Public Policy and Economic Growth
in an Imperfectly Competitive World
of Interdependent Economies

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EUROPEAN UNIVERSITY INSTITUTE, FLORENCE

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Abstract

We consider an artificial world of two interdependent economies which produce differentiated commodities and accumulate human capital. Commodities are traded and human capital production depends on country-specific public expenditure and world-wide knowledge. Public goods are differentiated in terms of their relative yields of consumption and production services. The terms of trade link between countries gives rise to negative policy spillover effects on welfare whilst the externalities in human capital production account for positive policy spillover effects on welfare. We study optimal policy as the equilibrium outcome of a dynamic game between benevolent governments. We show that, whilst welfare is never lower, growth may either be higher or lower under cooperation than under non-cooperation depending on the extent to which public goods are differentiated and the relative strengths of different cross-country externalities.

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1. Introduction

Beginning with the seminal contribution of Romer (1986), the new growth theory has produced many important insights into the growth and development processes of economies.[1] Not least of these insights is the role of public policy in determining growth activity. By endogenizing this activity, the theory has demonstrated the considerable potential for governments to influence growth incentives and affect long-run development through changes in fiscal, monetary, financial and trade regimes. Moreover, there is now overwhelming evidence of these policy effects on growth in real-world economies.[2] In this paper we study the link between policy and growth from a relatively new perspective. Using a model of two interdependent economies, we examine the international welfare and growth implications of cooperative and non-cooperative policy making. We show that cooperation, whilst never reducing welfare, may either promote or retard growth depending on the nature of public services and the source of cross-country externalities.

A minimum condition for generating sustainable growth is a production technology which is homogeneous of degree one in those factors that can be accumulated. This is the basis of all endogenous growth mechanisms and is often motivated by considering some form of (private or public) externality which converts decreasing returns (to accumulable inputs) at the individual level to constant returns at the aggregate level. In the model of this paper the mechanism of growth is human accumulation which is assumed to depend

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on two types of externality: a country-specific, publicly-provided input; and a cross-country, disembodied-knowledge transfer. together, these account for positive policy spillover effects on welfare and growth. We treat policy as endogenous, being determined as the equilibrium outcome that maximizes social welfare. This is in contrast to the exogenous and *ad hoc* treatment of policy in much of the existing growth literature. Here, we deal only with optimal policy.

Our analysis bears on the issue of international policy coordination which draws attention to the strategic aspects of policy design in a world of interdependent economies. There is a large literature on this issue, the basic message of which is that non-cooperative behaviour on the part of national governments leads to inefficient outcomes because of a failure to take account of cross-country externalities; by internalizing these externalities, cooperation is a means of improving efficiency.[3] Two shortcomings of the literature are, first, that most of the models are *ad hoc* and, second, that all of the models describe stationary economies. Consequently, the welfare implications are weak and the gains from cooperation may be seriously understated if growth effects are present. In this paper, the issue of policy coordination is addressed using a maximizing model with growth. Two recent contributions which make the same innovations in different frameworks are Blackburn and Ravn (1993) and Devereux and Mansoorian (1992). In the former it is shown that coordination unambiguously raises both welfare and growth. In the latter it is shown that coordination raises welfare but may either increase or decrease growth. We build on these analyses to produce new results which give further insights into the issue.

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Our model describes an imperfectly-competitive world of two interdependent economies in which households invest in human capital and consume differentiated commodities produced at home and abroad. The government of each economy produces two types of (tax-financed) public good which are differentiated according to their relative yields of consumption and human capital services. In contrast to the positive externalities in human capital accumulation, the terms of trade link between countries gives rise to negative policy spillover effects on welfare. The solution of the model is an inefficient competitive balanced growth equilibrium in which growth rates converge regardless of the distributions of taxes and initial human capital stocks. Per-capita income levels converge if taxes are the same across countries. We study optimal fiscal policy (optimal taxation or the optimal provision of public goods) as the equilibrium outcome of a dynamic game between governments. We show that, whilst welfare is never lower, growth may either be higher or lower under cooperation than under non-cooperation. The ambiguity depends on the degree of differentiation between public goods and the relative strengths of different spillover effects. We illustrate our results with some numerical simulations.

The model is set out in Section 2. Section 3 contains a description of the balanced growth equilibrium. Optimal policy is studied in Section 4. Section 5 concludes.

2.   The Model

We consider an artificial world of two symmetric economies, indexed by k = 1,2. In each economy there is a continuum of monopolistically-competitive firms within the unit interval and a constant population (normalized to one) of identical, infinitely-lived households endowed with perfect foresight.[4] Each firm produces a differentiated commodity, indexed by $i \in (0,1)$, using the services of labour (human capital) hired from households. Each household consumes goods produced at home and abroad, and allocates its time between leisure, work and human capital production. There is a sovereign government of each economy which raises revenue from taxation to finance its purchases of commodities. These purchases are used to provide public goods and services which substitute (imperfectly) for private output and contribute to human capital development. Time is discrete and indexed by $t = 0,1,...,\infty$.

A.   Public Sector Production and Consumption

We distinguish between different types of public good according to their relative yields of consumption and production services. For simplicity, we confine ourselves to the case of two (composite) public goods which the government of country-k provides to its citizens in the amounts $\tilde{G}_{kt}$ and $\vec{G}_{kt}$. By production services we mean services to the production of human capital, as in Blackburn and Ravn (1993). Devereux and Monsoorian (1992) consider the case of publicly-provided inputs (e.g., the maintenance of social infrastructure and provision of law and order) to final manufacturing.[5]

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As regards human capital creation, one may wish to think of a broader range of services, including the provision of information through such means as government publications, public libraries and national museums.

We denote by $\tilde{g}_{kt}(i)$ and $\bar{g}_{kt}(i)$ country-k government's purchases of domestically-produced commodity-i which are used in producing $\tilde{G}_{kt}$ and $\bar{G}_{kt}$, respectively.[6] We assume that public production takes place according to the following CES technologies:

(1) $\tilde{G}_{kt} = (\int_0^1 \tilde{g}_{kt}(i)^\alpha \, di)^{1/\alpha}, \quad \bar{G}_{kt} = (\int_0^1 \bar{g}_{kt}(i)^\alpha \, di)^{1/\alpha} \quad k = 1,2$

where $\alpha \in [0,1]$, α - 1 being the elasticity of substitution.

Government expenditures are financed from (domestic) income tax revenue.[7] Total labour income in country-k is given by $W_{kt} m_{kt} H_{kt}$, where W_{kt} is the nominal wage and $m_{kt} H_{kt}$ is total labour input which is the product of total time devoted to working, m_{kt}, and the aggregate stock of human capital, H_{kt}. Following Devereux and Mansoorian (1992), we assume that expenditures on different public goods are financed separately and define the flat-rate income taxes $\tilde{\tau}_{kt}$ and $\bar{\tau}_{kt}$. Hence, if $P_{kt}(i)$ is the price of commodity-i produced in country-k, then the government of country-k faces the budget constrains

(2) $\int_0^1 P_{kt}(i)\tilde{g}_{kt}(i)di = \tilde{\tau}_{kt} W_{kt} m_{kt} H_{kt}, \quad \int_0^1 P_{kt}(i)\bar{g}_{kt}(i)di = \bar{\tau}_{kt} W_{kt} m_{kt} H_{kt} \quad k = 1,2$

The duty of each government is to provide public services efficiently. This amounts to a two-stage decision problem which may be stated as follows: first, for any given quantity of public good, select those purchases of commodities which minimize expenditure; second, having disposed of cost minimization, choose that quantity of public good which maximizes social welfare. The first problem is standard and solved to yield the following government demands for commodities:

$$(3) \qquad \tilde{g}_{kt}(i) = \frac{\tilde{E}_{kt}^{g} P_{kt}(i)^{1/(\alpha-1)}}{Q_{kt}}, \qquad \vec{g}_{kt}(i) = \frac{\vec{E}_{kt}^{g} P_{kt}(i)^{1/(\alpha-1)}}{Q_{kt}} \qquad k = 1,2$$

where $\tilde{E}_{kt}^{g} = \int P_{kt}(j)\tilde{g}_{kt}(j)dj$, $\vec{E}_{kt}^{g} = \int P_{kt}(j)\vec{g}_{kt}(j)dj$ and $Q_{kt} = \int P_{kt}(j)^{\alpha/(\alpha-1)}dj$. The second problem requires consideration of private sector behaviour and is attended to subsequently in our analysis of dynamically optimal fiscal policies.

