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Further information on publisher's website:

<http://www.bepress.com/bejm/topics/vol6/iss3/art8/>

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Topics in Macroeconomics

Volume 6, Issue 3

2006

Article 8

The Role of Government Commitment for Environmental Policy and Capital Movements

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The Role of Government Commitment for Environmental Policy and Capital Movements*

Laura Marsiliani and Thomas I. Renström

Abstract

This paper explores the relationship between environmental protection and international capital movements, when tax policy is endogenous (through voting). A two-period general equilibrium model of a small open economy is specified to compare the effects of two different constitutions (commitment or no commitment in tax policy), as well as income inequality. Under the commitment regime, the equilibrium is characterised by a lower labour tax, higher environmental tax and less capital locating abroad than in the no-commitment equilibrium. Furthermore, given the degree of commitment, more equal societies are characterised by tougher environmental policy and less capital locating abroad.

KEYWORDS: time consistency, taxation, environmental policy, political economy, international capital movements

*Correspondence to T.I. Renström, Department of Economics and Finance, University of Durham, 23-26 Old Elvet, Durham DH1 3HY, UK; email: t.i.renstrom@durham.ac.uk. We wish to thank Per Krusell (Editor) and two anonymous referees for very helpful comments. We also wish to thank Wolfram Richter, Sjak Smulders, Simon Vicary and participants at the Second Workshop on “Environmental Policy, Competitiveness and the Location Behaviour of Firms”, Maastricht; the Public Economic Theory Conference, Warwick; the 54th IIPF Conference, Seville; the first EURESCO Conference on “The International Dimension of Environmental Policy”, Kerkrade; and The Royal Economic Society Annual Conference, Durham; for very useful comments on earlier versions of this paper. The first author gratefully acknowledges financial support from the Dutch Scientific Organisation NWO, the second author gratefully acknowledges financial support from the European Commission (TMR Grant FMBI983151). All errors and shortcomings are our own.

1. Introduction

Policymakers often express concern that strict environmental protection will lead to capital moving abroad with a consequent deterioration of international competitiveness, a rise in unemployment and a slowdown of economic growth. This view has been reflected in the recent political debate. For example, the European carbon/energy tax proposal of the early 1990s included the exemption of energy-intensive industries, in order to preserve their international competitiveness. The proposal has not been implemented yet, one of the reasons being a likely loss in competitiveness of European countries. At the same time, the debate concerning the implementation of the North-American-Free-Trade-Agreement (NAFTA) focused at a large extent on the fear that US industries would relocate in Mexico, where the environmental standards are more lax.

Economists have analysed the effects of environmental policy either on the movements of capital across regions or on the location behaviour of firms (see Jaffe et al., 1995, for a useful survey, and Wilson, 1996 for an overview).¹ The existing theoretical studies typically find a positive correlation between stringency of domestic environmental policy and capital or industries relocating abroad. In particular, a study of capital relocation and environmental concern in a small open economy has been conducted by Bovenberg and van der Ploeg (1994). They find that stronger preferences for the environment result in a reduction in output and capital demand, which in turn causes capital moving abroad.²

In contrast, the majority of the existing empirical studies, almost exclusively concerning the US, find that environmental policy typically is *not* significant in explaining capital movements and firms' migration. For a survey of the existing empirical studies see Levinson (1996).³

This reveals that standard theoretical models of environmental policy and capital movements may fail to capture some important aspects of the problem at

¹ In this paper we do not focus on decisions about firms' or plants' location but we focus on capital movements, that is whether individuals invest assets at home or abroad. In this respect our paper is different from the literature on strategic environmental policy and plant location. The two issues are however, often mentioned together in the policy debate. For the role of government commitment on firms' location decisions, see Ulph and Valentini (2002).

² A few theoretical papers, however, do not support a positive correlation between stringency of environmental protection and capital flight. See, in a tax competition framework, with redistributive concerns, Oates and Schawb (1988) and Wilson (1996). In this paper we want to point out another reason for a negative correlation, that is the effect of government commitment. This is why we model a small open economy and abstract from the tax competition issue.

³ An exception is List and Co (2000) who find empirical evidence for the impact of environmental policy on firms' location behaviour.

hand. For example, the majority of the theoretical studies are set up in a static framework, whereas dynamic considerations may play an important role. A relevant issue is at which date the environmental policy is implemented with respect to the household's decisions on consumption and investment (which is not an issue in a static framework). In a dynamic set up, whether the government can or cannot commit to the environmental policy will make a considerable difference, due to the time-inconsistency problem.⁴

Another feature of most of the existing studies is that only one policy instrument, namely the environmental tax (or standard), is modelled. We think it is important to incorporate a standard second-best framework, allowing for distortionary taxes as well (see among others, Sandmo, 1975, and Bovenberg and de Mooij, 1994). Furthermore, redistributive concerns from rich to poor individuals may play an important role in the government's decision about environmental policy (see Oates and Schwab, 1988; Marsiliani and Renström, 2000a,b; Eriksson and Persson, 2003 and McAusland, 2003).

Moreover, observed policies are endogenous, and the decisions taken by majority elected individuals. To our knowledge only two papers (Marsiliani and Renström, 2000a,b) model environmental *and* fiscal policy through voting.⁵ In a democratic system, individuals have the possibility of voting on representatives. Whether the majority elected candidate represents the preferences of the poor or rich part of the population, obviously influences the policy choice. In fact, if the environment is a normal good, poorer individuals prefer a lower environmental tax (see Marsiliani and Renström, 2000b).⁶

In this paper, we want to examine the relationship between the degree of commitment in policy, environmental protection, and international capital

⁴ A government's policy is dynamically inconsistent when, although being optimal at the outset, it is not longer optimal at a later date even if no new information has appeared. This means that the government has some incentive to change its plans (see the seminal paper by Kydland and Prescott, 1977, and for an application to environmental policy, see Marsiliani and Renström, 2000a).

⁵ Eriksson and Persson (2003) and McAusland (2003) present models with voting over aggregate pollution, but without taxation.

⁶ Baumol and Oates (1988) use indifference curve analysis to argue that a poorer individual demands less of the environment, if the latter is a normal good. However, their argument only holds in situations where individuals differ in endowments and face the same trade-off between private consumption and the environment. In more general situations, where individuals differ in factor ownership or productivities, individuals will no longer face the same trade-off, implying that we can have situations where poorer individuals demand more of the environment, even if all goods are normal. Nevertheless, as shown in Marsiliani and Renström (2000b), when looking at environmental protection (as measured by a pollution tax), non-inferiority of all goods (including the environment) makes a poorer individual to prefer less environmental protection.

movements. Our main interest is how a different degree of commitment influences environmental protection and location of capital, when both are endogenous. We take the view that governments adopt the optimal policy given the constitution (i.e. given commitment or no commitment),⁷ and we verify under which circumstances higher environmental taxes go hand in hand with capital outflow, when both are endogenous. Furthermore, rather than focusing on a government's incentive for changing one policy instrument (such as environmental policy) we focus on the incentives related to a wider tax system. To our knowledge, apart from Marsiliani and Renström (2000a), no other paper has analysed the consequences of the time-inconsistency problem on environmental policy in a second-best framework.

Our paper is related to the work of Klein, Krusell and Ríos-Rull (2004). They compare public goods provision under three constitutions: first best (the government has access to a lump sum tax), second-best (the government has access only to an income tax but can commit to all future taxes), and third-best (the government has access only to an income tax and cannot commit to future taxes). Our paper is different from Klein, Krusell and Ríos-Rull (2004) in that we use a small open economy model (Bovenberg and van der Ploeg, 1994a) and introduce the second-best through heterogeneous individuals.⁸ Furthermore, our focus is on environmental policy and capital movements, not public goods.

