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CAPITAL INCOME TAXATION IN GROWING OPEN ECONOMIES

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This paper studies how alternative capital mobility assumptions affect the incidence and efficiency of capital income taxation. The study uses a two-country intertemporal equilibrium model in which imperfectly elastic investment captures the notion of imperfectly mobile physical capital. If home goods and foreign goods are perfect substitutes and investment is inelastic, the tax effects in open and closed economies are similar. Only if physical capital is perfectly mobile are capital income taxes completely shifted in small open economies. Only then, and if significant terms of trade effects are absent, do open economy efficiency losses substantially exceed the closed economy losses.

1. Introduction

Concern with stagnating economic growth, a more integrated world financial system, and the increasing appeal of supply-side policies have led both policymakers and economists to critically examine taxes on capital income. There is a growing belief that, especially for open economies, taxes levied on domestically-earned capital income are an inefficient way of raising revenue. It is also believed that they may impose a heavy burden on labor income. In addition, several countries are considering lowering these taxes in order to stimulate capital accumulation. This paper evaluates the consequences of these policy changes for distribution, efficiency, and capital accumulation.

The study uses an intertemporal equilibrium growth model that explicitly considers the degree of international mobility of physical capital. While the explicit modeling of international capital mobility is essential for a realistic assessment of the impact of capital income taxation, it has not been incorporated satisfactorily into the literature devoted to capital income taxation.

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There exists an extensive body of literature on the incidence of capital income taxes. Static models of closed economies [see, for example, Harberger (1962) and Shoven (1976)] suggest that capital bears roughly the entire burden of a tax on capital income. Capital escapes a significant portion of the burden, however, in dynamic models of growing economies that account for endogenous capital accumulation [see, for example, Feldstein (1974) and Judd (1985)]. Endogenous international capital flows in open economies may further affect the incidence results. Harberger (1985) claims that in a small open economy capital shifts the entire burden of capital income taxes to labor. Feldstein and Horioka (1980) suggest that, if capital moves internationally to equate net-of-tax rates of return, closed economy incidence results are altered dramatically. Both Goulder, Shoven and Whalley (1983) and Mutti and Grubert (1985) find that it takes much less than perfect international capital mobility to invalidate the efficiency and distributional effects derived from models that ignore international capital mobility.

In examining the sensitivity of tax policy effects with respect to international capital mobility, the current paper continues the work on two-country models in Goulder, Shoven and Whalley (1983) and Mutti and Grubert (1985) but differs from these studies in several important respects. Most importantly, in contrast to these previous studies, the paper explicitly distinguishes between the mobility of financial capital and the mobility of physical capital. It assumes that, while financial capital is freely traded, adjustment costs in country-specific investment prevent physical capital from instantaneously relocating between countries. Therefore, if after-tax rental rates differ internationally, investment rates differ between countries but remain finite. Accounting for these adjustment costs is essential in obtaining realistic assessments of international capital relocation and the implied distributional and efficiency effects.

The framework developed here also adds to Goulder, Shoven and Whalley (1983) by modeling production both at home and abroad. This allows international capital flows to affect the productivity of capital in both parts of the world. It extends Mutti and Grubert (1985) by not only comparing balanced growth paths, but by also examining the transition to a new steady-state equilibrium. This paper will show that ignoring the transition can bring out misleading results. Additionally, this approach differs from both Goulder, Shoven and Whalley (1983) and Mutti and Grubert (1985) in deriving saving and investment from intertemporal optimizing behavior with perfect foresight. This intertemporal equilibrium approach allows for a fully dynamic welfare analysis. Short-run effects, transition paths, long-run equilibria, intertemporal welfare effects, and dynamic incidence are integrated by using microeconomic principles of intertemporal rationality.

The paper is organized as follows. Section 2 outlines the main elements of the two-country intertemporal framework. It elaborates on the adjustment

costs that give rise to imperfectly mobile physical capital. In contrast to numerical simulations [see, for example, Summers (1981), Lipton and Sachs (1983), Goulder, Shoven and Whalley (1983), and Mutti and Grubert (1985)], this study arrives at analytical solutions that have an intuitive economic interpretation and explicitly reveal the determinants of the welfare effects of taxes on capital income. Section 3 interprets the expressions characterizing the time paths for capital accumulation in both countries. Section 4 uses the analytical solutions to investigate the factors that determine the shifting of capital income taxes. Replacing capital income by labor income as a tax base is examined in section 5. This section explores how international capital flows affect the national welfare effects of such a tax reform. Section 6 performs numerical simulations to evaluate the quantitative impact of trade flows and capital flows on tax policy effects. The concluding section 7 summarizes the main points of the paper.