B.   Private Sector Production, Consumption and Human Capital Accumulation

The representative household in country-*k* consumes $c_{klt}(i)$ units of commodity-*i* produced in country-*l* and exhausts available time (which is fixed and normalized to one) on work, m_{kt}, human capital production, n_{kt}, and leisure. Its preferences are summarized by the intertemporal utility function,

$$(4) \qquad U_k = \sum_{t=0}^{\infty} \beta^t u(C_{kkt}, C_{klt}, m_{kt}, n_{kt}, \tilde{G}_{kt}, \vec{G}_{kt}) \qquad k, l = 1, 2; \ k \neq l$$

where

$$(5) \qquad u(\cdot) = \log[(C_{kkt}^{\mu} C_{klt}^{1-\mu})(1 - m_{kt} - n_{kt})^{\theta} (\tilde{G}_{kt}^{\varepsilon} \vec{G}_{kt}^{1-\varepsilon})^{\phi}] \qquad k, l = 1, 2; \ k \neq l$$

$$(6) \qquad C_{klt} = (\int_0^1 c_{klt}(i)^{\alpha} di)^{1/\alpha} \qquad k, l = 1, 2$$

such that $\beta, \mu, \theta, \varepsilon, \phi \in (0,1)$. We assume that households substitute goods and services intertemporally with unit elasticity and discount the future at the rate $(1-\beta)/\beta$. The important parameters in equation (5) are μ (the share of expenditure on domestically-produced commodities which determines the extent of terms-of-trade spillovers, ε (the weight on specific public good consumption services which differentiates public goods) and ϕ (the weight on composite public good consumption services). The formulation of the consumption indeces, C_{klt}, in equation (6) implies that the elasticity of substitution between commodities is the same for households as it is for government.[8]

A country-k household enters each period with a stock of human capital, h_{kt}. It faces the budget constraint

$$(7) \qquad \int_0^1 P_{kt}(i)c_{kkt}(i)di + \int_0^1 P_{lt}(i)c_{klt}(i)di = (1 - \tilde{\tau}_{kt} - \mathcal{T}_{kt})W_{kt}m_{kt}h_{kt} \qquad k, l = 1, 2; \ k \neq l$$

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and produces new human capital according to

$$(8) \qquad h_{kt+1} = A(n_{kt}h_{kt})^{\eta}(\tilde{G}_{kt}^{\xi}\vec{G}_{kt}^{1-\xi})^{\psi} H_{kt}^{\delta} H_{lt}^{1-\eta-\psi-\delta} \qquad k,l = 1,2; k \neq l$$

where $\eta, \xi, \psi, \delta \in (0,1)$, $\eta + \psi + \delta \in (0,1)$ and $A > 0$. Equation (8) is a generalization of the human capital production technology considered in Blackburn and Ravn (1993). There are decreasing returns to each input, individually, but constant returns to scale overall. The important parameters are ξ (which differentiates public goods according to their production services), ψ (which determines composite public input good productivity) and $1 - \eta - \psi - \delta$ (which governs the extent of cross-country knowledge spillovers).[9] The technology implies that there are both national and international externalities in the production of human capital which depends on aggregate outcomes $(\tilde{G}_{kt}, \vec{G}_{kt}, H_{kt}$ and $H_{kt})$ that the representative household treats rationally as beyond its control.

Given equation (5) and (8), we make an arbitrary distinction between different public goods by assuming that $\xi \geq \varepsilon$. This implies that a one percent change in $\tilde{G}_{kt}$ has at least the same percentage effect on human capital production relative to utility as a one percent change in $\vec{G}_{kt}$. In other words, $\tilde{G}_{kt}$ is more specialized in yielding production services and $\vec{G}_{kt}$ is more specialized in yielding consumption services. The two extreme cases are when $\varepsilon = \xi = 0.5$ (two identical public goods) and when $\varepsilon = 0$ and $\xi = 1$ (two completely specialized public goods).[10]

The decision problem of a household is to choose the sequences $\{c_{kkt}(i)\}_{t=0}^{\infty}$, $\{c_{klt}(i)\}_{t=0}^{\infty}$, $\{m_{kt}\}_{t=0}^{\infty}$, $\{n_{kt}\}_{t=0}^{\infty}$ and $\{h_{kt}\}_{t=0}^{\infty}$ which maximize utility and are feasible. In doing this, the household makes forecasts of, and takes as given, the sequences $\{\tilde{\tau}_{kt}\}_{t=0}^{\infty}$, $\{\vec{\tau}_{kt}\}_{t=0}^{\infty}$, $\{\tilde{G}_{kt}\}_{t=0}^{\infty}$, $\{\vec{G}_{kt}\}_{t=0}^{\infty}$, $\{H_{kt}\}_{t=0}^{\infty}$ and $\{H_{lt}\}_{t=0}^{\infty}$. The problem, denoted $\mathbf{P}_k$, may be written in terms of the functional equation

(9) $\mathbf{P}_k: V(h_{kt}, \tilde{G}_{kt}, \vec{G}_{kt}, \tilde{\tau}_{kt}, \vec{\tau}_{kt}, H_{kt}, H_{lt}) =$

$$\max_{[c_{kkt}(i), c_{klt}(i), m_{kt}, n_{kt}, h_{kt+1}]} \{u(C_{kkt}, C_{klt}, m_{kt}, n_{kt}, \tilde{G}_{kt}, \vec{G}_{kt})$$

$$+\beta V(h_{kt+1}, \tilde{G}_{kt+1}, \vec{G}_{kt+1}, \tilde{\tau}_{kt+1}, \tilde{\tau}_{kt+1}, H_{kt+1}, H_{lt+1})\}$$

s.t. (7) and (8); given h_{k0} $k,l = 1,2; k \neq l$

where $V(\cdot)$ is the value function. The dynamic program has a well-defined solution which is derived in the Appendix. The solution implies the following relationships describing aggregate household behaviour:

(10) $c_{kkt}(i) = \dfrac{\mu E_{kt} P_{kt}(i)^{1/(\alpha-1)}}{Q_{kt}}$, $c_{klt}(i) = \dfrac{(1-\mu)E_{kt}P_{lt}(i)^{1/(\alpha-1)}}{Q_{lt}}$

(11) $m_{kt} = m = \dfrac{1-\eta\beta}{1+\theta(1-\eta\beta)}$, $n_{kt} = n = \dfrac{\eta\beta}{1+\theta(1-\eta\beta)}$

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(12) $H_{kt+1} = An^{\eta}(\tilde{G}_{kt}^{\xi}\tilde{G}_{kt}^{1-\xi})^{\psi} H_{kt}^{\eta+\delta} H_{lt}^{1-\eta-\psi-\delta}$

$\quad k,l = 1,2; k \neq l$

where $E_{kt} = \int P_{kt}(j)c_{kkt}(j)dj + \int P_{lt}(j)c_{klt}(j)dj$. Equation (10) gives the demands for domestic and foreign commodities. Equation (11) shows that the fractions of time $(m,n \in (0,1)$ devoted to work and human capital production are the same in each country, being constant and independent of policy and growth. Equation (12) describes aggregate human capital accumulation.[11]

The monopolistically-competitive manufacturer of commodity-i in country-k employs $m_{kt}(i)h_{kt}(i)$ units of labour to produce $y_{kt}(i)$ units of differentiated product according to the constant returns to scale technology.

(13) $y_{kt}(i) = m_{kt}(i)h_{kt}(i)$ $\qquad k = 1,2$

The firm's total costs are equal to variable labour costs, $W_{kt}m_{kt}(i)h_{kt}(i)$, plus a fixed cost, κ. The firm chooses the price, $P_{kt}(i)$, which maximizes profits subject to $y_{kt}(i) = c_{kkt}(i) + c_{lkt}(i) + \tilde{g}_{kt}(i) + \tilde{g}_{kt}(i)$, given equations (3) and (10). The result is the standard constant mark-up rule

(14) $P_{kt}(i) = P_{kt} = \dfrac{W_{kt}}{\alpha}$ $\quad k = 1,2$

for all $i \in (1,0)$. In equilibrium the firm earns zero profits.[12]

3. General Equilibrium

Our prototype world economy has a perfect foresight equilibrium in which all decisions are optimal and feasible, and all forecasts are realised. The equilibrium is inefficient due to the presence of externalities, distortionary taxation and imperfect competition. It is constructed as follows.