In analysing the consequences of commitment for environmental policy and capital movements we need (at least) two periods (to capture intertemporal decisions), and a second-best framework (to model distortionary taxation).⁹ We introduce the second best by analysing an economy with heterogeneous individuals, ruling out individual-specific lump-sum taxes. Finally, policy is endogenised by letting individuals vote on representatives, and the majority-elected representative implements her preferred policy. To capture the degree of capital

⁷ In practice we have in mind constitutional arrangements that cause a delay between policy decision and policy implementation. This could be the length of the budgetary period, the time delay between passing the budget in the legislature and when it is adopted, or the presence of a second chamber of the legislature that has the power of delaying (but not rejecting) a policy proposal (e.g. the House of Lords in England).

⁸ There are two ways of introducing the second best. Either by ruling out lump-sum taxes in a representative agent model, or by introducing heterogeneous individuals and ruling out individual-specific lump sum taxes (still allowing for a poll tax). We introduce it in the second way, while Klein et. al. (2004) in the first.

⁹ The time-inconsistency problem is a feature of second-best analysis (it never arises in the first-best). They may arise either in one-person economies if lump-sum taxes are ruled out, or in many-person economies if individual-specific lump-sum taxation is impossible. In both cases the problem arises if the elasticities of the tax bases are dependent on *when* the policy decision is taken.

movements, we present an open economy where individuals own assets domestically and abroad; the domestic assets are rented to firms. Consequently, we take the difference between the stock of total assets and capital invested in domestic production as measuring the capital being allocated abroad (or alternatively the negative of foreign capital attracted).

Specifically, individuals differ in their learning abilities and this will make them spend different amounts of time on learning, and thereby accumulate different amounts of human capital, which in turn will give rise to wage differentials. Firms are perfectly competitive and employ a CRS technology in physical capital, human capital and emissions. We will consider a tax system consisting of a linear labour tax and an environmental tax (a tax on firms' emissions that generate pollution externalities). The tax receipts are used for provision of a lump-sum transfer. Individuals vote on candidates and the majority elected candidate implements her preferred fiscal policy. Throughout the paper we refer to the *second best* when a government can commit to future tax policy, and the *third best* when it cannot.

In our paper a time-inconsistency problem in labour taxation arises. When the government can commit to a level of the future labour tax, it takes into account that a higher level of the tax causes individuals to switch from labour to study-time. If the government can reoptimise in the future, the individuals have already invested in human capital and that stock is fixed. The individuals only change their labour supply. The elasticity of the labour tax base is (expectedly) smaller. Thus, labour is overtaxed in the third best (when the government takes the tax decision after the individuals have chosen their investment in human capital), because labour supply in efficiency units is less elastic.

We show that changing the constitution from discretion to commitment¹⁰ makes the optimal environmental tax greater and at the same time the economy attracts foreign capital. Then, commitment in tax policies results to be a factor which can explain a negative correlation between environmental protection and capital being relocated abroad. The reason is that the efficiency gain in moving to commitment increases the consumption possibilities of all goods, and if the environment is a normal consumption good, the majority elected representative tends to want to provide more of it, i.e. implementing a larger environmental tax.¹¹ At the same time, under commitment, less capital is allocated abroad. The

¹⁰ In practice we have in mind an increase in the length of the budget period, or introducing a second chamber of the legislature with the power of delaying (but not rejecting) a policy proposal (with the members of the second chamber not being elected at the same time or elected at all), like the House of Lords in England.

¹¹ In a static optimal tax setting, Bovenberg and van der Ploeg (1994b) show that higher marginal cost of public funds (i.e. a tighter second-best constraint) implies a lower environmental tax.

reason is that the labour tax is smaller, and human capital investment larger. The larger supply of human capital increases the productivity of physical capital and therefore tends to retain physical capital at home.

This paper is structured as follows. In Section 2 the economy is introduced and the assumptions are formalised, and in Section 3 the economic equilibrium is solved. In Section 4 we characterise individuals' preferences over policy, under the various timing assumptions. In Section 5 we solve three politico-economic equilibria: the first when elections take place in the second period and the majority elected individual implements policy in the second period, the second when elections take place in the first period, but the majority elected individual cannot commit to future taxation, and the third when elections take place in the first period and the majority elected individual can commit. Several questions are of interest. Does a stricter environmental policy go hand in hand with capital locating abroad, when redistributive concerns play a role? And under which constitutions? What is the role of inequality (in terms of learning ability and consequently income distribution) for the implementation of a stringent environmental policy? And how does inequality relate to capital movements? Section 6 concludes the paper.

2. The Economy

We shall specify an economy which is rich enough to analyse the relationship between environmental policy and capital movements and that formalises the time-inconsistency problem, but simple enough to keep the analysis tractable.

Individuals have preferences over period-one consumption, c_0^i , period-one time spent learning h^i , period-two labour supply, l^i , period-two consumption, c^i , and period-two provision of clean environment, $(-x)$, where x denotes pollution. Individuals are indexed by i and characterised by their learning ability parameter γ^i , which is distributed according to the distribution function $\Gamma(i)$. The ability is known to the individuals while the government only knows the distribution of abilities (Mirrlees, 1971). The labour productivity of the individual in the second period is her time spent learning in period one times her learning ability. Through most of the paper we shall assume that the median (second-period) productivity is not greater than the mean.¹² Furthermore, we normalise the population size to unity.

In the first period individual i (with ability γ^i) receives a lump-sum endowment W_0 , which is used for period-one consumption, and savings in assets

¹² This implies an assumption on the distribution of learning abilities, Γ . See further Section 3.

a^i . In the second period, before production takes place, these assets can be invested both domestically (i.e. rented as physical capital to domestic firms, with R the rental price of capital) and abroad (foreign investments).¹³ The difference between total assets and productive capital denotes capital outflow. In the second period, the individual supplies labour, and earns the pre-tax wage rate w , per unit of efficient labour. The after-tax wage income plus a lump-sum transfer from the government, T , and the returns on assets are used for consumption. The price of consumption is normalised to unity. Pollution x is generated by production, which takes place in period two. The government provides lump-sum transfers by taxing labour income at rate τ^l , and pollution at rate τ^x .¹⁴ The after-tax wage is denoted ω . In order to gain tractability, we assume specific functional forms. The next section states these assumptions.

2.1. Assumptions

A1 Individuals' Preferences

The utility function is assumed to be of the form

$$U_0^i = \ln\left(c_0^i - \eta \frac{h^{i^{1+\epsilon}}}{1+\epsilon}\right) + \beta U^i \quad (1a)$$

where the second period utility is

$$U^i = \ln\left(c^i - \eta \frac{l^{i^{1+\epsilon}}}{1+\epsilon}\right) - \Psi(x) \quad (1b)$$

and where $h^i, l^i \geq 0$, $\epsilon > 1$, and the parameters β , and η are strictly positive. Leisure has been normalised to 1 and x denotes aggregate pollution. $\Psi'(x) > 0$, and $\Psi''(x) \geq 0$.

A2 Individuals' Constraints

The individuals' budget constraints are

¹³ Under perfect foresight, in equilibrium, nobody has an incentive to relocate their capital on the international market, since the return on domestic investment will equal the return on the international market.

¹⁴ We have not introduced capital taxes, but in Section 6 we discuss the likely consequences of including capital taxation. For source based capital taxation our analysis remains unchanged (see Section 6).

$$c_0^i + a^i \leq W_0 \quad (2a)$$

$$c^i \leq Ra^i + \omega h^i \gamma^i l^i + T \quad (2b)$$

where $\omega \equiv (1 - \tau^l)w$ is the after tax wage.