2. The model

The model describes two countries, each producing a single good. Country one (the home country) produces good one. Good two is produced in the foreign country (country two). Investors and consumers in both countries demand a composite of the two tradable goods. This formulation allows for imperfect substitution in demand:

$$I_f^i = H_I^i(I_1^i, I_2^i), \quad i = 1, 2, \quad (1)$$

$$C_f^i = H_c^i(C_1^i, C_2^i), \quad i = 1, 2, \quad (2)$$

where I_f^i and I_j^i denote total gross investment demands for, respectively, the composite investment good and good j by investors in country i . Consumption demands C_f^i and C_j^i are defined similarly.¹ In the rest of this paper the superscript or subscript i stands for either of the two countries.²

Competitive maximizing behavior yields:

$$p_I^i \frac{\partial H_I^i}{\partial I_j^i}(\cdot) = p_j, \quad i = 1, 2, j = 1, 2, \quad (3)$$

and

$$p_c^i \frac{\partial H_c^i}{\partial C_j^i}(\cdot) = p_j, \quad i = 1, 2, j = 1, 2, \quad (4)$$

¹By aggregating consumption demands over all households residing in a particular country, it is implicitly assumed that households within each country have identical preferences.

²All variables are to be understood as dated at time t unless indicated otherwise.

where p_j represents the price of good j .³ The shadow prices for composite investment and composite consumption are denoted by p_I^i and p_C^i , respectively. Assuming that the functions $H_n^i(\cdot)$ $i=1, 2$, $n=I, C$, are homogeneous of degree one, the following price relations hold:

$$p_I^i I_f^i = p_1 I_1^i + p_2 I_2^i, \quad i=1, 2, \quad (5)$$

$$p_C^i C_f^i = p_1 C_1^i + p_2 C_2^i, \quad i=1, 2. \quad (6)$$

2.1. Production

The production technology in each country is represented by a constant returns to scale neo-classical production function. It relates output of good i , Y_i , to capital K_i and labor L_i employed in country i :

$$Y_i = F_i(K_i, L_i) \quad \text{or} \quad y_i = f_i(k_i), \quad i=1, 2, \quad (7)$$

where $y_i = Y_i/L_i$, $k_i = K_i/L_i$, and

$$f_i' = \frac{df_i}{dk_i} = \frac{\partial F_i}{\partial K_i} > 0, \quad f_i'' = \frac{d^2 f_i}{dk_i^2} < 0.$$

Both countries feature the same constant rate of population growth, n . Assuming that labor supply is a constant fraction of the population and abstracting from migration and unemployment, labor employed in each country grows at the rate of population growth:

$$\frac{\dot{L}_i}{L_i} = n, \quad i=1, 2, \quad (8)$$

where a dot denotes a time derivative.

Labor demand is represented by the marginal productivity condition:

$$p_i[f_i(k_i) - k_i f_i'(k_i)] = p_L^i, \quad i=1, 2, \quad (9)$$

where p_L^i represents the gross wage rate.

2.2. Investment

In addition to the production technology (7), the production sector in each country faces a second technology constraint – the installation function. This

³The demand prices for each of the two goods is the same in both countries because taxes on tradable goods are absent.

function was introduced by Uzawa (1969) to model adjustment costs associated with investment.⁴ The installation function describes how the capital stock and the investment flow combine to yield the accumulation of country-specific capital:

$$\dot{K}_i = G_i(I_f^i, K_i), \quad i = 1, 2. \quad (10)$$

The installation function is linearly homogeneous [see Hayashi (1982)]. The flow of gross investment, I_f^i , can be negative. Negative investment represents a reversal of the installation process so that investment goods are available for investment elsewhere. Using (8), the rates of growth of the capital-labor ratios can be written as

