified equations (6) and (7) equal to zero:
\[ (du/d\tau) = \left[-E_\rho a(1-\beta) + \tau \right] H^{-1} = 0, \] (8)
\[ (du^*/d\tau^*) = \left[-E_{\rho}^* a(1-\beta) + \tau^* \right] H^{-1} = 0. \] (9)

When regions choose capital taxes to maximize their joint welfare, then the cooperative equilibrium tax rates are given by setting \( du / d\tau + du^* / d\tau^* = 0 \) for Home and \( du^* / d\tau^* + du^* / d\tau^* = 0 \) for Foreign. From equations (6) and (7) we get the following expression for the small regions case.

\[ (du^*/d\tau^*) = \left[E_\rho^* a(1-\beta) - \tau^* \right] H^{-1} \text{ and } (du/d\tau) = \left[E_\rho a(1-\beta) - \tau \right] H^{-1} \] (10)

Comparing equations (8) and (9) with (10) reveals that at the Nash equilibrium where \( (du/d\tau) = 0 \) and \( (du^*/d\tau^*) = 0 \), we also have that \( (du/d\tau) = 0 \) and \( (du^*/d\tau^*) = 0 \). Thus the capital tax rates under decentralized (Nash) policymaking are socially efficient since in equilibrium there are no any spillovers. Put it differently, the decentralized and the cooperative equilibrium policies are the same and equally efficient. Using equations (7) and (8) we can obtain the cooperative and Nash equilibrium capital taxes for both regions as follows:

\[ \tau^N = \tau^c = \alpha E_\rho a(1-\beta), \quad \tau^N = \tau^* = \alpha E_{\rho}^* a(1-\beta), \] (11)

where superscript \((c)\) and \((N)\) stands for cooperative and Nash equilibrium tax rates. From equations (8) we can see that the decentralized and cooperative equilibrium policies lead to the same result and are equally efficient. This result has been shown recently by Ogawa and Wildasin (2009). They show that in the presence of transboundary pollution and inter-jurisdictional capital mobility decentralized policymaking leads to Pareto efficient outcome, when perfect competition prevails in factor and commodity markets.

3.1.2 Large Regions

Now examine the Nash and the cooperative equilibrium when the net rate of return to capital is not fixed. Using equations (6) and (7) we can obtain the effects of capital taxes on welfare as follows:
\[ du = \left[ kR^*_k - E^*_{\rho,a}(1 - \beta) + \tau \right] H^{-1} d\tau, \quad du^* = \left[ -kR_{kk} - E^*_{\rho,a}(1 - \beta) + \tau^* \right] H^{-1} d\tau^* \]  \hfill (12)

Setting \((du / d\tau) = 0\) and \((du^* / d\tau^*) = 0\), the Nash equilibrium capital taxes are given by

\[ \tau^N = \alpha E^*_{\rho,(1 - \beta)} - kR^*_{k,K'}, \quad \tau^{*N} = \alpha E^*_{\rho,(1 - \beta)} + kR_{kk}. \]  \hfill (13)

Next, we examine the cooperative equilibrium. The cooperative equilibrium capital taxes are determined by setting \(du / d\tau + du^* / d\tau = 0\) for Home and \(du^* / d\tau^* + du / d\tau = 0\) for Foreign. From equations (7) and (8) we have

\[ (du / d\tau) = \left[ E_{\rho,a}(1 - \beta) - \tau + kR_{kk} \right] H^{-1}, \quad (du^* / d\tau^*) = \left[ -kR^*_{k,K'} + E^*_{\rho,a}(1 - \beta) - \tau^* \right] H^{-1}. \]  \hfill (14)

At the Nash equilibrium where \((du / d\tau) = 0\) and \((du^* / d\tau^*) = 0\), we can show that \((du / d\tau^*) = k\) and that \((du^* / d\tau) = -k\). Thus, the slope of the joint welfare function for the capital importing region is positive at the Nash equilibrium. That means that the cooperative capital tax is higher than the Nash equilibrium capital tax. For the capital exporting region we have the opposite result. That is, the slope of the joint welfare function at the Nash equilibrium is negative, which means that the cooperative capital tax is lower than the Nash equilibrium capital tax. Equation (14) indicates that in the presence of endogenous rate of return to capital then the Nash capital tax rate is not efficient. Comparing equation (11) with (13) we can see that capital tax rate under decentralized policy making is higher than the cooperative equilibrium rate for the capital importer region (Home). The key difference between this result and the OW result is the terms of trade externality in capital market. This is because the capital importer (Home) has incentive to reduce the payment to foreign capital by increasing the tax rate at a rate higher than the cooperative one.