By virtue of symmetry (in particular, equation (14)), the commodity index, $i \in (0,1)$, can be dropped from all variables. Hence, from equations (1), (3), (6) and (10), we have $\tilde{G}_{kt} = \tilde{g}_{kt} = \tilde{E}_{kt}^g / P_{kt}$, $\vec{G}_{kt} = \vec{g}_{kt} = \vec{E}_{kt}^g / P_{kt}$, $C_{kkt} = c_{kkt} = \mu E_{kt} / P_{kt}$ and $C_{klt} = c_{klt} = (1-\mu)E_{kt} / P_{lt}$. The expenditure terms in these expressions follow from equations (2) and (7) as $\tilde{E}_{kt}^g (= P_{kt}\tilde{g}_{kt}) = \tilde{\tau}_{kt}W_{kt}mH_{kt}$, $\vec{E}_{kt}^g (= P_{kt}\vec{g}_{kt}) = \vec{\tau}_{kt}W_{kt}mH_{kt}$ and $E_{kt}(= P_{kt}c_{kkt} + P_{lt}c_{klt}) = (1 - \tilde{\tau}_{kt} - \vec{\tau}_{kt})W_{kt}mH_{kt}$, where we have also made use of $m_{kt} = m$ from equation (11). Appropriate substitution in equation (12) reveals that aggregate human capital accumulation satisfies

$$(15) \quad H_{kt+1} = Z(\tilde{\tau}_{kt}^{\xi}\vec{\tau}_{kt}^{1-\xi})^\psi H_{kt}^{\eta+\psi+\delta} H_{lt}^{1-\eta-\psi-\delta} \quad k,l = 1,2; k \neq l$$

where $Z = An^\eta(\alpha m)^\psi$.

The growth rate of country-k is given by H_{kt+1}/H_{kt}. As in Blackburn and Ravn (1993), a key implication of equation (15) is that, if taxes are constant,

there is cross-country convergence of growth rates regardless of the distributions of taxes and initial human capital stocks. The irrelevance of initial human capital is accounted for by the international spillovers of knowledge which imply that the economy with the least human capital has the highest rate of return to human capital investment. This insight is credited to Tamura (1991) but, unlike the model in that paper, the framework developed here does not predict automatic convergence of per-capita income levels: for this to occur, tax rates must be the same across countries.[13]

Each economy is subject to the same balance of payments constraint. Since there are no (physical) capital flows between countries, this is equivalent to the balance of trade equilibrium condition $\int P_{kt}(i)c_{lkt}(i)di - \int P_{lt}(i)c_{klt}(i)di = 0$. From this, together with our previous expressions, we obtain

$$(16) \quad \frac{P_{kt}}{P_{lt}} = \frac{(1-\tilde{\tau}_{lt}-\daleth_{lt})H_{lt}}{(1-\tilde{\tau}_{kt}-\daleth_{kt})H_{kt}} \quad k,l = 1,2; \; k \neq l$$

which determines the terms of trade, where the ratio on the right-hand-side measures relative real expenditures in the two countries.[14]

Given the above, we may write the household's momentary utility function in equation (5) as $u(\cdot) = v(\cdot)$, where

$$(17) \quad v(\tilde{\tau}_{kt},\daleth_{kt},\tilde{\tau}_{lt},\daleth_{lt},H_{kt},H_{lt}) = X + \log[(1-\tilde{\tau}_{kt}-\daleth_{kt})H_{kt}]$$

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$$+(1-\mu)(\log[(1-\widetilde{\tau}_{lt}-\overline{\tau}_{lt})H_{lt}]-\log[(1-\widetilde{\tau}_{kt}-\overline{\tau}_{kt})H_{kt}])$$

$$+\phi\varepsilon\log[\widetilde{\tau}_{kt}H_{kt}]+\phi(1-\varepsilon)\log[\overline{\tau}_{kt}H_{kt}] \qquad k,l=1,2;\ k\neq l$$

such that $X=\log[\mu^{\mu}(1-\mu)^{1-\mu}(\alpha m)^{1+\phi}(1-m-n)^{\theta}]$. Equations (15) and (17) reveal the trade-offs in fiscal policy. On the one hand, higher domestic taxation means more public good consumption and production services which makes domestic households better off both directly (in the present) and indirectly (in the future) through greater human capital accumulation. On the other hand, higher domestic taxes means less (current) disposable income which makes domestic households worse off. The international dimensions to the problem are manifested in the cross-country spillovers in human capital production and the terms of trade. The spillovers in human capital production (accounted for by the term $H_{lt}^{1-\eta-\psi-\delta}$ in equation (15)) imply that there are positive externalities from taxation. The spillovers through the terms of trade (reflected in the term $(1-\mu)(\cdot)$ in equation (17)) mean that there are negative externalities from taxation. In providing public goods efficiently, the government of each country must optimally take account of these aspects of policy. The trade-offs involved mean that maximizing welfare is not the same as maximizing growth: growth, itself, has no normative significance in our world.

4.   Optimal Policy

A benevolent government maximizes social welfare by maximizing the utility of the representative household. It does so by choosing policies for tax rates which optimize the intertemporal trade-off between current and future income (consumption). This dynamic optimal taxation problem is made interesting by the interdependence between countries associated with the human capital and terms of trade spillover effects. Because of this interdependence, growth and welfare in each country are determined by the fiscal policies of both countries.

The problem is solved as the equilibrium outcome of a dynamic game between governments. The game may be played either cooperatively or non-cooperatively. In the case of cooperation, governments choose tax strategies together so as to maximize a joint welfare function, taking account of the cross-country externalities. In the case of non-cooperation, governments choose tax strategies separately so as to maximize their own welfare functions, taking as given the tax strategy of each other. We distinguish between two types of non-cooperative environment: by "isolationist" we mean a situation in which each government also takes as given the production of human capital in the other country; by "strategic" we mean the case in which each government recognizes the effects of its policies on human capital production abroad.[15]   For simplicity, we assume that countries are endowed with the same initial stock of human capital, $H_{k0} = H_0$. In all cases, optimization is conducted subject to the world competitive equilibrium.

Let P_k^{gNI}, P_k^{gNS} and P^{gC} denote the problems facing the government of country-k under "isolationsist" non-cooperation, "strategic" non-cooperation and cooperation, respectively. These problems are defined by the functional equations

$$(18) \quad P_k^{gNI}: V^g(H_{kt}, H_{lt}) \underset{[\tilde{\tau}_{kt}, \daleth_{kt}, H_{kt+1}]}{\max.} \{v(\tilde{\tau}_{kt}, \daleth_{kt}, \tilde{\tau}_{lt}, \daleth_{lt}, H_{kt}, H_{lt})$$

$$+\beta V^g(H_{kt+1}, H_{lt+1})\}$$

$$(19) \quad P_k^{gNS}: V^g(H_{kt}, H_{lt}) \underset{[\tilde{\tau}_{kt}, \daleth_{kt}, H_{kt+1}, H_{lt+2}]}{\max.} \{v(\tilde{\tau}_{kt}, \daleth_{kt}, \tilde{\tau}_{lt}, \daleth_{lt}, H_{kt}, H_{lt})$$

$$+\beta V^g(H_{kt+1}, H_{lt+1})\}$$

$$(20) \quad P^{gC}: V^g(H_{kt}, H_{lt}) \underset{[\tilde{\tau}_{kt}, \daleth_{kt}, \tilde{\tau}_{lt}, \daleth_{lt}, H_{kt+1}, H_{lt+1}]}{\max.} \{v(\tilde{\tau}_{kt}, \daleth_{kt}, \tilde{\tau}_{lt}, \daleth_{lt}, H_{kt}, H_{lt})$$

$$+v(\tilde{\tau}_{lt}, \daleth_{lt}, \tilde{\tau}_{kt}, \daleth_{kt}, H_{lt}, H_{kt}) + \beta V^g(H_{kt+1}, H_{lt+1})\}$$

s.t. (15); given I_0 $k,l = 1,2$; $k \neq l$

where $V^g(\cdot)$ is the value function of the government. In P_k^{gNI} the government chooses policies for $\tilde{\tau}_{kt}$ and $\daleth_{kt}$ which maximize its own welfare, given the policies of the other government and ignoring the spillovers in human capital production. In P_k^{gNS} the government solves the same problem but, this time, takes account of the knowledge spillovers. In P^{gC} the two