$$\frac{\dot{k}_i}{k_i} = g_i(x_f^i) - n, \quad i = 1, 2, \quad (11)$$

with $x_f^i = I_f^i/K_i$ and $g_i(x_f^i) = G_i(x_f^i; 1)$. At the investment-capital ratio, x_f^i , the marginal productivity of the composite investment good in terms of installed capital equals $g'_i(x_f^i)$. The units in which capital is measured are defined as follows. On a balanced growth path a marginal unit of investment turns into one unit of capital

$$g'_i(g_i^{-1}(n)) = 1, \quad i = 1, 2. \quad (12)$$

Marginal installation costs rise with the rate of investment, which is reflected in the concavity of the installation function in investment. How rapidly costs increase is mirrored by the elasticity of the marginal productivity of investment, σ_x^i , defined as

$$\sigma_x^i(x_f^i) = \frac{-x_f^i g''_i(x_f^i)}{g'_i(x_f^i)} > 0, \quad i = 1, 2. \quad (13)$$

For any given capital stock, the faster the capital stock expands, the more capital goods per additional unit of capital are required.

Firms maximize the present value of their after-tax cash flow subject to the installation function. Using (1), (3), and (5), the Hamiltonian corresponding to this intertemporal optimization problem can be expressed as

$$H = \{(1 - t_k^i)[p_i f(k_i) - p_L^i - p_I^i \delta_f^i k_i] - (x_f^i - \delta_f^i) p_I^i k_i + q_i k_i [g_i(x_f^i) - n]\} \\ \times L_i(0) e^{nt} \exp\left(-\int_0^t r_i(s) ds\right), \quad (14)$$

⁴Following Lucas (1967), Summers (1981) models adjustment costs in an alternative way. His formulation, however, leads to similar results for the optimal investment rule.

where $r_i(s)$ stands for the required after-tax rate of return at time s . The present discounted value due to an additional unit of installed capital is given by the shadow price for constraint (11), q_i . δ_f^i denotes the investment-capital ratio at which the capital stock is kept constant. t_k^i represents the tax rate on capital income (net of depreciation). Dynamic optimization yields the implicit demand function for composite investment:

$$q_i g'_i(x_f^i) = p_I^i, \quad i = 1, 2. \quad (15)$$

Investment occurs until the marginal value of capital installed equals the marginal cost of investment. Given the concavity of the installation function, the first-order condition (15) can be inverted to arrive at an explicit investment function. The elasticity of country-specific investment with respect to the ratio q_i/p_I^i is given by $1/\sigma_x^i$.

Using (14) the optimal path for the shadow value of capital can be written as

$$r_i = \frac{\dot{q}_i}{q_i} + \frac{(1 - t_k^i)[p_i f'(k_i) - p_I^i \delta_f^i]}{q_i} + [g_i(x_f^i) - (x_f^i - \delta_f^i)g'_i(x_f^i)],$$

$$i = 1, 2. \quad (16)$$

The after-tax return on capital r_i consists of capital gains $\dot{q}_i/q_i$ and two marginal productivity terms. The marginal rental rate of capital in production is given by the second term on the right-hand side of (16). The third term represents the marginal contribution of capital in raising the productivity of investment in installation.

2.3. Financial markets

Financial claims on country-specific capital are freely traded in world financial markets. With perfect foresight, these claims are perfect substitutes. Thus, the required after-tax return, r_i , is identical for all types of capital and the right-hand side of (16) equals the world rate of return. In the absence of adjustment costs (i.e. $\sigma_x = 0$) and with identical composite investment goods, perfect financial markets imply the equality of after-tax rentals:⁵

$$(1 - t_k^1)[p_1 f'_1(k_1) - \delta_f^1 p_I] = (1 - t_k^2)[p_2 f'_2(k_2) - \delta_f^2 p_I]. \quad (17)$$

⁵The absence of adjustment costs corresponds to linear installation functions (11). Linear installation functions imply that the third term at the right-hand side of (16) is zero [use $g(\delta_f^i) = 0$]. Moreover, the linearity of the installation functions together with (12), (15), and identical prices for the composite investment goods, p_I^i , imply that q_i are identical across the two countries.

Without adjustment costs, physical capital is perfectly mobile. Thus, if only the home country cuts its tax rate on capital income, country-specific investment rates become infinite. Physical capital is instantaneously relocated toward the home country such that the marginal productivity of home capital falls sufficiently relative to the marginal productivity of foreign capital for (17) to hold.