A3 Production

A large number of firms operate with a Cobb-Douglas technology in physical capital, labour (in efficiency units) and pollution. Production y_i , can therefore be calculated as if there was a representative firm employing aggregate labour H , physical capital k and emissions x

$$y = A k^\alpha x^\mu H^{1-\alpha-\mu} \quad (3) \quad \text{where} \quad H \equiv \int h^i \gamma^i l^i d\Gamma(i) \quad (4)$$

A4 Government's Constraint

The tax receipts are fully used for lump-sum transfers

$$T = \tau^l w H + \tau^x x \quad (5)$$

A5 Representative Democracy

The tax rates, τ_i^l , τ_i^x and, consequently, the spending decision are determined by a majority elected representative, under either of three constitutions:

(a) elections are held in period 2, and the majority elected representative chooses taxes before the choice on period-2 labour supply and consumption is taken, and before the allocation of assets at home and abroad are made;

(b) elections are held in period 1, and the majority elected representative chooses taxes in period 2, before the choice on period-2 labour supply and consumption is taken, and before the allocation of assets at home and abroad are made;

(c) elections are held in period 1, and the majority elected representative chooses taxes before both period 1 and period 2 decisions are taken.

Cases (a), (b), and (c) are referred to as *no commitment* (third best), *partial commitment* (third best), and *full commitment* (second best), respectively.

3. Economic Equilibrium

In this section, the individual and aggregate economic behaviour are solved for given arbitrary tax rates and public expenditure. We solve the model recursively, first the second period equilibrium, then the first. We focus on interior solutions.

3.1. Second Period Individual Economic Behaviour

Maximisation of (1b) subject to (2b), taking h^i and a^i as given, gives the individuals' labour supply

$$l^i = \left(\frac{\gamma^i}{\eta} \right)^{\frac{1}{\epsilon}} (\omega h^i)^{\frac{1}{\epsilon}} \quad (6)$$

and indirect utility (up to an additive constant)

$$\max U^i = \ln \left(Ra + \frac{\epsilon}{1+\epsilon} \left(\frac{1}{\eta} \right)^{\frac{1}{\epsilon}} (\gamma^i)^{\frac{1+\epsilon}{\epsilon}} (\omega h^i)^{\frac{1+\epsilon}{\epsilon}} + T \right) \quad (7)$$

We notice that the higher the after-tax salary is, the higher is the labour supply. Individuals with more human capital (larger h^i) will supply more labour (everything else being equal).

A direct property of the preferences in (1) is that all income effect is removed from the labour supply and carried over to consumption. An increase in lump-sum allowance therefore makes the individual consume more, without changing the labour decision.

3.2. First Period Individual Economic Behaviour

Substituting (7) into (1a) and maximising subject to (2a) gives an individual's choice of the level of h and a as functions of the second period after-tax wage rate, ω , and second-period productivity,

$$h^i = R^{-\frac{\epsilon}{\epsilon^2-1}} \left(\frac{\omega \gamma^i}{\eta} \right)^{\frac{1}{\epsilon-1}} \quad (8)$$

$$a^i = -\frac{T}{(1+\beta)R} - \frac{\epsilon+\beta}{(1+\epsilon)(1+\beta)} \eta R^{-\frac{\epsilon}{\epsilon-1}} \left(\frac{\omega \gamma^i}{\eta} \right)^{\frac{1+\epsilon}{\epsilon-1}} + \frac{\beta}{1+\beta} W \quad (9)$$

We notice that there is a trade-off between time spent studying and investment in assets: a higher rate of interest causes individuals to study less and to invest more in assets. We also see that the higher the after-tax wage is, the longer is the time spent learning.¹⁵ Also, what will matter for the individual's attitude towards redistribution is not the ability to learn, but the productivity in work in the second period. The productivity in work is $\gamma^i h^i$, which is proportional to $\gamma^{j(1+\epsilon)/(\epsilon-1)}$. This is the key measure we will refer to in the rest of the paper.

3.3. Aggregate Economic Behaviour

The second- and first-period aggregate economic behaviour is generated by aggregating the individuals' quantities obtained in Sections 3.1 and 3.2 respectively. To obtain the aggregate labour supply (in efficiency units), defined in (4), we integrate (8) over the population to get

$$H = \tilde{h} \left(\frac{\omega}{\eta} \right)^{\frac{1}{\epsilon}} \quad (10)$$

where

$$\tilde{h} \equiv \int (\gamma^i h^i)^{\frac{1+\epsilon}{\epsilon}} d\Gamma(\mathbf{i}) = \tilde{\gamma} R^{\frac{-1}{\epsilon-1}} \left(\frac{\omega}{\eta} \right)^{\frac{1}{\epsilon} \frac{1+\epsilon}{\epsilon-1}} \quad (11) \quad \tilde{\gamma} \equiv \int (\gamma^i)^{\frac{1+\epsilon}{\epsilon-1}} d\Gamma(\mathbf{i}) \quad (12)$$

The difference between the second and first periods is that in the second period individuals have invested in their human capital and assets and consequently h and a are fixed, while viewed from the first period h and a are functions of the taxes. $\tilde{\gamma}$ is the $(1+\epsilon)/(\epsilon-1)$ th moment of the ability distribution, and is linearly related to the average work productivity. Whether an individual earns a higher/lower wage rate (per hour) than average depends whether the ratio $\gamma^{j(1+\epsilon)/(\epsilon-1)}/\tilde{\gamma}$ is greater/smaller than unity.

3.4. Firm's Behaviour

The representative firm chooses the pollution level so that the marginal product

¹⁵ If we are in the third best, so that the policy decision is not yet taken, the individuals make their private choices on the basis of the expected policy outcome (i.e. the expected after tax wage ω^e). In equilibrium the actual policy outcome will coincide with the expected one $\omega = \omega^e$.

of pollution equals the tax rate, i.e. $\tau^x = F_x$.¹⁶ The firm's optimality condition with respect to k (i.e. $F_k = R$) gives optimal k , and production, as functions of x and H

$$k = (\alpha A/R)^{\frac{1}{1-\alpha}} x^\theta H^{1-\theta} \quad (13) \quad y = \tilde{F} = \tilde{A} x^\theta H^{1-\theta} \quad (14)$$

where

$$\theta \equiv \mu/(1-\alpha) \quad (15) \quad \tilde{A} \equiv A(\alpha A/R)^{\frac{\alpha}{1-\alpha}} \quad (16)$$

In the next section, we shall examine the policymakers' preferences over fiscal policy.

4. Preferences over Policy

Any individual elected into office will choose policy to maximise her own utility, subject to the government budget constraint. We therefore need to characterise how each type would choose policy. Policy will then be a function of the type in office, and we can construct a voting equilibrium (in section 5) where individuals vote over candidates.