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governments choose policies together so as to maximize an equal-weighted world welfare function, taking into account all externalities.[16]

The problems are solved in the Appendix to produce perfect Nash equilibria, where the optimal tax rates in each case satisfy $\tilde{\tau}_{kt} = \tilde{\tau} \in (0,1)$ and $\tilde{\daleth}_{kt} = \tilde{\daleth} \in (0,1)$ such that $\tilde{\tau} + \tilde{\daleth} \in (0,1)$; equilibrium policies are constant and the same in both countries. It follows from equation (15) that each country experiences the same (time invariant) equilibrium rate of growth given by

$$(21) \quad \frac{H_{kt+1}}{H_{kt}} = \gamma = Z(\tilde{\tau}^{\xi}\tilde{\daleth}^{1-\xi})^{\psi} \qquad k = 1,2$$

Using equation (17), the value of welfare in each country may be expressed as

$$(22) \quad U_k = U = \frac{1}{1-\beta}\left[X' + \log(1 - \tilde{\tau} - \tilde{\daleth}) + \left(\frac{\beta\psi\xi(1+\phi)}{1-\beta} + \phi\varepsilon \right)\log(\tilde{\tau}) \right.$$

$$\left. + \left(\frac{\beta\psi(1-\xi)(1+\phi)}{1-\beta} + \phi(1-\varepsilon) \right)\log(\tilde{\daleth}) \right] \qquad k = 1,2$$

where $X' = X + (1+\phi)\log(H_0) + \beta(1+\phi)\log(Z)/(1-\beta)$.[17] It is evident that there are no transitional dynamics in the model. Both economies are always on the balanced growth path and everything is determined once initial human capital is known.

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The precise expressions for equilibrium tax rates are summarized in Table 1. We emphasize the dependence on certain key parameters, namely ε, ξ, μ and Ω. Recall that the parameters ε and ξ determine the degree of differentiation between public goods and that the parameters μ and Ω govern the strengths of cross-country externalities. The extent to which these externalities are taken into account explains the differences between optimal policies. Taking account of the terms of trade spillovers means that the prospect of reducing the current costs (future benefits) of taxation by causing a current improvement (future deterioration) in the terms of trade is eliminated. Taking account of the human capital spillovers means that the prospect of raising future benefits through greater world-wide human capital accumulation is realised. "Isolationism" and cooperation define opposite extremes, producing policies which mix together in the intermediate case of "strategic" non-cooperation. The internalization of externalities under cooperation is clearly visible in the valuations of the quantities $\tau^0(\cdot)$ and $\tau^1(\cdot)$. It is straightforward to show that countries are never worse off under cooperation than under non-cooperation.[18] This result is not surprising but the fact that our model admits growth means that the quantitative gains from international policy coordination may be very different from those suggested so far in the literature.

The interesting results of the paper relate to the growth implications of policy coordination. Our main finding is that growth may either be higher or lower under cooperation than under non-cooperation depending on the extent to which public goods are differentiated and the relative strengths of

different cross-country externalities. In Table 2 we report the qualitative effects of parameter variations on equilibrium taxes. In Table 3 we report the results of comparing equilibrium taxes. Since higher taxes (higher public services) mean higher growth, the conclusion to be drawn is that growth is more likely to be higher under cooperation than under non-cooperation the more specialized are public goods (the smaller is ε and the larger is ξ), the more potent are human capital spillovers (the smaller is Ω) and the less potent are terms of trade spillovers (the larger is μ). The intuition is as follows.[19]

The two spillover effects exert opposite forces on optimal policies. On the one hand, the spillovers through human capital production imply positive externalities on welfare which tend to bias non-cooperative tax rates downwards. On the other hand, the spillovers through the terms of trade imply negative externalities on welfare which tend to bias non-cooperative tax rates upwards. Whether taxes (and hence growth) are higher or lower under cooperation than under non-cooperation depends essentially on which of the spillover effects dominates. The precise magnitudes of these effects on equilibrium taxes depend on the degree of public good specialization. Under non-cooperation, greater specialization makes both the effect of human capital spillovers on $\bar{\tau}$ and the effect of terms of trade spillovers on $\bar{\tau}$ relatively stronger. Since the more productive policy ($\bar{\tau}$) suffers a greater downward bias, the conditions for cooperation to promote growth are more favourable.

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Confirmation of the above reasoning is provided by the results of limiting cases, reported in Table 4. These are the cases of no human capital spillovers ($\Omega = 1$), no terms of trade spillovers ($\mu = 1$), zero public good specialization ($\varepsilon = \xi = 0.5$), complete public good specialization ($\varepsilon = 0$, $\xi = 1$) and, additionally, no public consumption goods ($\phi = 0$). Where no inequality appears between terms, the ranking of these terms remains ambiguous. In the case of $\Omega = 1$ ($\mu = 1$) the presence of only negative (positive) policy spillovers means that growth is never higher (lower) under cooperation than under non-cooperation. On moving from the case of $\varepsilon = \xi = 0.5$ to the case of $\varepsilon = 0$, $\xi = 1$ the ranking of growth rates shifts in favour of cooperation. For the case in which $\phi = 0$, terms of trade spillovers have relatively little influence so that cooperation never produces inferior growth. These results may be compared with those obtained by others. In the framework of Devereux and Mansoorian (1992) the ranking of cooperative and non-cooperative growth rates depends essentially on the elasticity of intertemporal substitution such that an elasticity equal to (or greater than) one establishes the ranking in favour of cooperation. This dependence disappears when public goods yield only production services, in which case cooperative and non-cooperative outcomes (including welfare levels) coincide. In our model the ranking of growth rates depends on other factors and is generally ambiguous even though there is unit elasticity. Also, the coincidence of outcomes in the case of $\phi = 0$ requires the additional restriction that $\Omega = 1$. In the framework of Blackburn and Ravn (1993), the absence of terms of trade spillovers means that cooperation necessarily improves growth. We approach the results of that framework by imposing

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$\mu = 1$ and replicate the results exactly after setting $\phi = 0$ and $\xi = 1$. As a final observation, we note that the differences between "isolationist" and "strategic" non-cooperative outcomes vanish when $\Omega = 1$ since there are then no human capital externalities either to ignore or to take account of (which is what distinguishes these cases).

To gain an idea of the quantitative differences between alternative scenarios, we have simulated the model under a range of parameter values around a benchmark set of $\{\beta = 0.956, \mu = 0.750, \alpha = 0.920, \theta = 0.466, \varepsilon = 0.350, \phi = 0.022, A = 1.547, \eta = 0.750, \xi = 0.650, \psi = 0.022, \delta = 0.114\}$. This benchmark is the product of a calibration based on an average annual rate of growth of 1.7 per cent and an average total rate of taxation of 25 per cent across cooperative and non-cooperative regimes.[20] Unless otherwise stated, deviations from this benchmark are the result of varying each parameter in turn, holding all other parameters constant. Two types of normative analysis are conducted. The first is a straightforward comparison of welfare levels across regimes. The second involves finding the percentage reduction in consumption each period which reduces the level of welfare in one regime to the level in another.[21] Our results, summarized in Table 5 and Figures 1 - 4, show that, depending on parameter values, the growth and welfare effects of cooperation can be sizeable. Of course, the results are meant only to be illustrative rather than definitive, especially given the uncertainty surrounding some of the parameters.

Table 5 contains the results for the benchmark case. There is as much as an 18 per cent reduction in growth and a 2.5 per cent reduction in welfare (equivalent to a 1.3 per cent decrease in consumption each period) on moving from cooperation to "strategic" non-cooperation. The costs become greater still on moving to the "isolationist" environment, there being a further 70 per cent reduction in growth and a further 33 per cent reduction in welfare (equivalent to a further 15 per cent decrease in consumption each period).