However, if the installation function is concave reflecting adjustment costs, the right-hand side of (16) is dependent on the investment rate. Infinite investment flows are excluded because they give rise to prohibitive adjustment costs. When the home tax cut occurs, investment remains finite and the relocation of capital happens only gradually over time. Even if world financial markets equalize after-tax returns, net home rentals initially exceed those in the foreign country and the initial adjustment is absorbed by the relative prices of the capital stocks.

2.4. Households

In each country tastes are homogeneous. Consumption behavior is modeled by an infinitely-lived representative household for each country optimizing additive separable intertemporal utility, u^i :

$$u^i = \int_0^{\infty} e^{-\beta t} e^{nt} u_i(c_f^i(t)) dt, \quad i = 1, 2, \quad (18)$$

where $c_f^i(t)$ is composite consumption per capita at time t . All households have the same rate of time preference, β , and grow at the same rate, n . Instantaneous per capita utility $u_i(c_f^i(t))$ is weighted by an index for the size of the household and is discounted by the rate of time preference. It is convenient to define a composite discount factor $b = \beta - n$. The preference for a smooth time path of consumption is reflected in the elasticity of marginal instantaneous utility, σ_c^i :

$$\sigma_c^i(c_f^i) = - \frac{c_f^i u_i''(c_f^i)}{u_i'(c_f^i)}, \quad i = 1, 2. \quad (19)$$

The intertemporal substitution elasticity is given by the reciprocal of $\sigma_c^i(c_f^i)$.

Maximization of intertemporal utility subject to a wealth constraint yields the following implicit consumption function:

$$u_i'(c_f^i) = \mu_i p_c^i, \quad i = 1, 2. \quad (20)$$

The optimal path for the shadow price for the wealth constraint, μ_i , is given by

$$\frac{\dot{\mu}_i}{\mu_i} = \beta - r, \quad i = 1, 2. \quad (21)$$

It is convenient to define Q_i as the value of capital in terms of marginal instantaneous utility,

$$Q_i = q_i \mu_i, \quad i = 1, 2. \quad (22)$$

2.5. Governments

The two national governments finance their expenditures by levying taxes on labor income⁶ and capital income (net of economic depreciation) that is earned in production in their areas of jurisdiction. The balanced public budget constraints can be expressed as

$$p_1 g_1^i + p_2 g_2^i = t_k^i [p_i y_i - p_L^i - p_I^i \delta_f^i k_i] + t_L^i p_L^i, \quad i = 1, 2, \quad (23)$$

where g_j^i denotes the ratio of fixed public demand for good j and labor supply in country i . The tax rates on capital income are the policy instruments. The tax rates on labor income, t_L^i , adjust to preserve budget balance (23).

The market equilibria for the two goods are given by

$$\sum_{i=1}^2 (g_j^i + c_j^i + x_j^i k_i) = y_j, \quad j = 1, 2, \quad (24)$$

where c_j^i is the ratio of consumption demand for good j and labor supply in country i .

3. Accumulation and reallocation of capital

Following an unanticipated change in capital income taxation, the world economy diverges from its initial balanced growth path. In order to analyze the time path of the changes from the initial growth path, the model is log-linearized around the initial steady state.⁷ Appendix A contains the log-linearized model. Relative changes are denoted by a tilde.⁸

⁶Given inelastic labor supply, a tax on labor is equivalent to a lump-sum tax on the earners of labor income.

⁷For similar approaches, see Chamley (1981) and Judd (1985).

⁸The time derivative of a relative change is denoted by the combination of a tilde and a dot. Under certain regularity conditions, this equals the policy-induced change in the rate of growth.

A tilde above a tax rate t_n ; $n = k, L$; is defined as $d(1 - t_n)/(1 - t_n)$.