First, it is more convenient optimising with respect to the after-tax wage, ω , and the amount of the polluting factor, x , used, rather than with respect to the tax rates themselves. In fact, in equations (6)-(11), (13)-(14) only ω and x appear. We only need to rewrite the government's budget constraint in terms of those quantities. Equation (5) can be written as

$$T = (1-\alpha) \tilde{A} x^\theta H^{1-\theta} - \omega H \quad (17)$$

The timing matters only to the extent that H (aggregate efficient supply of human capital) responds differently to changes in the after-tax wage, depending on when the tax decision is taken. In fact, the first-order conditions will take the same form under the various assumptions about timing. This is due to the fact that the elected individual chooses l^i (and a^i, h^i if commitment) as well as policy, so the derivatives of l^i (and a^i, h^i if commitment) with respect to policy can be ignored (by the Envelope condition). The problem of a hypothetical candidate is to

¹⁶ We will use this relation later in Section 4, to replace the pollution tax rate in the government's budget constraint. In the policy maker's problem, we will optimise with respect to pollution, and later on back out the implied pollution tax rate.

$$\max_{\omega, x} \ln \left(Ra^i + \omega h^i \gamma^i l^i + T - \eta \frac{(l^i)^{1+\epsilon}}{1+\epsilon} \right) - \Psi(x) \quad (18)$$

subject to (17), (effects on l^i , a^i , and h^i can be ignored by the Envelope condition). The first-order conditions to (18) are

$$h^i \gamma^i l^i + \frac{\partial T}{\partial \omega} = 0 \quad (19)$$

$$\frac{\partial T / \partial x}{Ra^i + \omega h^i \gamma^i l^i + T - \eta (1+\epsilon)^{-1} (l^i)^{1+\epsilon}} - \Psi'(x) = 0 \quad (20)$$

These conditions have to be evaluated under the different assumptions of timing. First we clarify how they differ.

(a) *No commitment*

An individual, if elected in the *second* period, will take the decision upon ω and x , taking as given the quantity of \tilde{h} . Optimal policy will be a function of the identity of the candidate and \tilde{h} , which in turn is a function of ω^e (i.e. of *expected* ω).

(b) *Partial commitment*

An individual, if elected in the *first* period, will take the decision upon ω and x , given the quantity of \tilde{h} . However, the choice of ω and x have to be compatible with the expectations of ω in \tilde{h} . This is so because individuals will observe who the elected candidate is already in the first period and can form expectations of ω based on the identity of the candidate. Optimal policy will be a function of the identity of the candidate only.

(c) *Full commitment*

An individual, if elected in the first period, will take the decision upon ω and x , recognising the influence on \tilde{h} .

Since from the policymaker's point of view \tilde{h} is given under both partial and no commitment, partial commitment can be treated as no commitment for time being.

Aggregate labour in efficiency units as a function of policy can be written in one equation, with the parameters reinterpreted under the various timing assumptions. Combining (10) and (11) we can write

$$H = \sigma \omega^{1/\nu} \quad (21)$$

where

$$\sigma = \begin{cases} (\mathbf{R}\eta^2)^{\frac{-1}{e-1}} \tilde{\gamma} & \text{if commitment} \\ (\mathbf{R}\eta^2)^{\frac{-1}{e-1}} \tilde{\gamma} (\omega^e)^{\frac{1}{e} \frac{1-e}{e-1}} & \text{if no commitment} \end{cases} \quad (22)$$

$$v = \begin{cases} \frac{e-1}{2} & \text{if commitment} \\ e & \text{if no commitment} \end{cases} \quad (23)$$

Next, since all individuals have the same expectations (regardless timing) we can write

$$h^i \gamma^i l^i = H \hat{\gamma}^i \quad (24) \quad \text{where} \quad \hat{\gamma}^i \equiv \gamma^{i(1+e)/(e-1)} / \tilde{\gamma} \quad (25)$$

Differentiating (17) with respect to ω , using (21), and inserting the derivative into the first-order condition (19) gives

$$h^i \gamma^i l^i + [(1-\theta)(1-\alpha)\tilde{A}x^\theta H^{-\theta} - \omega] \frac{1}{v} \frac{H}{\omega} - H = 0 \quad (26)$$

Using (24) and rearranging gives

$$\omega = m^i x^\theta H^{-\theta} \quad (27)$$

where

$$m^i \equiv \frac{(1-\theta)(1-\alpha)\tilde{A}}{1+v(1-\hat{\gamma}^i)} \quad (28)$$

Also, substituting (27) into (21) gives

$$\omega = (m^i)^{\frac{v}{v+\theta}} (x/\sigma)^{\frac{\theta v}{v+\theta}} \quad (29)$$

$$H = (m^i)^{\frac{1}{v+\theta}} \sigma^{\frac{v}{v+\theta}} x^{\frac{\theta}{v+\theta}}$$

Since $w=(1-\alpha-\mu)\tilde{A}x^\theta H^{-\theta}$, and $1-\tau^l=\omega/w$, equation (27) gives (also using (15))

$$\tau^l = \frac{v(1-\hat{\gamma}^i)}{1+v(1-\hat{\gamma}^i)} \quad (30)$$

as the labour tax rate preferred by individual i .

Recall that $\hat{\gamma}^i$ is the ratio of individual i 's labour productivity to the average labour productivity. If $\hat{\gamma}^i$ is smaller than unity the individual earns less wage per

hour worked than the average. Since v takes on different values depending on the timing, the same individual prefers a different tax rate under different timing assumptions. In fact, since v is larger under no commitment than under commitment, the labour tax is larger under no commitment than under commitment. The reason is that the tax base H is less elastic under no commitment and thus would be over taxed. We also see that, given the timing, an individual with greater learning ability prefers to tax labour less.

We will now make a complete characterisation of the choice of a hypothetical individual in office. This will involve substituting for ωH , as a function of the identity of the decision maker and of x (equation (28)), into (19) and finding $\partial x / \partial \hat{\gamma}$. It turns out that $\partial x / \partial \hat{\gamma} > 0$ under all timing assumptions (see the appendix). Since $\partial m^i / \partial \hat{\gamma} > 0$, then by (28) $\partial \omega / \partial \hat{\gamma} > 0$, so the decisions are monotone in the decision maker's learning ability.

Lemma 1 *If one assumes A1-A5, and considers a hypothetical decision maker $\hat{\gamma}^*$, then the decision maker's choice will be functions of $\hat{\gamma}^*$ with the following properties*

$$\frac{\partial \tau^l}{\partial \hat{\gamma}^*} < 0, \quad \frac{\partial \omega}{\partial \hat{\gamma}^*} > 0, \quad \frac{\partial x}{\partial \hat{\gamma}^*} > 0, \quad (31)$$

and for any given $\hat{\gamma}^*$

$$\tau^l \text{ (no commitment)} > \tau^l \text{ (commitment)}.$$

Proof: See the appendix.

We will now turn to the characterisation of the various politico-economic equilibria, and examine the consequences of time inconsistency on environmental policy and capital movements.

5. Politico-Economic Equilibria

Regarding voting we have a one-dimensional choice space (the identity of the decision maker). We now need to examine the individuals' preferences over candidates (potential decision makers). If preferences over candidates are single peaked, then we know that the candidate preferred by the median individual in the voting distribution cannot lose against any other candidate in a binary election. Denote a hypothetical decision maker by superscript *. Substitute the policy functions in Lemma 1 into individual i 's indirect utility, to obtain an indirect utility in terms of $\hat{\gamma}^*$. This indirect utility has the following properties

Lemma 2 *If one assumes A1-A5, then individual i 's preferences over candidates' $\hat{\gamma}^*$ are single peaked, with the maximum attained*
at $\hat{\gamma}^ = \hat{\gamma}^i$ if no commitment,*
at $\hat{\gamma}^ = (1+\varepsilon)/(2\varepsilon) + [(\varepsilon-1)/(2\varepsilon)]\hat{\gamma}^i$ if partial commitment, and*
at $\hat{\gamma}^ = \hat{\gamma}^i$ if full commitment.*

Proof: See the appendix.