Figures 1 - 4 illustrate the effects of deviations from the benchmark in terms of cooperative and "strategic" non-cooperative outcomes. The effect of increasing (decreasing) μ is to increase (decrease) both the growth and welfare gains from cooperation which are maximized at $\mu = 1$ (Figure 1). The value $\mu *$ is the critical point at which cooperative and non-cooperative growth rates coincide: successively lower values of μ below $\mu *$ lead to successively higher rates of growth under non-cooperation. Similar observations are made for variations in $1 - \Omega$ (Figure 2).[22] Both the growth and welfare costs of non-cooperation are increasing in this parameters with $1 - \Omega *$ being the critical value at which cooperative and non-cooperative growth rates are equal and below which successively lower values of $1 - \Omega$ lead to successively higher rates of growth under non-cooperation. Together, these results for μ and $1 - \Omega$ suggest that one needs either relatively large terms of trade spillovers or relatively small human capital spillovers for non-cooperation to have a growth advantage. This need not be the case under more general parameter variations for which more moderate

pairs of μ and $1 - \Omega$ might equalize cooperative and non-cooperative growth rates. It is possible to see this simply by varying both μ and $1 - \Omega$ simultaneously around their mid-values (Figure 3). Finally, the effects of varying ε and ξ are illustrated for the case in which $\mu < \mu^*$ so that growth is initially lower under cooperation than under non-cooperation when these parameters are at their benchmark values (Figure 4). Starting from the position of $\varepsilon = \xi = 0.5$ (zero public good differentiation), the effect of decreasing ε and increasing ξ (that is, increasing the degree of differentiation) is to raise cooperative growth at a faster rate then non-cooperative growth such that the former overtakes the latter beyond some critical point, $\varepsilon^*(\xi^*)$.

5.   Conclusions

This paper is intended both as a contribution to the new growth literature and as a contribution to the international policy coordination literature. Its contribution to the growth literature is the endogenization of policy in an endogenous growth model such that policy is determined optimally as the equilibrium outcome that maximizes social welfare. Its contribution to the policy coordination literature is the incorporation of growth effects into a model of strategically-interdependent economies engaged either in cooperative or non-cooperative behaviour. We believe that the analysis could be usefully extended to address other, related issues. For example, if

policy coordination is counter-productive, might not the costs of coordination be much greater in a growth model than in a non-growth model? And likewise, if, in the absence of precommitment, time inconsistency leads to inferior discretionary equilibria, might not the costs of non-commitment be much larger if growth effects are present than if they are not? We hope to address such issues in future research.

ENDNOTES

1. Subsequent major contributions include Lucas (1988), Grossman and Helpman (1989, 1991a) and Romer (1987, 1990). For surveys of the new growth theory, see Barro and Sala-i-Martin (1995) and Grossman and Helpman (1991b).

2. For surveys of this evidence, see Easterly and Rebelo (1992) and Fischer (1992, 1993).

3. See, e.g. Canzoneri and Henderson (1988), Jensen (1994), Levine and Currie (1987), Miller and Salmon (1985) and Oudiz and Sachs (1984). Some authors (e.g. Kehoe 1990; Rogoff 1985) have constructed models in which cooperation can be counter-productive. This arises when there are strategic interactions not only between governments but also between governments and private agents. Fischer (1987) provides a survey of the literature.

4. The assumption that population is constant and the same in each country is not entirely innocuous. As pointed out by Barro and Sala-i-Martin (1995), in almost any model with externalities there are scale effects which mean that growth is increasing in population. By precluding these effects (which do not directly concern us and which can be disputed empirically), we ensure that the model has a steady state equilibrium in which both countries grow at the same, constant rate.

5. This was originally studied by Barro (1990) in the context of a closed economy.

6. The assumption that each government purchases only domestically-produced output is made largely for simplicity. The implications of relaxing the assumption are commented upon when appropriate.

7. Thus, as in Blackburn and Ravn (1993) and Devereux and Mansoorian (1992) we abstract from debt-related issues and consider only balanced budget fiscal policies.

8. Our assumptions ensure tractibility without too much loss of generality. Since there is unit intertemporal elasticity of substitution and $\beta \in (0,1)$, utility is bounded under constant geometric growth.

9. The inclusion of H_{lt}, the aggregate stock of human capital abroad, was first motivated by Tamura (1991) as reflecting a system of imperfect property rights in the acquisition and transmission of knowledge across countries.

10. The first case is more-or-less equivalent to that of $\varepsilon = \xi = 1$ which reduces to the specification in Blackburn and Ravn (1993) when $\mu = 1$ and $\phi = 0$. The second case is considered by Devereux and Mansoorian (1992).

11. The properties of the time allocations are specific to logarithmic utility. A more general CES preference structure would make the model less tractible without substantially altering the main results.

12. The simple price-setting rule in equation (13) is a result of our assumption that households and governments substitute between commodities with the same elasticity. Relaxing the assumption would complicate the analysis without changing the basic message of the paper.

13. These results may be established as follows. Define $H'_t = \log(H_{kt}) - \log(H_{lt})$ and $\tau' = \log(\bar{\tau}_{kt}^{\xi} \beth_{kt}^{1-\xi}) - \log(\bar{\tau}_{lt} \beth_{lt}^{1-\xi})$. From equation (14), we have $H'_{t+1} = (2(\eta + \psi + \delta) - 1)H'_t + \eta\tau'_t$. Since $\eta, \psi, \delta \in (0,1)$ and $\eta + \psi + \delta \in (0,1)$, we know that $|2(\eta + \psi + \delta) - 1| \in (0,1)$ so that this difference equation is stable, generating monotonic (cyclical) convergence if $\eta + \psi + \delta > 1/2$ ($\eta + \psi + \delta < 1/2$). If tax rates are constant, the solution is $H'_t = (2(\eta + \psi + \delta) - 1)' H'_0 + \eta\tau' / 2(1 - \eta - \psi - \delta)$. Hence, $H'_{t+1} - H'_t = (2(\eta + \psi + \delta) - 1)' H'_0 2(\eta + \psi + \delta - 1)$ so that $\lim_{t \to \infty} (H'_{t+1} - H'_t) = 0$, implying convergence of growth rates. If taxes are the same across countries, $\tau' = 0$ so that $\lim_{t \to \infty} H'_t = 0$, implying convergence of per-capita income levels.

14. It is here where our assumption that governments purchase only domestically-produced goods is important. If one were to relax this

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assumption, then the effect of government expenditures on the terms of trade would make the analysis considerably less tractible.

15. "Isoltionaism" would describe the case of an irrational government or a government of a small open economy. In the case of "strategic" non-cooperation, a government takes account of the fact that, by affecting human capital production at home, its policies have spillover effects on human capital production abroad which, in turn, have spillover effects back on domestic human capital production.

16. The equal weighting assumption is not only convenient but also appropriate, given our assumption that countries are endowed with equal initial stocks of human capital.

17. Equation (22) establishes that U is bounded so that the problem is well-defined, as we claimed earlier.

18. Observe that equilibrium welfare in equation (22) is maximized when $\bar{\tau} = [\beta\psi\xi(1+\phi) + \phi\varepsilon(1-\beta)]/(1+\phi)(1-\beta-\beta\psi)$ and $\bar{\partial} = [\beta\psi(1-\xi)(1+\phi) + \phi(1-\varepsilon)(1-\beta)]/(1+\phi)(1-\beta-\beta\psi)$ which are precisely the cooperative equilibrium policies, $\bar{\tau}^c$ and $\bar{\partial}^c$, respectively.

19. We maintain the assumption made earlier that $\xi \geq \varepsilon$. The effect of Ω on $\bar{\partial}^{NI}$ and $\bar{\partial}^{NS}$ is positive (negative) if $(1-\xi)(\mu+\phi) >(<) \phi(1-\varepsilon)$.

20. Given 1.7 per cent growth, the discount factor, β, is assigned a value consistent with an annual real rate of interest of 6.4 per cent. The value of μ is chosen to reflect a 75 per cent share of consumers' expenditure on domestically-produced goods. Setting the average output share of government expenditure equal to 23 per cent, and given the average total tax rate of 25 per cent, we infer the value of α from the government's consolidated budget constraint (the sum of the constraints in equation (2)). The extent to which public goods are differentiated is chosen subject to the restriction $\varepsilon = 1 - \xi$. The magnitude of η is selected so as to make the externalities in human capital production small, while the restriction $\delta = 1.005(1-\Omega)$ is imposed so as to grant knowledge spillovers within a country slightly more influence than knowledge spillovers across countries. Summing the expressions for tax rates in each of the regimes, and taking the

average of these, we set $\phi = \psi$ and compute its implied value. Under the assumption that the share of time devoted to market work is 25 per cent, equation (11) is used to value θ. This leaves the technology parameter, A, which is evaluated by taking the average of equation (21) across regimes.