From the static equations contained in appendix A, one can express the endogenous variables in terms of the exogenous tax rates on capital income and four dynamic endogenous variables. It is convenient to adopt, as these dynamic endogenous variables, the 'aggregate' variables, k_A and Q_A , and the 'relative' variables, k_R and q_R . A change in an aggregate variable, $\tilde{m}_A$, is defined as the weighted average of the changes in the country-specific variables:

$$\tilde{m}_A = \sum_{j=1}^2 a_y^j \tilde{m}_j. \quad (25)$$

The weights a_y^j are the country shares in the value of the world production. A change in a relative variable, $\tilde{m}_R$, is given by the difference between the country-specific changes,

$$\tilde{m}_R = \tilde{m}_1 - \tilde{m}_2. \quad (26)$$

In order to find a 'temporary equilibrium' solution for the endogenous variables, one needs the information on the history and the future of the system that is contained in the dynamic endogenous variables. Q_A and q_R embody information on the future of the system. In a saddle-point stable system, the initial conditions for these forward-looking variables are uniquely determined by the transversality conditions. The stock variables, k_A and k_R , are backward-looking. Their initial conditions are predetermined by history.

The model contained in appendix A is simplified by imposing some symmetry conditions. The initial tax rates on labor and capital, the shares of gross investment in national income, a_I , the depreciation shares, d , the labor shares $(1 - \alpha_k)$,⁹ the installation elasticities, σ_x , and the local substitution elasticities in production, σ_k , are identical for the two countries. Even though these assumptions seem rather restrictive, they enable us to focus on the main determinants of international capital allocation and accumulation. If a variable is identical across countries, subscripts or superscripts representing the country are dropped. For both countries the shares of good j in composite private consumption, α_{cj} , in composite investment, α_{Ij} , and in public demand, α_{Gj} , equal the share of the good in world production, a_y^j .¹⁰ As the last restriction, it is assumed that in the initial steady state countries do not hold net equity claims on one another.¹¹

⁹Consequently, the cash flow-GNP ratios $z = (1 - t_k)\alpha_k - a_I + t_k d$ are identical in both countries.

¹⁰These assumptions are only necessary when goods are imperfect substitutes.

¹¹In the absence of net claims, the consumption share in income for country i , a_c^i , is given by

$$a_c^i = (1 - t_L^i)(1 - \alpha_k^i) + z_i.$$

With the symmetry assumptions above, it is implied that the initial consumption shares are the same for the two countries.

Substituting the temporary equilibrium solutions in the dynamic relations, one arrives at two saddle-point stable systems – the accumulation system (derived in appendix B) and the reallocation system (derived in appendix C):

$$\begin{bmatrix} \dot{z}^A \\ \dot{z}^R \end{bmatrix} = \begin{bmatrix} C^A & 0 \\ 0 & C^R \end{bmatrix} \begin{bmatrix} z^A \\ z^R \end{bmatrix} + \begin{bmatrix} D^A \\ D^R \end{bmatrix} \begin{bmatrix} \tilde{t}_k^A \\ \tilde{t}_k^R \end{bmatrix}, \quad (27)$$

where z^A and z^R represent two-dimensional column vectors of the aggregate dynamic endogenous variables $(\tilde{k}_A; \tilde{Q}_A)$ and the relative dynamic endogenous variables $(\tilde{k}_R; \tilde{q}_R)$, respectively. Because this paper deals only with permanent policy changes, the exogenous policy instruments, $\tilde{t}_k^A = d(1 - t_k^A)/(1 - t_k^A)$ and $\tilde{t}_k^R = d(1 - t_k^R)/(1 - t_k^R)$, remain constant after the policy shock.¹² The elasticity matrix C^A and the elasticity vector D^A characterizing the accumulation system are given in appendix B. Appendix C presents the matrix C^R and the vector D^R .

3.1. Steady-state results

The accumulation system yields the following solution for long-run aggregate capital deepening:

$$(\tilde{k}_{A\infty}/\tilde{t}_k^A) = [\sigma_k/(1 - \alpha_k)] [(\alpha_k - d)/\alpha_k]. \quad (28)$$

The steady-state international capital relocation is derived from the reallocation system as

$$\left(\frac{\tilde{k}_{R\infty}}{\tilde{t}_k^R} \right) = \frac{\{(\alpha_k - d)/\alpha_k\}}{\{(1 - \alpha_k)/\sigma_k + (\alpha_k/\sigma_D)\}}. \quad (29)$$

The aggregate demand elasticity σ_D is the weighted sum of local substitution elasticities between the two goods in investment demand, σ_I^i , and in consumption demand, σ_H^i :

$$\sigma_D = a_I \sum_{i=1}^2 (\sigma_I^i a_y^i) + a_C \sum_{i=1}^2 (\sigma_H^i a_y^i). \quad (30)$$