Lemma 3 *If one assumes A1-A5, then the economic equilibrium under partial commitment with policymaker $\hat{\gamma}^*$ coincides with the economic equilibrium under full commitment with policymaker $\hat{\gamma}^{*'} = (1+\varepsilon)/(2\varepsilon) + [(\varepsilon-1)/(2\varepsilon)] \hat{\gamma}^*$.*

Proof: Inserting $\hat{\gamma}^{*'}$ in equation (30), and evaluating under no commitment ($v=\varepsilon$), gives the same labour tax as when inserting $\hat{\gamma}^*$ in equation (30) and evaluating under full commitment ($v=(\varepsilon-1)/2$). If the labour tax is the same in both equilibria, then by equation (20), also the pollution level x is the same in both equilibria.

QED

Lemma 2 implies that we have a median-voter equilibrium, and that we can completely characterise policy making given the underlying distribution of abilities. The single peakedness follows from the monotonicity in the policy variables with respect to the ability of the decision maker. Lemma 2 also implies that when individuals vote in the first period, but the elected policymaker implements policy in the second period, they will vote strategically on a representative with a different (higher) ability than themselves.

Proposition 1 *If one assumes A1-A5, then in politico-economic equilibrium, the economic equilibrium under partial commitment (voting in period 1, policy decision in period 2) coincides with the economic equilibrium under full commitment (voting and policy decision in period 1), and the policymaker has a higher ability in the partial commitment than in the full commitment equilibrium.*

Proof: Follows from Lemma 1, 2, 3.

QED

Proposition 1 implies that due to strategic voting, the period-one elected representative will implement the same policy in period 2, as a period-one elected representative would have implemented in period 1. Thus the partial-commitment

equilibrium will coincide with the full-commitment equilibrium.¹⁷ Since the partial commitment equilibrium coincides with the full commitment equilibrium we will not distinguish between them two. We will henceforth only refer to *commitment* versus *no commitment*.

Proposition 2 *If one assumes A1-A5, then in politico-economic equilibrium the following holds*

$$\frac{\partial \tau^l}{\partial \hat{\gamma}^*} < 0, \quad \frac{\partial \omega}{\partial \hat{\gamma}^*} > 0, \quad \frac{\partial x}{\partial \hat{\gamma}^*} > 0, \quad (32)$$

where $\hat{\gamma}^*$ is the median, and given any $\hat{\gamma}^*$
 τ^l (no commitment) $>$ τ^l (commitment).

Proof: Follows from Lemma 1-2.

QED

We notice that the wage tax decreases in the productivity of the decisive individual. This is a standard result, and is caused by the fact that a less productive individual has more to gain from redistributive taxation.

Furthermore, labour is *overtaxed* when no commitment is possible (i.e. in the third best). This is because once the individuals have invested in their human capital, the elasticity of labour supply in efficiency units with respect to taxes is less elastic (at that stage, it is too late to spend more time learning). When commitment is possible, individual responses to changes in wages are greater. We see also from (30) that the greater the difference between the median productivity and the average, the greater is the difference between the commitment and the no commitment solution. Thus, inequality (in the form of skewness of the distribution) makes the time-inconsistency problem more severe.

Finally, pollution in absolute terms is increasing in the productivity of the decisive individual. This is so because this individual wishes to tax labour less, inducing individuals to accumulate more human capital, which in turn makes pollution more productive.

Next, when we make all individuals identical we have the following result:

¹⁷ We do not expect this is a general property though, but is due to the assumptions regarding utilities and technologies. Generally one should not expect all policy variables to exactly coincide. When policy is one-dimensional, though, and the candidate space is rich (continuous), the full commitment and partial commitment ought to coincide. This happens indeed in Persson and Tabellini (1994).

Corollary 1 *If one assumes A1-A5, and that all individuals are identical, then the commitment and no commitment equilibria coincide, and the environmental tax is at the Pigovian level.*

Proof: When all individuals are the same $\hat{\gamma}^*=1$, and the labour tax is zero regardless of timing. Equation (20) then gives the Pigou rule (which is the same regardless of timing).

QED

Thus, we verify that there is no time-inconsistency problem in the first best. This is a general property, since the time-inconsistency problem is only a second-best phenomenon. In the first best the wage tax is zero and any funding in addition to the environmental tax receipts is obtained by lump-sum taxation, $-T$.

Furthermore, we get the following results

Proposition 3 *If one assumes A1-A5, then total emissions, the after-tax wage, and production are smaller under no commitment than under commitment, and for a given level of commitment, the lower the ability of the decisive individual is, the lower are emissions, the after-tax wage, and production.*

Proof: See the appendix.

Proposition 4 *If one assumes A1-A5, then*

- (i) *the pollution tax is smaller and the ratio between emissions and production is greater under no commitment than under commitment,*
- (ii) *given the level of commitment, the lower the ability of the decisive individual is, the lower is the pollution tax, and the higher is the ratio of emissions to production.*

Proof: See the appendix.

Intuitively, under commitment the consumption possibilities are greater; if the environment is a normal good (which is ensured by additive separability in (1b)), the efficiency gains achieved in the second best (in comparison to the third best) means more consumption of the environment. This is achieved by taxing pollution more. Furthermore, if the labour tax is small, investment in human capital is large and the marginal productivity of emissions is large too. Consequently, it is optimal to increase emissions, but not to the extent that x/y increases.

We will next address the question of capital movements. Using the decision rules for individuals' savings as a function of the taxes we can state:

Proposition 5 *If one assumes A1-A5, then*

- (i) *the politico-economic equilibrium under no commitment has larger capital outflow than the politico-economic equilibrium under commitment,*
- (ii) *given the level of commitment, the lower the ability of the decisive individual is, the larger is the capital outflow.*

Proof: Since the after-tax wage is greater under commitment (or under a policymaker with higher ability), individuals invest less in physical assets (and more in human capital), by equation (9). Since domestic firms' capital demand is proportional to production (equation (13)), and production is greater under commitment (or under a policymaker with higher ability), domestic firms capital demand is greater under commitment. Thus, the difference domestic savings - domestic capital use, is less under commitment (or under a policymaker with higher ability). QED

Intuitively, commitment on the one hand increases the returns on human capital, which in turn reduces domestic savings, and on the other hand increases the productivity of capital, overall attracting foreign capital.

Proposition 6 *If one assumes A1-A5, then difference between the politico-economic equilibria under commitment and under no commitment is larger the lower the ability of the decisive individual is, at least as long as $\epsilon \leq 2$.*

Proof: See the appendix.

This shows that the time-inconsistency problem becomes more severe as one tightens the second-best constraint, i.e. as the ability of the decisive individual becomes smaller in relation to the average.

6. Summary and Conclusions

We have presented a general-equilibrium model of environmental taxation and capital movements. The most important feature of this model is that it examines the effects of different constitutions, that is whether the government can or cannot commit to future tax policy.

When individuals differ in learning abilities a time-inconsistency problem in labour taxation arises, implying that the commitment and no-commitment equilibria do not coincide. The reason is that a majority-elected individual would want to use the distortionary labour tax for redistribution. The optimal tax from the viewpoint of the majority elected individual depends on the elasticity of the tax base. The elasticity of the tax base depends on the timing of the policy

decision. This is because individuals have the possibility of choosing the time they spend on learning. They have to form expectations about the labour tax the government is going to impose in the future. Once individuals have invested in their human capital, the government is tempted to raise the labour tax in order to redistribute from high earners to low earners. Individuals expecting this will invest too little in human capital, and at the same time labour is overtaxed.

We have demonstrated that under commitment (second best), the labour tax is smaller and the environmental tax is greater than under no commitment (third best). Intuitively, there is a conflict between environmental and labour taxation and lump-sum transfers. If the labour tax is small, the distortions caused by the tax system will be small as well. In this case, the marginal utility of transfers is lower and the median voter will prefer to protect the environment more (by paying a higher environmental tax). Furthermore, under commitment, the increasing returns on human capital reduces domestic savings and increases the productivity of capital, which in turns attracts foreign capital or discourages domestic capital locating abroad.