21. This is calculated as follows. By appropriate substitution, we may write $u(\cdot) = \upsilon(\cdot)$, where

$\upsilon(c_{kt}, \tilde{\tau}, \tilde{d}, H_{kt}) = \log[((1-\mu)/\mu)^{1-\mu}(1-m-n)^{\theta}(\alpha m)^{\bullet}] + \log[c_{kt}(\tilde{\tau}^{\epsilon}\tilde{d}^{1-\epsilon}H_{kt})^{\bullet}$. Taking any pair of regimes - 1 and 2, say - we compute the quantity π which satisfies the condition $\sum_{t=0}^{\infty}\beta^{t}\upsilon(c_{kt}^{1}(1-\pi), \tilde{\tau}^{1}, \tilde{d}^{1}, H_{kt}^{1}) = \sum_{t=0}^{\infty}\beta^{t}\upsilon(c_{kt}^{2}, \tilde{\tau}^{2}, \tilde{d}^{2}, H_{kt}^{2})$.

Since consumption grows at a constant rate, π is determined such that agents are indifferent between (1) the tax rates under one regime and (2) the tax rates under another with a 100 x π per cent reduction in consumption each period. The computation can be made using the formula

$\log(1-\pi) = \log((1 - \tilde{\tau}^{2} - \tilde{d}^{2})/(1 - \tilde{\tau}^{1} - \tilde{d}^{1})) + [\epsilon\phi + \xi\beta\psi(1+\phi)/(1-\beta)]\log(\tilde{\tau}^{2}/\tilde{\tau}^{1})$

$+ [(1-\epsilon)\phi + (1-\xi)\beta\psi(1+\phi)/(1-\beta)]\log(\tilde{d}^{2}/\tilde{d}^{1}) = (1-\beta)(U^{2} - U^{1})$, where U is given in equation (22).

22. Variation in Ω are the result of variations in δ (rather than variations in η or ψ) which do not affect any other aspects of the equilibrium. The range of variations is forced to satisfy the condition $\delta \geq 1 - \Omega \geq 0$, given the benchmark values for η and ψ.

APPENDIX

A. *The Household's Problem*

Problem $\mathbf{P}_k$, defined in equation (9), is solved as follows. Let

$V(\cdot|t+s) = V(h_{kt+s}, \tilde{G}_{kt+s}, \vec{G}_{kt+s}, \tilde{\tau}_{kt+s}, \vec{\tau}_{kt+s}, H_{kt+s}, H_{lt+s})$, $E_{kt} = \int P_{kt}(i)c_{kkt}(i)di +$

$\int P_{lt}(i)c_{klt}(i)di = (1 - \tilde{\tau}_{kt} - \vec{\tau}_{kt})W_{kt}m_{kt}h_{kt}$ and $N_{kt} = n_{kt}/(1 - m_{kt} - n_{kt})$. In addition,

observe that $\partial h_{kt+1}/\partial n_{kt} = \eta h_{kt+1}/n_{kt}$ and $\partial h_{kt+1}/\partial h_{kt} = \eta h_{kt+1}/h_{kt}$. The marginal

conditions may be expressed as

(A1) $\quad \dfrac{\mu c_{kkt}(i)^{\alpha-1}}{C_{kkt}^{\alpha}} = \zeta_{kt} P_{kt}(i)$

(A2) $\quad \dfrac{(1-\mu)c_{klt}(i)^{\alpha-1}}{C_{klt}^{\alpha}} = \zeta_{kt} P_{lt}(i)$

(A3) $\quad \dfrac{\theta}{1 - m_{kt} - n_{kt}} = \dfrac{\zeta_{kt} E_{kt}}{m_{kt}}$

(A4) $\quad \dfrac{\theta}{1 - m_{kt} - n_{kt}} = \dfrac{\beta \partial V(\cdot|t+1)}{\partial h_{kt+1}} \dfrac{\partial h_{kt+1}}{\partial n_{kt}}$

(A5) $\quad \dfrac{\partial V(\cdot|t+1)}{\partial h_{kt+1}} = \dfrac{\beta \partial V(\cdot|t+2)}{\partial h_{kt+2}} \dfrac{\partial h_{kt+2}}{\partial h_{kt+1}} + \dfrac{\zeta_{kt+1} E_{kt+1}}{h_{kt+1}}$

where ζ_{kt} is the multiplier on the budget constraint. Equations (A1), (A2)
and (A3) are the static optimality conditions, where the terms on the left-
hand-sides are the momentary marginal utilities of $c_{kkt}(i)$, $c_{klt}(i)$ and m_{kt},

respectively. Equation (A4) establishes the equality between the current marginal cost and discounted future marginal benefits of n_{kt}, where the future benefits accrue from the effect on human capital, $\partial h_{kt+1} / \partial n_{kt}$. Equation (A5) gives the marginal value of h_{kt+1} which contributes to future welfare through the effect $\partial h_{kt+2} / \partial h_{kt+1}$.

Conditions (A1) and (A2) imply the relative commodity demands

$$(A6) \quad \frac{c_{kkt}(i)}{c_{kkt}(j)} = \left(\frac{P_{kt}(i)}{P_{kt}(j)} \right)^{1/(\alpha-1)}$$

$$(A7) \quad \frac{c_{klt}(i)}{c_{klt}(j)} = \left(\frac{P_{lt}(i)}{P_{lt}(j)} \right)^{1/(\alpha-1)}$$

The same equations may be integrated and combined to yield $\zeta_{kt} = 1/E_{kt}$. By appropriate substitution, the expressions for $c_{kkt}(i)$ and $c_{klt}(i)$ in equation (10) are obtained.

Combining conditions (A4) and (A5) yields the difference equation

$$(A8) \quad \beta\eta N_{kt+1} - N_{kt} = \frac{\beta\eta}{\theta}$$

The solution to this equation is

$$(A9) \quad N_{kt} = \frac{\beta\eta}{\theta(1-\beta\eta)}$$

Using condition (A3), one obtains the results for m_{kt} and n_{kt} in equation (11).

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B. The Government's Problem

Problems P_k^{gNI}, P_k^{gNS} and P^{gC}, defined in equations (18), (19) and (20), are solved following the procedure set out in Blackburn and Ravn (1993). Let $V^g(\cdot|t+s) = V^g(H_{kt+s}, H_{lt+s})$, $\tilde{T}_{kt} = \tilde{\tau}_{kt} / (1 - \tilde{\tau}_{kt} - \vec{a}_{kt})$ and $\vec{P}_{kt} = \vec{a}_{kt} / (1 - \tilde{\tau}_{kt} - \vec{a}_{kt})$. In addition, observe that

$$\partial H_{kt+1} / \partial \tilde{\tau}_{kt} = \psi \xi H_{kt+1} / \tilde{\tau}_{kt}, \partial H_{kt+1} / \partial \vec{a}_{kt} = \psi(1-\xi) H_{kt+1} / \vec{a}_{kt}, \partial H_{kt+1} / \partial H_{kt}$$

$$= \Omega H_{kt+2} / H_{kt+1} \text{ and } \partial H_{kt+1} / \partial H_{lt} = (1-\Omega) H_{kt+1} / H_{lt}, \text{ where } \Omega = \eta + \psi + \beta.$$

For problem P_k^{gNI}, the optimality conditions are

$$\text{(B1)} \quad \frac{\mu}{1 - \tilde{\tau}_{kt} - \vec{a}_{kt}} - \frac{\theta \varepsilon}{\tilde{\tau}_{kt}} = \frac{\beta \partial V^g(\cdot|t+1)}{\partial H_{kt+1}} \frac{\partial H_{kt+1}}{\partial \tilde{\tau}_{kt}}$$

$$\text{(B2)} \quad \frac{\mu}{1 - \tilde{\tau}_{kt} - \vec{a}_{kt}} - \frac{\theta(1-\varepsilon)}{\vec{a}_{kt}} = \frac{\beta \partial V^g(\cdot|t+1)}{\partial H_{kt+1}} \frac{\partial H_{kt+1}}{\partial \vec{a}_{kt}}$$

$$\text{(B3)} \quad \frac{\partial V^g(\cdot|t+1)}{\partial H_{kt+1}} = \frac{\mu + \phi}{H_{kt+1}} + \frac{\beta \partial V^g(\cdot|t+2)}{\partial H_{kt+2}} \frac{\partial H_{kt+2}}{\partial H_{kt+1}}$$

Equations (B1) and (B2) equalize the net current marginal costs and discounted future marginal benefits of $\tilde{\tau}_{kt}$ and $\vec{a}_{kt}$ respectively, where the future benefits accrue from the effects on human capital $\partial H_{kt+1} / \partial \tilde{\tau}_{kt}$ and $\partial H_{kt+1} / \partial \vec{a}_{kt}$. Equation (B3) gives the effect of H_{kt+1} on welfare as the sum of the effects on current and discounted future utilities, where the future benefits accrue here through the term $\partial H_{kt+2} / H_{kt+1}$. Observe that the

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additional effect of human capital spillovers, $\partial V^{g}(\cdot|t+2)/\partial H_{lt+2})(\partial H_{lt+2}/H_{kt+1})$, is ignored since each government assumes that $\partial H_{lt+2}/\partial H_{kt+1}=0$ in this problem.