The absolute sizes of the steady-state effects for both capital accumulation and capital allocation are increasing functions of the substitution elasticity between capital and labor, σ_k . Intuitively, with a larger elasticity the marginal product of capital is less sensitive to changes in the capital stock. Therefore,

¹²For arbitrarily complex changes in future and current policy, see Judd (1985).

larger adjustments in employed capital, which result in larger changes in product supplies, are required to change the before-tax returns on capital. Expressions (28) and (29) show that, if the two tradable goods are perfect substitutes (i.e. $\sigma_D \rightarrow \infty$), the long-run effect on capital accumulation scaled by the change in aggregate tax rates, $\tilde{k}_{A\infty}/\tilde{t}_k^A$, equals the long-run effect on capital allocation scaled by the change in relative tax rates, $\tilde{k}_{R\infty}/\tilde{t}_k^R$. If goods are imperfect substitutes, however, the scaled long-run reallocation effect is smaller than the scaled long-run accumulation effect because a smaller demand elasticity, σ_D , reflecting less substitution in demand, reduces steady-state reallocation but leaves steady-state accumulation unaffected. The economic intuition is as follows. While changes in aggregate tax rates do not affect the relative supplies of the two goods, changes in relative tax rates alter the relative good supplies. Relative tax changes, therefore, require a shift in demand between the two goods and, if the goods are imperfect substitutes, a change in their relative price. These relative price changes partly offset the effect of relative tax changes on relative after-tax profitability and, thus, reduce the effect on capital allocation. If relative demand becomes less elastic with respect to the relative price (captured by a smaller σ_D), or if relative supply becomes more sensitive with respect to changes in relative tax rates (captured by a larger σ_k), a larger relative price change is required in response to a given change in relative tax rates. Consequently, the divergence between the reallocation effect and the accumulation effect widens.

Theorem 1. The long-run accumulation effect scaled by the change in aggregate tax rates, $\tilde{k}_{A\infty}/\tilde{t}_k^A$, exceeds the long-run reallocation effect scaled by the change in relative tax rates, $\tilde{k}_{R\infty}/\tilde{t}_k^R$, if the ratio σ_D/σ_k is finite. If the ratio σ_D/σ_k becomes larger, the difference between the scaled long-run effects becomes smaller. The scaled long-run reallocation effect approaches the scaled long-run accumulation effect if the ratio σ_D/σ_k becomes infinitely large.

3.2. Transition effects

During the transition, the aggregate capital-labor ratio is given by

$$\tilde{k}_A(t) = \tilde{k}_{A\infty}(1 - e^{-h^A t}). \quad (31)$$

The rate of convergence of the aggregate capital stock toward its new steady-state value is h^A . This accumulation speed is computed as the absolute value of the stable (i.e. the negative) root of the elasticity matrix C^A :

$$(h^A/b) = -1/2v + \sqrt{1/4(v^2) + \{(1-t_k)\alpha_k/z\}(a_I/z\sigma_A)\{(\alpha_k-d)/\alpha_k\}(\tilde{t}_k^A/\tilde{k}_{A\infty})}, \quad (32)$$

$$v = 1 + \{(a_I/a_c)\sigma_c/\sigma_A\}\{t_k(\alpha_k - d)/z\}, \quad (33)$$

where a_c stands for the ratio of consumption and gross income and z is the share of the cash flow in gross income. The aggregate intertemporal substitution elasticity, $1/\sigma_c$, is the weighted average of the country-specific elasticities:

$$(1/\sigma_c) = (a_y^1/\sigma_c^1) + \{(1 - a_y^1)/\sigma_c^2\}. \quad (34)$$

The elasticity σ_A aggregates the costs of fluctuations in investment–capital ratios (or the rates of capital accumulation) and consumption rates. These costs are captured by the installation elasticity, σ_x , and the utility elasticity, σ_c , respectively:

$$\sigma_A = \sigma_x + (a_I/a_c)\sigma_c. \quad (35)$$

Rapid adjustment requires larger fluctuations in the rates of capital accumulation and consumption than is implied by slow adjustment. The larger the elasticity σ_A , the costlier these fluctuations associated with rapid adjustment are, and the slower the adjustment occurs.