Everything else being equal, societies with more commitment in fiscal policy would have a tougher environmental policy and less capital moving abroad. In practice, commitment translates into the delay between policy decisions and implementation. For example, countries with longer budget periods, or delays in decision making (perhaps caused by having a policy proposal passing a second chamber in the legislature), would have more commitment in policy. Since countries differ in their constitutional arrangements, an empirical investigation not accounting for constitutional differences would not necessarily find a relationship between actual environmental policy and capital movements. Thus, this paper provides us with a theoretical explanation for why no empirical evidence can generally be found of a positive relationship between the stringency of environmental policy and capital migration.

In addition, we have shown that the no-commitment equilibrium tax differs more from the commitment equilibrium one, the larger the difference is in learning ability between the decisive individual (median voter) and the average individual. This suggests that the time-inconsistency problem becomes more severe when the second-best constraint is tightened (i.e. when there is more inequality in terms of mean-median distance). In this case, a poorer decisive individual will prefer a higher labour tax and also have a greater marginal utility of private consumption and lump-sum transfers, and therefore will be less willing to protect the environment; at the same time capital productivity decreases and capital migrates abroad. Viceversa, a more equal society, given the level of commitment, would have tougher environmental policy and less capital outflow. Thus, through the inequality channel we can also generate a negative correlation between environmental policy and capital moving abroad. Future work should be devoted

to empirically assessing this relationship.

In constructing our model we made a number of simplifying assumptions, in particular: no capital taxes, no income effect on labour supply, and Cobb-Douglas production technology. We will point out the likely consequences of relaxing some of them.

We modelled an economy without capital taxes. If we had introduced source-based capital taxes, as is usually done in the tax-competition literature, (i.e. when the government taxes k), little would have changed in our model. Due to mobility of capital (and the small-economy assumption), the after-tax domestic interest rate must equal the foreign interest rate. The capital tax would have no effect on the domestic individuals' return on savings. The only effect the tax has is on tax revenue. All individuals (regardless commitment regime) would agree on maximising the tax revenue from capital taxation. The revenue maximising capital tax rate equals $1-\alpha$. Inserting this into the government's budget one obtains the same equation (17) with \tilde{A} redefined (multiplied by $1+\alpha$), leaving the remaining analysis unchanged.

If we had introduced residence based capital taxation, then individuals differing in their savings, a , would have different preferences over the capital tax. Capital poorer individuals would prefer a higher capital tax. We suspect that similar conclusions would remain in this case. Economies with more commitment could afford stricter environmental policy. However, more commitment may mean more savings, and therefore less reliance on foreign capital.

The utility function implied that there were no income effects on labour supply. We expect that income effects would make the difference between the commitment and no-commitment equilibria greater. To see this, we may think of the extreme situation where the income effect is strong enough to exactly cancel the substitution effect, making labour supply inelastic. Then, under no commitment human capital can be confiscated. Individuals rationally expecting this would not invest in human capital, just in physical. Under commitment confiscation is never optimal. Thus, strong income effects may produce larger differences across the commitment regimes.

We assumed a Cobb-Douglas production technology. For broader classes of production technologies some results may weaken. A production technology with less substitutability between human capital and pollution may give rise to a situation where commitment yields more pollution. Commitment makes individuals to invest more in human capital for the usual reasons. With low elasticity of substitution, however, pollution's marginal product may be large enough for the median voter to accept a larger level of pollution (pollution is more productive).

Appendix

Proof of Lemma 1

First $\partial\tau^i/\partial\hat{\gamma}^i < 0$ follows from equation (30). Next, we only need to prove that $\partial x/\partial\hat{\gamma}^i > 0$ under all assumptions on timing. This is so since $\partial x/\partial\hat{\gamma}^i > 0$ implies, (by (29) in the full commitment and no-commitment cases, and by (50) (below) in the partial commitment case), that $\partial\omega/\partial\hat{\gamma}^i > 0$ (notice that by (28) $\partial m^i/\partial\hat{\gamma}^i > 0$). Taking the partial derivative of (17) w.r.t. x gives

$$\frac{\partial T}{\partial x} = \theta(1-\alpha)\tilde{A}x^{\theta-1}H^{1-\theta} = \theta(1-\alpha)\tilde{F}/x \quad (33)$$

which is the numerator in (20) (the second equality follows by (14)). Next, the denominator in (20) may be written as follows (by using (6))

$$Ra^i + \frac{\epsilon}{1+\epsilon}\omega h^i \hat{\gamma}^i l^i + T = Ra^i + \frac{\epsilon}{1+\epsilon}\hat{\gamma}^i \omega H + T \quad (34)$$

where the equality follows from (24). Then the first order condition (20) may be written as

$$\frac{\theta(1-\alpha)x^{-1}}{Z} - \Psi'(x) = 0 \quad (35) \quad \text{where } Z \equiv \left[Ra^i + \frac{\epsilon}{1+\epsilon}\hat{\gamma}^i \omega H + T \right] / \tilde{F} \quad (36)$$

We treat Z as a function of $\hat{\gamma}^i$ and x : $Z(\hat{\gamma}^i, x)$. Denote the derivatives by subscripts. We then find the sought derivative by differentiating (35)

$$\frac{\partial x}{\partial \hat{\gamma}^i} = -x Z_{\hat{\gamma}^i} \left[Z + Z_x x + Z \frac{\Psi''(x)}{\Psi'(x)} x \right]^{-1} \quad (37)$$

We now need to find the derivatives of Z . First we will rewrite (36). Premultiply (27) by H and use (14), then we have the following

$$\omega H = m^i x^\theta H^{1-\theta} = m^i \tilde{F} / \tilde{A} \quad (38)$$

Next,

$$T = (1-\alpha)\tilde{F} - \omega H = \left[\frac{(1-\alpha)\tilde{A}}{m^i} - 1 \right] \omega H = \frac{\theta + v(1-\hat{\gamma}^i)}{1-\theta} \omega H \quad (39)$$

where the first equality follows by using (14) in (17), the second equality by using (38), and the third equality by using (28). Using the last equality of (39) in (36) gives

$$Z = \left[Ra^i + \left(\frac{\epsilon \hat{\gamma}^i}{1+\epsilon} + \frac{\theta + v(1-\hat{\gamma}^i)}{1-\theta} \right) \omega H \right] / \tilde{F} \quad (40)$$

Sofar the analysis is valid under all assumptions on timing. We now need to proceed differently, depending on which timing of events we assume. We begin with the no-commitment case.