Conditions (B1) and (B3) may be combined to produce

(B4) $\quad \beta\Omega\tilde{T}_{kt+1}-\tilde{T}_{kt}=-\left(\dfrac{\beta\psi\xi(\mu+\phi)+\phi\varepsilon(1-\beta\Omega)}{\mu}\right)$

The solution to this difference equation is

(B5) $\quad \tilde{T}_{kt}=\dfrac{\beta\psi\xi(\mu+\phi)+\phi\varepsilon(1-\beta\Omega)}{\mu(1-\beta\Omega)}$

Together with equation (B1) and (B2), it is straightforward to solve for the values $\tilde{\tau}^{NI}$ and $\tilde{a}^{NI}$ given in Table 1.

For problem P_{k}^{gNS}, the optimality conditions are (B1), (B2) and

(B6) $\quad \dfrac{\partial V^{g}(\cdot|t+1)}{\partial H_{kt+1}}=\dfrac{\mu+\phi}{H_{kt+1}}+\dfrac{\beta\partial V^{g}(\cdot|t+2)}{\partial H_{kt+2}}\dfrac{\partial H_{kt+2}}{\partial H_{kt+1}}+\dfrac{\beta\partial V^{g}(\cdot|t+2)}{\partial H_{lt+2}}\dfrac{\partial H_{lt+2}}{\partial H_{kt+1}}$

(B7) $\quad \dfrac{\partial V^{g}(\cdot|t+2)}{\partial H_{lt+2}}=\dfrac{1-\mu}{H_{lt+2}}+\dfrac{\beta\partial V^{g}(\cdot|t+3)}{\partial H_{kt+3}}\dfrac{\partial H_{kt+3}}{\partial H_{lt+2}}+\dfrac{\beta\partial V^{g}(\cdot|t+3)}{\partial H_{lt+3}}\dfrac{\partial H_{lt+3}}{\partial H_{lt+2}}$

Here, the effect of H_{kt+1} on welfare is given by equation (B6) which incorporates the effect of $\partial H_{lt+2} / \partial H_{kt+1}$ as governments now take account of the human capital spillovers. Equation (B7) shows how these spillovers affect welfare through the terms of trade (accounted for by the quantity $(1 - \mu)H_{lt+2}$) and future human capital production at home and abroad (the terms $\partial H_{kt+3} / \partial H_{lt+2}$ and $\partial H_{lt+3} / \partial H_{lt+2}$).

Conditions (B1), (B6) and (B7) can be consolidated into the difference equation

(B8) $\quad \beta^2(1 - 2\Omega)\tilde{T}_{kt+1} + 2\beta\Omega\tilde{T}_{kt+1} - T_{kt}$

$$= -\left(\frac{\beta\psi\xi[(\mu + \phi)(1 - \beta\Omega) + \beta(1 - \mu)(1 - \Omega)] + \phi\varepsilon(1 - \beta)(1 + \beta - 2\beta\Omega)}{\mu} \right)$$

Given the characteristic roots Λ_1 and Λ_2, the homogenous part of this equation can be written as

(B9) $\quad (\beta^2(1 - 2\Omega)L^{-2} + 2\beta\Omega L^{-1} - 1)\tilde{T}_{kt} = -(1 - \lambda_1 L^{-1})(1 - \lambda_2 L^{-1})\tilde{T}_{kt}$

where L is the lag operator and $\lambda_i = 1/\Lambda_i$ ($i = 1,2$). The roots are $\Lambda_1 = 1/\beta$ and $\Lambda_2 = 1/\beta(2\Omega - 1)$. Hence, the solution is

(B10) $\quad \tilde{T}_{kt} = \dfrac{\beta\psi\xi[(\mu + \phi)(1 - \beta\Omega) + \beta(1 - \mu)(1 - \Omega)] + \phi\varepsilon(1 - \beta)(1 + \beta - 2\beta\Omega)}{\mu(1 - \beta)(1 + \beta - 2\beta\Omega)}$

which, in conjunction with equations (B1) and (B2), yields the expressions for $\tilde{\tau}^{NS}$ and $\tilde{\jmath}^{NS}$ in Table 1.

Problem $\mathbf{P}^C$ delivers the following optimality conditions:

(B11) $\dfrac{1}{1-\widetilde{\tau}_{kt}-\overline{\tau}_{kt}} - \dfrac{\phi\varepsilon}{\widetilde{\tau}_{kt}} = \dfrac{\beta\partial V^g(\cdot|t+1)}{\partial H_{kt+1}}\dfrac{\partial H_{kt+1}}{\partial\widetilde{\tau}_{kt}}$

(B12) $\dfrac{1}{1-\widetilde{\tau}_{kt}-\overline{\tau}_{kt}} - \dfrac{\phi(1-\varepsilon)}{\overline{\tau}_{kt}} + \dfrac{\beta\partial V^g(\cdot|t+1)}{\partial H_{kt+1}}\dfrac{\partial H_{kt+1}}{\partial\overline{\tau}_{kt}}$

(B13) $\dfrac{\partial V^g(\cdot|t+1)}{\partial H_{kt+1}} = \dfrac{1+\phi}{H_{kt+1}} + \dfrac{\beta\partial V^g(\cdot|t+2)}{\partial H_{kt+2}}\dfrac{\partial H_{kt+2}}{\partial H_{kt+1}} + \dfrac{\beta\partial V^g(\cdot|t+2)}{\partial H_{lt+2}}\dfrac{\partial H_{lt+2}}{\partial H_{kt+1}}$

(B14) $\dfrac{\partial V^g(\cdot|t+1)}{\partial H_{lt+1}} = \dfrac{1+\phi}{H_{lt+1}} + \dfrac{\beta\partial V^g(\cdot|t+2)}{\partial H_{kt+2}}\dfrac{\partial H_{kt+2}}{\partial H_{lt+1}} + \dfrac{\beta\partial V^g(\cdot|t+2)}{\partial H_{lt+2}}\dfrac{\partial H_{lt+2}}{\partial H_{lt+1}}$

Governments choose tax policies jointly and all externalities are internalized. The absence of μ from these expressions reflects the internalization of terms-of-trade spillovers, whilst the welfare effects of H_{kt+1} and H_{lt+1} reflect the internalization of human capital spillovers.

By appropriate manipulation of conditions (B11), (B13) and (B14), the following difference equation is obtained:

(B15) $\beta^2(1-2\Omega)\widetilde{T}_{kt+1} + 2\beta\Omega\widetilde{T}_{kt+1} - T_{kt} =$
$\qquad -[\beta\psi\xi(1+\phi)+\phi\varepsilon(1-\beta)](1+\beta-2\beta\Omega)$

This has the same homogeneous part as equation (B8) so that equation (B9) applies and the solution is

$$(B16) \quad \tilde{T}_{kt} = \frac{\beta\psi\xi(1+\phi) + \phi\varepsilon(1-\beta)}{1-\beta}$$

Using conditions (B11) and (B12), the expressions for $\tilde{\tau}^c$ and $\tilde{z}^c$ in Table 1 are obtained.