The transition path for capital relocation is given by

$$\tilde{k}_R(t) = \tilde{k}_{R\infty}(1 - e^{-h^R t}). \quad (36)$$

In the absence of adjustment costs, the reallocation speed, h^R , is infinite. When investment is less than perfectly elastic, however, international capital relocation happens gradually over time. The reallocation speed is derived from the stable root of the elasticity matrix C^R as

$$(h^R/b) = -1/2 + \sqrt{1/4 + \{(1 - t_k)\alpha_k/z\}(a_I/z\sigma_x)\{(\alpha_k - d)/\alpha_k\}(\tilde{t}_k^R/\tilde{k}_{R\infty})}. \quad (37)$$

Both adjustment speeds are reduced by more concave installation functions capturing less elastic investment. Furthermore, both rates of adjustment are decreasing functions of the corresponding long-run effect on the capital stock scaled by the change in the tax rate. Intuitively, the larger the gap between the old equilibrium and the new long-run equilibrium is, the more time is required to bridge a given proportion of that gap.

Expressions (32) and (37) reveal that the two adjustment speeds are equal under two necessary conditions. First, saving needs to be perfectly elastic relative to investment (i.e. $\sigma_c/\sigma_x = 0$). Second, relative product demand needs to be perfectly elastic with respect to the relative price, compared to the sensitivity of relative product supply with respect to relative tax changes so as to equate the scaled long-run effects (i.e. $\sigma_k/\sigma_D = 0$, see Theorem 1). If one

of these two conditions is not met, the reallocation speed exceeds the accumulation speed; less elastic saving reduces the accumulation speed but leaves the reallocation speed unaffected, while less elastic relative product demand raises the reallocation speed but does not affect the accumulation speed. More concave utility functions reflecting less elastic saving behavior decrease the rate of aggregate capital accumulation because they increase the costs of the fluctuations in consumption rates that are associated with rapid accumulation of the aggregate capital stock. The features of the utility functions, however, do not affect the rate of capital reallocation; in the presence of a perfect international market for financial capital, the reallocation of capital does not require fluctuations in consumption. A smaller demand elasticity σ_D , however, allows for more rapid capital relocation by decreasing long-run capital reallocation. This elasticity affects neither long-run aggregate capital accumulation nor the accumulation speed. Thus, the larger the aversion is against fluctuations in consumption rates compared to the costs of varying rates of capital accumulation (reflected in a larger ratio σ_c/σ_x) and the less elastic relative good demand is with respect to the relative price compared to the sensitivity of relative good supply with respect to relative tax changes (reflected in a smaller ratio σ_D/σ_k), the more the reallocation speed exceeds the accumulation speed.

Theorem 2. The reallocation speed exceeds the accumulation speed if either the ratio σ_x/σ_c is finite or the ratio σ_D/σ_k is finite. If these ratios become larger, the divergence between the two rates of adjustment becomes smaller. The two adjustment speeds approach each other if both ratios become infinitely large.

4. Tax-shifting

This section examines how an unanticipated increase of the capital income tax imposed by the home government [i.e. $\tilde{t}_k^1 = \{d(1-t_k^1)\}/(1-t_k^1) < 0$] to substitute for taxes on labor affects the welfare of the capitalists who receive their entire income in the initial steady-state from the capital stock in the home country. It investigates the sensitivity of this welfare effect, which captures the shifting of the capital income tax, with respect to the closure of the model in time and space. A welfare effect is defined as the relative change in initial wealth that is equivalent to the change in intertemporal utility induced by the policy change. Appendix D derives the welfare effect corresponding to the owners of the home capital stock, $\tilde{w}_{k1}$, as

$$\tilde{w}_{k1} = \left\{ \frac{b}{b+h^A} a_y^1 + \frac{b}{b+h^R} (1-a_y^1) \right\} \frac{(1-t_k)(\alpha_k-d)}{z} \tilde{t}_k^1. \quad (38)$$

4.1. Closed economy

In a static model (i.e. $h^A = 0$, reflecting no capital accumulation) of a closed economy (i.e. $a_y^1 = 1$), the taxed capital stock is fixed. Thus, capital bears the full tax burden:

$$\tilde{w}_{k1} = \frac{(1 - t_k)(\alpha_k - d)}{z} \tilde{t}_k^1. \quad (39)$$

Dynamic models modify the model closure in time by allowing for endogenous capital accumulation. By reducing capital accumulation, taxes on capital income can be shifted. If households are infinitely lived with additive separable utility as specified in (18), the steady-state after-tax return is fixed at the rate of time preference. The fixed steady-state after-tax rate of return implies that in the long run, capital shifts the entire burden. Consequently, capital income taxes are ineffective as an instrument for long-run redistribution between labor and capital.