Under no commitment the last period's learning and savings are taken as given, and only the identity of the policy maker (as well as her choice) can vary. Here we have $v=\epsilon$ (by (23)), then Z^n , where superscript n denotes no commitment, (i.e. equation (40)) becomes

$$\begin{aligned} Z^n &= \left[Ra^i + \frac{\epsilon + \theta}{(1-\theta)(1+\epsilon)} [1 + \epsilon (1 - \hat{\gamma}^i)] \omega H \right] / \tilde{F} \\ &= \left[Ra^i + \frac{\epsilon + \theta}{1+\epsilon} (1-\alpha)\tilde{A} \frac{\omega H}{m^i} \right] / \tilde{F} = Ra^i / \tilde{F} + (1-\alpha) \frac{\epsilon + \theta}{1+\epsilon} \end{aligned} \quad (41)$$

where the second equality follows by using (28), and the third by using (38). Use (21), (29), and (38) to substitute for \tilde{F} , then we have

$$Z^n = \frac{Ra^i}{\tilde{A}} (m^i \sigma^v)^{\frac{\theta-1}{\theta+v}} x^{-\theta \frac{1+v}{\theta+v}} + (1-\alpha) \frac{\epsilon + \theta}{1+\epsilon} \quad (42)$$

Take the derivatives with respect to x and $\hat{\gamma}^i$, to obtain¹⁸

$$Z^n + \frac{\partial Z^n}{\partial x} x = v \frac{1-\theta}{\theta+v} \frac{Ra^i}{\tilde{A}} (m^i \sigma^v)^{\frac{\theta-1}{\theta+v}} x^{-\theta \frac{1+v}{\theta+v}} + (1-\alpha) \frac{\epsilon + \theta}{1+\epsilon} > 0 \quad (43)$$

$$\frac{\partial Z^n}{\partial \hat{\gamma}^i} = \frac{Ra^i}{\tilde{A}} (m^i \sigma^v)^{\frac{\theta-1}{\theta+v}} x^{-\theta \frac{1+v}{\theta+v}} \left(\frac{\partial a^i / \partial \hat{\gamma}^i}{a^i} - \frac{1-\theta}{\theta+v} \frac{\partial m^i / \partial \hat{\gamma}^i}{m^i} \right) < 0 \quad (44)$$

Substituting (43) and (44) in (37) gives $\partial x / \partial \hat{\gamma}^i > 0$ under no commitment.

Under partial commitment ω^e in \tilde{h} and σ changes as $\hat{\gamma}^i$ changes. When $\hat{\gamma}^i$ is known also ω^e will be known (and coincides with ω). This has to be taken into account in differentiating Z . Under full commitment ω^e is under the control of the policymaker. The two cases can be captured simultaneously. In both cases a^i will respond to changes in the identity of the decision maker. Combining (8), (6) and (24), and substituting into (9) gives

$$Ra^i = -\frac{T}{1+\beta} - \frac{\epsilon + \beta}{(1+\epsilon)(1+\beta)} \omega H \hat{\gamma}^i + \frac{\beta}{1+\beta} RW \quad (45)$$

No expectations on ω is needed because the decision maker will be known in advance.

¹⁸ N.B. under no commitment a^i is invariant with respect to policy, and varies only with respect to identity i . The derivative (44) is negative since $\partial a^i / \partial \hat{\gamma}^i < 0$, which follows from (9).

Substituting (45) into (36) gives

$$Z^{c,p} = \frac{\beta}{1+\beta} \left[T + \frac{\epsilon-1}{1+\epsilon} \omega H \hat{\gamma}^i + RW \right] / \tilde{F} \quad (46)$$

where superscript c,p denote commitment, partial commitment, respectively. Substituting for T according to the second equality in (39), and for \tilde{F} according to (38) gives

$$Z^{c,p} = \frac{\beta}{1+\beta} \left[1 - \alpha - \frac{m^i}{\tilde{A}} + \frac{\hat{\gamma}^i m^i}{\tilde{A}} \frac{\epsilon-1}{1+\epsilon} + \frac{RW}{\tilde{A}} \frac{m^i}{\omega H} \right] \quad (47)$$

or rearranged

$$Z^{c,p} = \frac{\beta}{1+\beta} \left[1 - \alpha - \frac{m^i}{\tilde{A}} \frac{2+(\epsilon-1)(1-\hat{\gamma}^i)}{1+\epsilon} + \frac{m^i}{\tilde{A}} \frac{RW}{\omega H} \right] \quad (48)$$

Full commitment implies $v=(\epsilon-1)/2$, then using (28) in (48) we obtain

$$Z^c = \frac{\beta}{1+\beta} \left[(1-\alpha) \frac{\epsilon-1+2\theta}{1+\epsilon} + \frac{RW}{\tilde{A}} (m^i \sigma^v)^{-\frac{1-\theta}{\theta+v}} x^{-\theta \frac{1+v}{v+\theta}} \right] \quad (49)$$

where $m^i/(\omega H)$ has been substituted for by using (29).

Partial commitment implies that ω^ϵ in (22) has to be replaced by ω . Setting $\omega^\epsilon=\omega$ in (22) and substituting into (29) gives (wherever v appears it equals ϵ according to (23))

$$\omega = (m^i(x/\sigma_0)^\theta)^{\frac{\epsilon-1}{\epsilon-1+2\theta}} \quad (50)$$

where $\sigma_0 = \tilde{\gamma}(R\eta^2)^{-1/(\epsilon-1)}$. Set $\omega^\epsilon=\omega$ in (22) and substitute into (21), premultiply both sides by ω , and substitute for ω on the right-hand side by using (50) to obtain (N.B. $v=\epsilon$)

$$\omega H = \sigma_0^{\frac{(1-\theta)(\epsilon-1)}{\epsilon-1+2\theta}} (m^i x^\theta)^{\frac{1+\epsilon}{\epsilon-1+2\theta}} \quad (51)$$

In (48), using (28) to eliminate m^i where it first appears and (51) to eliminate $m^i/(\omega H)$ we have

$$Z^p = \frac{\beta}{1+\beta} \left[(1-\alpha) \left(1 - \frac{1-\theta}{1+\epsilon} \frac{2+(\epsilon-1)(1-\hat{\gamma}^i)}{1+\epsilon(1-\hat{\gamma}^i)} \right) + \frac{RW}{\tilde{A}} \left(m^i \sigma_0^{\frac{\epsilon-1}{2}} \right)^{\frac{-2(1-\theta)}{\epsilon-1+2\theta}} x^{\frac{-\theta(1+\epsilon)}{\epsilon-1+2\theta}} \right] \quad (52)$$

We are now ready to take the derivatives of (49) and (52), respectively.

Differentiating Z^c (i.e. (49)) with respect to x and $\hat{\gamma}^i$ gives

$$Z_x^c x + Z^c = \frac{\beta}{1+\beta} \left[(1-\alpha) \frac{\epsilon-1+2\theta}{1+\epsilon} + v \frac{1-\theta}{v+\theta} \frac{RW}{\tilde{A}} (m^i \sigma^v)^{-\frac{1-\theta}{\theta+v}} x^{-\frac{\theta}{v+\theta}} \right] > 0 \quad (53)$$

$$Z_{\hat{\gamma}^i}^c < 0 \quad (54)$$

The inequality in (54) follows since Z^c is declining in m^i , and m^i is increasing in $\hat{\gamma}^i$. Then (37) implies that $\partial x/\partial \hat{\gamma}^i > 0$ holds here as well.

Finally differentiating Z^p (i.e. (52)) with respect to x and $\hat{\gamma}^i$ gives

$$Z_x^p x + Z^p = \frac{\beta}{1+\beta} \left[(1-\alpha) \left(1 - 2 \frac{1-\theta}{1+\epsilon} \frac{1+\eta(1-\hat{\gamma}^i)}{1+\epsilon(1-\hat{\gamma}^i)} \right) + \frac{\eta(1-\theta)}{\eta+\theta} \frac{RW}{\tilde{A}} (m^i \sigma_0^\eta)^{-\frac{1-\theta}{\eta+\theta}} x^{-\frac{\theta}{2} \frac{1+\epsilon}{\eta+\theta}} \right] \quad (55)$$

$$Z_{\hat{\gamma}^i}^p = - \frac{\beta}{1+\beta} \left[\frac{(1-\alpha)(1-\theta)}{[1+\epsilon(1-\hat{\gamma}^i)]^2} + \frac{1-\theta}{\eta+\theta} \frac{RW}{\tilde{A}} (m^i \sigma^\eta)^{-\frac{1-\theta}{\eta+\theta}} x^{-\frac{\theta}{2} \frac{1+\epsilon}{\eta+\theta}} \frac{\partial m^i / \partial \hat{\gamma}^i}{m^i} \right] < 0 \quad (56)$$

where $\eta=(\epsilon-1)/2$. Then (37) gives $\partial x/\partial \hat{\gamma}^i > 0$.