3.2 Efficiency of emission taxes

Now, we will examine the case where regions have only pollution taxes as a policy instrument at its disposal i.e., \(\tau = 0\) and \(\tau^* = 0\).
3.2.1 Small regions
First we examine the case where the two regions are small and thus in each region the net rate of return to capital is fixed. Following the same procedure as in the previous section, the welfare effects of changes in the emission taxes are given by given by the modified equations (6) and (7) as follows,

\[
\begin{align*}
du & = \left[ E_{\rho}a(1-\beta) - ta \right] R_k H^{-1} dt \quad \text{and} \quad du^* = \left[ E_{\rho}^*a(1-\beta) - t^* a \right] R_{k^*}^* H^{-1} dt^*. 
\end{align*}
\] (15)

The Nash equilibrium emission taxes are obtained by setting \( (du/\,dt) = 0 \) and \( (du^*/\,dt^*) = 0 \). To derive the cooperative equilibrium emission taxes we need to set \( (du/\,dt) + (du^*/\,dt^*) = 0 \) for Home and \( (du^*/\,dt^*) + (du/\,dt^*) = 0 \) for Foreign. To determine if the Cooperative equilibrium is different than the Nash equilibrium, we need to evaluate the terms \( (du^*/\,dt) \) and \( (du/\,dt^*) \) at the Nash equilibrium. Using equations (7) and (8), evaluated at the Nash equilibrium, we obtained that \( (du^*/\,dt) = 0 \) and \( (du/\,dt^*) = 0 \). This means that the Nash and the cooperative equilibrium emission taxes are identical and equally efficient and are given by:

\[
\begin{align*}
t^N = t^* = E_{\rho}(1-\beta), \\
t^{*N} = t^{*e} = E_{\rho}^*(1-\beta).
\end{align*}
\] (16)

3.2.2 Large regions
Now consider the case where the two regions are large in the capital markets and thus the rate of return to capital is not fixed. By setting \( (du/\,dt) = 0 \) and \( (du^*/\,dt^*) = 0 \) in equations (7) and (8), we get the Nash equilibrium emission taxes as follows:

\[
\begin{align*}
t^N = E_{\rho}(1-\beta) - kR_k^* \quad \text{and} \quad t^{*N} = E_{\rho}^*(1-\beta) + kR_{kk^*}. 
\end{align*}
\] (17)

The cooperative equilibrium emission tax is derived, as before by setting \( (du/\,dt) + (du^*/\,dt) = 0 \) for Home and \( (du^*/\,dt) + (du/\,dt^*) = 0 \) for Foreign. To compare the Nash and cooperative equilibrium we need to evaluate \( (du^*/\,dt) \) and \( (du/\,dt^*) \) at the Nash
equilibrium. Using that $(du^* / dt^*) = 0$, we get that $(du^* / dt) = kR_{K_i}$ and that $(du / dt) = 0$, we get that $(du / dt^*) = -kR_{K_i}$. Since $R_{K_i}$ is negative, i.e., an increase in capital increases pollution, then we can again conclude that the slope of the joint welfare function at the Nash equilibrium is negative for the capital importing region. This implies that the Cooperative equilibrium emission tax is lower than the Nash equilibrium emission tax. The opposite is true for the capital exporting region. The cooperative equilibrium emission tax is higher than its Nash equilibrium emission tax.

Thus, in the presence of endogenous rate of return to capital, the Nash emission tax rate is not efficient. Comparing equation (16) with (17) we can see that emission tax rate under decentralized policy making is higher than the cooperative equilibrium rate for the capital importer region (Home). The key difference between this result and the OW result is the terms of trade externality in capital market. This is because the capital importer (Home) has incentive to reduce the payment to foreign capital by increasing the tax rate at a rate higher than the cooperative one. The emission tax rate under decentralized policy making is lower than the cooperative equilibrium rate for the capital exporting region (Foreign). Foreign has incentive to subsidize capital to reduce capital outflow. The following proposition summarizes the above results.

**Proposition 1.** Consider two regions with pollution related to capital, capital or pollution taxes, cross-border pollution and interregional capital mobility. If the return to capital is fixed, then the decentralized choice of emission or capital taxes is efficient. If, however, the return to capital is not fixed, then the decentralized choice of these taxes is not efficient.

**3.3 Efficiency of intra-regionally traded emission permits**

Now, assume that the authorities of the two regions, instead of emission or capital taxes, uses emission permits to control pollution. Each region issues one permit per unit of pollution. Thus, we have $Z_n = z = \alpha K$ for Home and $Z_n^* = z^* = \alpha K^*$ for Foreign. These emission permits are sold to domestic producers at a price $s_n$ and the revenue from these sales are lump sum distributed to domestic households. Since total capital is fixed in the two regions, then the total
number of pollution in the two regions is fixed i.e., $Z_n + Z_n^* = a(K^* + K)$. The income expenditure identity in the two regions are written as

$$E(\rho, u) = R(s_n, K) + s_n Z_n - k R_{K} (s_n, K), \quad E^*(\rho^*, u^*) = R^*(s_n^*, K^*) + s_n^* Z_n^* + k R_{K} (s_n, K). \quad (18)$$

The effect of changes in the number of emission permits on the welfare of each region is given by totally differentiating equations (18) as follows,

$$E_u du = -\alpha [E_{\rho} (1-\beta) + s_n - k R_{KK} ] dK - k R_{Ks} ds_n, \quad (19)$$

$$E_u^* du^* = \alpha \left[ E_{\rho}^* (1-\beta) + s_n^* + k R_{KK} \right] dK + k R_{Ks} ds_n. \quad (20)$$

The Nash equilibrium level of emission permits is determined by setting $(du / dZ_n) = 0$ and $(du^* / dZ_n^*) = 0$. The price of the emission permits is determined in the emission permits markets to equalize demand and supply. That is $Z_n = z = -R_{s_n} (s_n, K)$. The cooperative equilibrium is determined by setting $(du / dZ_n) + (du^* / dZ_n^*) = 0$ and $(du^* / dZ_n^*) + (du / dZ_n) = 0$.