Table 1	**Equilibrium Tax Rates**

<u>Non-cooperation</u>

$$\tilde{\tau}^{NI} = \frac{\tau^0(\varepsilon, \xi, \mu, \Omega)}{\tau^1(\mu, \Omega)}$$

$$\overline{\tau}^{NI} = \frac{\tau^0(1-\varepsilon, 1-\xi, \mu, \Omega)}{\tau^1(\mu, \Omega)}$$

$$\tilde{\tau}^{NS} = \frac{(1-\beta)\tau^0(\varepsilon, \xi, \mu, \Omega) + \beta(1-\Omega)\tau^0(\varepsilon, \xi, 1, 1)}{(1-\beta)\tau^1(\mu, \Omega) + \beta(1-\Omega)\tau^1(1,1) - \beta(1-\beta)(1-\Omega)(1-\mu)}$$

$$\overline{\tau}^{NS} = \frac{(1-\beta)\tau^0(1-\varepsilon, 1-\xi, \mu, \Omega) + \beta(1-\Omega)\tau^0(1-\varepsilon, 1-\xi, 1, 1)}{(1-\beta)\tau^1(\mu, \Omega) + \beta(1-\Omega)\tau^1(1,1) - \beta(1-\beta)(1-\Omega)(1-\mu)}$$

<u>Cooperation</u>

$$\tilde{\tau}^C = \frac{\tau^0(\varepsilon, \xi, 1, 1)}{\tau^1(1,1)}$$

$$\overline{\tau}^C = \frac{\tau^0(1-\varepsilon, 1-\xi, 1, 1)}{\tau^1(1,1)}$$

$$\tau^0(\varepsilon, \xi, \mu, \Omega) = \beta\psi\xi(\mu+\phi) + \varepsilon\phi(1-\beta\Omega)$$

$$\tau^1(\mu, \Omega) = (\mu+\phi)(1-\beta\Omega+\beta\psi)$$

$$\Omega = \eta + \psi + \delta$$

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Table 2

Effects of Parameter Variations on Equilibrium Tax Rates

	Non-cooperation				Cooperation	
	$\bar{\tau}^{NI}$	$\bar{z}^{NI}$	$\bar{\tau}^{NS}$	$\bar{z}^{NS}$	$\tilde{\tau}^{C}$	$\bar{z}^{C}$
ε	+	-	+	-	+	-
ξ	+	-	+	-	+	-
μ	-	-	-	-	0	0
Ω	+	?	+	?	0	0

Table 3   **Comparisons of Equilibrium Tax Rates**

$$\tilde{\tau}^C \underset{<}{\overset{>}{=}} \tilde{\tau}^{NI} \ \text{ if } \ \frac{\mu}{1-\mu} \underset{<}{\overset{>}{=}} \frac{\iota^0(\varepsilon,\xi,\Omega)}{\iota^1(\varepsilon,\xi,\Omega)}$$

$$\tilde{\tau}^C \underset{<}{\overset{>}{=}} \tilde{\tau}^{NS} \ \text{ if } \ \frac{\mu}{1-\mu} \underset{<}{\overset{>}{=}} \frac{\iota^0(\varepsilon,\xi,\Omega)+\iota^2(\varepsilon,\xi,\Omega)}{\iota^1(\varepsilon,\xi,\Omega)}$$

$$\tilde{z}^C \underset{<}{\overset{>}{=}} \tilde{z}^{NI} \ \text{ if } \ \frac{\mu}{1-\mu} \underset{<}{\overset{>}{=}} \frac{\iota^0(1-\varepsilon,1-\xi,\Omega)}{\iota^1(1-\varepsilon,1-\xi,\Omega)}$$

$$\tilde{z}^C \underset{<}{\overset{>}{=}} \tilde{z}^{NS} \ \text{ if } \ \frac{\mu}{1-\mu} \underset{<}{\overset{>}{=}} \frac{\iota^0(1-\varepsilon,1-\xi,\Omega)+\iota^2(1-\varepsilon,1-\xi,\Omega)}{\iota^1(1-\varepsilon,1-\xi,\Omega)}$$

$$\tilde{\tau}^{NS} \underset{<}{\overset{>}{=}} \tilde{\tau}^{NI} \ \text{ if } \ (1-\Omega)((\mu+\phi)\xi-\phi\varepsilon)\underset{<}{\overset{>}{=}}0$$

$$\tilde{z}^{NS} \underset{<}{\overset{>}{=}} \tilde{z}^{NI} \ \text{ if } \ (1-\Omega)((\mu+\phi)(1-\xi)-\phi(1-\varepsilon))\underset{<}{\overset{>}{=}}0$$

$$\iota^0(\varepsilon,\xi,\Omega) = \varepsilon\phi(1-\beta\Omega)(1-\beta+\beta\psi)+\phi\beta^2\psi(1-\Omega)(\varepsilon\phi-\xi(1+\phi))$$

$$\iota^1(\varepsilon,\xi,\Omega) = \beta^2\psi(1-\Omega)(1+\phi)(\xi(1+\phi)-\varepsilon\phi)$$

$$\iota^2(\varepsilon,\xi,\Omega) = \beta(1-\Omega)(\varepsilon\phi(1-\beta)+\beta\xi\psi(1+\phi))$$

Table 4   **Equilibrium Tax and Growth Rates in Limiting Cases**

	$\Omega, \mu \in (0,1)$	$\Omega = 1$	$\mu = 1$
$\varepsilon, \xi, \phi \in (0,1)$		$\tilde{\tau}^{NI} = \tilde{\tau}^{NS} > \tilde{\tau}^{C}$ $\daleth^{NI} = \daleth^{NS} > \daleth^{C}$ $\gamma^{NI} = \gamma^{NS} > \gamma^{C}$	$\tilde{\tau}^{NI} < \tilde{\tau}^{NS} < \tilde{\tau}^{C}$ $\daleth^{NI}, \daleth^{NS} < \daleth^{C}$ $\gamma^{NI}, \gamma^{NS} < \gamma^{C}$
$\varepsilon = \xi = 0.5$		$\tilde{\tau}^{NI} = \tilde{\tau}^{NS} > \tilde{\tau}^{C}$ $\daleth^{NI} = \daleth^{NS} > \daleth^{C}$ $\gamma^{NI} = \gamma^{NS} > \gamma^{C}$	$\tilde{\tau}^{NI} < \tilde{\tau}^{NS} < \tilde{\tau}^{C}$ $\daleth^{NI} < \daleth^{NS} < \daleth^{C}$ $\gamma^{NI} < \gamma^{NS} < \gamma^{C}$
$\varepsilon = 0, \xi = 1$	$\tilde{\tau}^{NI} < \tilde{\tau}^{NS}, \tilde{\tau}^{C}$ $\daleth^{NS} < \daleth^{NI} < \daleth^{C}$ $\gamma^{NI} < \gamma^{NS}, \gamma^{C}$	$\tilde{\tau}^{NI} = \tilde{\tau}^{NS} = \tilde{\tau}^{C}$ $\daleth^{NI} = \daleth^{NS} > \daleth^{C}$ $\gamma^{NI} = \gamma^{NS} = \gamma^{C}$	$\tilde{\tau}^{NI} < \tilde{\tau}^{NS} < \tilde{\tau}^{C}$ $\daleth^{NS} < \daleth^{NI} < \daleth^{C}$ $\gamma^{NI} < \gamma^{NS} < \gamma^{C}$
$\phi = 0$	$\tilde{\tau}^{NI} < \tilde{\tau}^{NS} < \tilde{\tau}^{C}$ $\daleth^{NI} < \daleth^{NS} < \daleth^{C}$ $\gamma^{NI} < \gamma^{NS} < \gamma^{C}$	$\tilde{\tau}^{NI} = \tilde{\tau}^{NS} = \tilde{\tau}^{C}$ $\daleth^{NI} = \daleth^{NS} = \daleth^{C}$ $\gamma^{NI} = \gamma^{NS} = \gamma^{C}$	$\tilde{\tau}^{NI} < \tilde{\tau}^{NS} < \tilde{\tau}^{C}$ $\daleth^{NI} < \daleth^{NS} < \daleth^{C}$ $\gamma^{NI} < \gamma^{NS} < \gamma^{C}$

Table 5   **Simulation Results for Benchmark Parameter Values**

	Cooperation	Non-cooperation	
		"Strategic"	"Isolationist"
Optimal tax $\tilde{\tau}$	0.213	0.172	0.086
$\tilde{\tau}$	0.121	0.102	0.058
Growth rate	0.024	0.020	0.006
Welfare	11.404	11.098	7.466
% decrease in growth rate	18.022	70.094	
% decrease in welfare	2.684	32.730	
% decrease in consumption	1.337	14.771	

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