QED

Proof of Lemma 2

All three commitment regimes can be handled in the same proof. By (17), the transfer is a function of ω , x , and $H(\omega)$, i.e. $T=T(\omega, x, H(\omega))$. Taking the derivative of individual i 's indirect utility function with respect to $\hat{\gamma}^*$ gives

$$\frac{h^i \gamma^i l^i + \frac{\partial T}{\partial \omega}}{Ra^i + \omega h^i \gamma^i l^i + T - \eta \frac{(l^i)^{1+\epsilon}}{1+\epsilon}} \frac{\partial \omega}{\partial \hat{\gamma}^*} + \left[\frac{\frac{\partial T}{\partial x}}{Ra^i + \omega h^i \gamma^i l^i + T - \eta \frac{(l^i)^{1+\epsilon}}{1+\epsilon}} - \Psi'(x) \right] \frac{\partial x}{\partial \hat{\gamma}^*} \quad (57)$$

The first term is the individual's first-order variation with respect to ω times the change in ω when $\hat{\gamma}^*$ changes. The second term is the first-order variation with respect to x times the change in x when $\hat{\gamma}^*$ changes. With no commitment, and with full commitment, these first-order variations are those that the individual would face if she was to choose policy [equations (19) and (20)]. The peak is reached at $\hat{\gamma}=\hat{\gamma}^*$. If $\hat{\gamma}^* < (>) \hat{\gamma}$ the first-order variation is positive (negative) due to the monotonicity of ω and x in $\hat{\gamma}^*$. With partial commitment, the first order variations will not be zero when evaluated at $\hat{\gamma}=\hat{\gamma}^*$. The reason is that the candidate is chosen in period 1, and consequently the identity of the candidate would reveal the policy to be chosen in period 2. To see this more clearly let $\omega^c(\hat{\gamma}^*)$, $x^c(\hat{\gamma}^*)$, $H^c(\omega)$, and $\omega^n(\hat{\gamma}^*)$, $x^n(\hat{\gamma}^*)$, $H^n(\omega)$, be the functions under commitment

and no commitment, respectively. Under commitment the derivatives of $T(\omega^c(\hat{\gamma}^*), x^c(\hat{\gamma}^*), H^c(\omega^c(\hat{\gamma}^*)))$ with respect to ω and x are what a period-one policy maker would face. Similarly, under no commitment the derivatives of $T(\omega^n(\hat{\gamma}^*), x^n(\hat{\gamma}^*), H^n(\omega^n(\hat{\gamma}^*)))$ are what a period-two policy maker would face. However, with partial commitment the policy functions are the no-commitment policy functions, while the human-capital supply function is the supply function under commitment (evaluated at the no-commitment policy function): $T(\omega^n(\hat{\gamma}^*), x^n(\hat{\gamma}^*), H^c(\omega^n(\hat{\gamma}^*)))$. By choosing the $\hat{\gamma}$ of the policy maker in period one in such a way that $\omega^n(\hat{\gamma}^{*'}) = \omega^c(\hat{\gamma}^j)$, the first-order variations under partial commitment evaluated at $\hat{\gamma}^{*'}$ are zero. This is the case when $\hat{\gamma}^{*'} = (1+\epsilon)/(2\epsilon) + [(\epsilon-1)/(2\epsilon)]\hat{\gamma}^j$ (follows from (30) and (23)). Thus, under partial commitment the peak is reached at $\hat{\gamma}^{*'}$, and, as above, single peakedness follows from the monotonicity of ω and x in $\hat{\gamma}^*$. QED

Proof of Propositions 3-4

In the no-commitment case, individuals will predict ω^e accurately. To characterise the equilibrium, ω^e has to be substituted by ω in equation (22). This will result in equation (29), with $v=(\epsilon-1)/2$ in the exponents, but with m^i evaluated at $v=\epsilon$ (see equation (50)). Then, in equation (29) the only difference between the no-commitment and the commitment equilibria is that the former is evaluated at $m^i|_{v=\epsilon}$, and the latter at $m^i|_{v=(\epsilon-1)/2}$. Consequently, in comparing the two equilibria we use equation (51) and perform comparative statics with respect to m^i . First, by using (35),

$$\frac{m^i}{x} \frac{dx}{dm^i} = - \frac{Z_{m^i} m^i}{Z + Z_x x + Z \Psi''(x) x / \Psi'(x)} > 0 \tag{58}$$

since $\partial Z / \partial m^i < 0$. Since $m^i|_{v=\epsilon} < m^i|_{v=(\epsilon-1)/2}$, m^i is greater under commitment, and consequently x is greater under commitment.

Next, since the pollution tax is

$$\tau^x = \mu \tilde{A} x^{\theta-1} H^{1-\theta} \tag{59}$$

we need to evaluate the ratio H/x .

First, using (29),

$$\begin{aligned} \frac{d(H/x)}{dm^i} &= \frac{1}{v+\theta} \frac{H/x}{m^i} - \frac{v}{v+\theta} \frac{H/x}{x} \frac{dx}{dm^i} \\ &= \frac{H/x}{(v+\theta)m^i} \left(1 - v \frac{m^i}{x} \frac{dx}{dm^i} \right) \end{aligned} \tag{60}$$

Next, use (58) to obtain (N.B. $v=(\varepsilon-1)/2$)

$$1 - v \frac{m^i}{x} \frac{dx}{dm^i} = \frac{Z + Z_x x + Z \Psi''(x)x/\Psi'(x) + v Z_{m^i} m^i}{Z + Z_x x + Z \Psi''(x)x/\Psi'(x)} \quad (61)$$

$$= \frac{\frac{\beta}{1+\beta} (1-\alpha) \frac{\varepsilon-1+2\theta}{1+\varepsilon} + Z \Psi''(x)x/\Psi'(x)}{Z + Z_x x + Z \Psi''(x)x/\Psi'(x)} > 0$$

Therefore, $\partial(H/x)/\partial m^i > 0$, and H/x is greater under commitment, implying that τ^x is greater under commitment. Finally since production is $\tilde{A}x^\theta H^{1-\theta} = \tilde{A}x(H/x)^{1-\theta}$, the result on production follows. The result on the after-tax wage follows from (29). The results regarding the identity of the policymaker go through, since m^i is greater under a policymaker with higher ability.

QED

Proof of Proposition 6

As in the proof of Propositions 3-4, the only difference between the no-commitment and the commitment equilibria is that the former is evaluated at $m^i|_{v=\varepsilon}$, and the latter at $m^i|_{v=(\varepsilon-1)/2}$. The distance between the two equilibria is therefore

$$m^i|_{v=(\varepsilon-1)/2} - m^i|_{v=\varepsilon} = (1-\theta)(1-\alpha)\tilde{A} \left(\frac{1}{1+(1-\hat{\gamma}^i)(\varepsilon-1)/2} - \frac{1}{1+(1-\hat{\gamma}^i)\varepsilon} \right) \quad (62)$$

$$= \frac{(1-\theta)(1-\alpha)(1+\varepsilon)\tilde{A}(1-\hat{\gamma}^i)}{[2+(1-\hat{\gamma}^i)(\varepsilon-1)][1+(1-\hat{\gamma}^i)\varepsilon]}$$

This distance is larger the smaller $\hat{\gamma}^i$ is, at least as long as $\varepsilon \leq 2$.

QED

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