Since $dK = -dK^*$, whenever emission permits at Home increase, emission permits in Foreign decrease by the same level i.e., $dZ_n = -dZ_n^*$. Thus $(dK / dZ_n) = -(dK / dZ_n^*)$, and $(ds_n / dZ_n) = -(ds_n / dZ_n^*)$. Taking this into account we can conclude that $(du / dZ_n) = -(du^* / dZ_n^*)$ and $(du / dZ_n) = -(du^* / dZ_n^*)$. We can conclude that at the Nash equilibrium where $(du / dZ_n) = 0$ and $(du^* / dZ_n^*) = 0$, we also have that $(du^* / dZ_n) = 0$ and $(du / dZ_n^*) = 0$. Thus the Nash and cooperative level of emission permits are identical and equally efficient either for fixed or endogenous net rate of return to capital.

### 3.4 Efficiency of the inter-regionally traded emission permits

Next, consider the case where the emission permits issued by each region are traded in both regions. In this case, the common emission price is determined by the equilibrium in the interregional permits markets which is given by

$$Z_r + Z_r^* = z + z^* = -R_{s_r} (s_r, K) - R^*_r (s_r, K^*) = a(K^* + K). \quad (21)$$
The income expenditure identities for the two regions are given by equations in (18) where the subscript \((n)\) is replaced with \((t)\). Differentiating the modified equations in (18) we get

\[
E_u du = [-\alpha E_E (1 - \beta) - kR_{\rho \rho}] dK + (R_{s} + Z_{s} - kR_{K}) ds_i + s_i dZ_i, \tag{22}
\]

\[
E'_u du' = [\alpha E_E' (1 - \beta) + kR_{K}] dK + (R'_s + Z'_s + kR_{K}) ds_i + s_i dZ'_i. \tag{23}
\]

Following the same procedure as before, the Nash equilibrium is determined by setting \((du / dZ_i) = 0\) and \((du' / dZ'_i) = 0\). The cooperative equilibrium requires that \((du / dZ_i) + (du' / dZ'_i) = 0\) and \((du' / dZ'_i) + (du / dZ_i) = 0\). Since from equation (21) \(dZ_i = -dZ'_i\), then \((dK / dZ_i) = -(dK / dZ'_i)\) and \((ds_i / dZ_i) = -(ds_i / dZ'_i)\). Using the previous results in the Nash equilibrium where \((du' / dZ'_i) = 0\), we also get that \((du / dZ_i) = 0\). Similarly, at the Nash equilibrium where we have that \((du / dZ_i) = 0\), we also have \((du / dZ'_i) = 0\). Thus, we can conclude that the Nash and cooperative equilibrium are the same and equally efficient. The following proposition summarizes the above results.

**Proposition 2.** Consider two regions with pollution related to capital, intra-regional or interregional tradable emission permits, cross-border pollution and interregional capital mobility. The decentralized choice of the intra-regionally or interregional traded emission permits is efficient irrespectively of whether the return to capital is fixed of variable.

### 4. Conclusions

This paper extends the analysis of Ogawa and Wildasin (2009) for the case of large open regions in capital markets. It is shown that efficiency of the non-cooperative (Nash) equilibrium critically depends on the applied environmental policy instrument. Thus, a Pareto efficient outcome can be achieved as a Nash equilibrium outcome when emission permits, either intra-regionally or inter-regionally tradable, are implemented. When regions are small in capital markets, efficiency is always satisfied regardless of the environmental policy instruments regions choose to control pollution.
Appendix

\[
\begin{bmatrix}
1 & 0 & A
0 & 1 & A^*
0 & 0 & H
\end{bmatrix}
\begin{bmatrix}
du \\
du^*
\end{bmatrix}
=
\begin{bmatrix}
-kR_{Kt} \\
kR_{Kt}
\end{bmatrix}
dt +
\begin{bmatrix}
0 \\
0
\end{bmatrix}
dt^* +
\begin{bmatrix}
k \\
-k
\end{bmatrix}
d\tau +
\begin{bmatrix}
0 \\
0
\end{bmatrix}
d\tau^*
\begin{bmatrix}
R^*_{Kt} \\
1
\end{bmatrix}
\]

where \( A = aE_\rho(1-\beta) - ta + kR_{kk} - \tau \) and \( A^* = aE^*_\rho(1-\beta) + ta - kR_{kk} + \tau^* \). The determinant of the left-hand-side matrix of coefficients is \( H = R_{kk} + R^*_{kk} < 0 \).

References