Capital deepening, however, occurs gradually over time. Taking into account the transition to a new balanced growth path, capital shifts only part of the burden.¹³ From (38) with $a_y^1 = 1$:

$$\tilde{w}_{k1}^c = \frac{b}{(b + h^A)} \frac{(1 - t_k)(\alpha_k - d)}{z} \tilde{t}_k^1, \quad (40)$$

where the superscript c represents a closed economy. The size of the dynamic shifting depends on how rapidly the new steady state with less capital-intensive production and higher capital earnings is approached.

4.2. Open economy

Proceeding by altering the model closure in space, in a small open economy the welfare effect for capital, $\tilde{w}_{k1}^o$, is given by letting the home share in world production, a_y^1 , in eq. (38) approach zero:¹⁴

$$\tilde{w}_{k1}^o = \frac{b}{(b + h^R)} \frac{(1 - t_k)(\alpha_k - d)}{z} \tilde{t}_k^1. \quad (41)$$

Only with instantaneous relocation of capital is there complete shifting

¹³Judd (1985) examines incidence and efficiency along the adjustment path as well as in the new steady state using a model of a closed economy without adjustment costs.

¹⁴For a not necessarily small economy, the open economy result (38) is given by the weighted average of the effects for the closed economy (40) and the small open economy (41). The weight of the closed economy effect is the share of the country in world production.

and are capital taxes implicit taxes on labor [see Harberger (1985)]. If physical capital is not perfectly mobile, however, the reallocation speed remains finite. Real after-tax earnings on home capital return only gradually to the fixed level in the rest of the world. Thus, when the unanticipated tax increase occurs, capital suffers a windfall loss that capitalizes the decline in future earnings. The size of the capitalization effect depends on how rapidly the reallocation of capital restores the earnings on home capital.

The ratio of (41) and (40) captures the consequences for tax-shifting of opening up a small economy to world financial markets:

$$\frac{\tilde{w}_{k1}^o}{\tilde{w}_{k1}^c} = \frac{(b + h^A)}{(b + h^R)}. \quad (42)$$

With the reallocation speed exceeding the accumulation speed (see Theorem 2), capital widens more rapidly in the open economy. Consequently, in the open economy capital earnings rise faster, resulting in a smaller burden suffered by capital owners from capital taxes. However, if investment is inelastic relative to saving (i.e. the ratio σ_x/σ_c is large) and the goods produced by home and foreign capital are close substitutes (i.e. the ratio σ_D/σ_k is large), the accumulation speed approaches the reallocation speed. In that case, therefore, capital earnings increase at similar rates in the open economy and the closed economy and the dynamic shifting of capital taxes in a closed economy is a good approximation for the shifting in an open economy.

Theorem 3. The burden from unanticipated taxes on capital income borne by the owners of the taxed capital stock in closed economies exceeds the burden borne by these owners in similar open economies if either the ratio σ_x/σ_c or the ratio σ_D/σ_k is finite. If these ratios become larger, the divergence between the burdens in open and closed economies becomes smaller. The two burdens approach each other if both ratios become infinitely large.

5. National welfare effects

With financial capital becoming increasingly mobile, the use of capital income as a tax base has become more controversial. This section analyzes the national welfare effects associated with replacing taxes on capital income by taxes on labor income (i.e. $\tilde{t}_k^1 > 0$).

5.1. Closed economy

Appendix D derives the aggregate welfare effect for a closed economy, $\tilde{w}^c$, as

$$\tilde{w}^c = \frac{h^A}{(h^A + b)} \frac{(\alpha_k - d)}{\alpha_k} \frac{t_k(\alpha_k - d)}{a_c} \frac{\sigma_k}{(1 - \alpha_k)} \tilde{t}_k^1. \quad (43)$$

With an initial intertemporal distortion, t_k^1 , capital deepening induced by a decrease in taxes on capital income is unambiguously welfare improving. The more rapidly capital deepens, the larger are the discounted efficiency gains. The distribution of these gains over labor and capital crucially depends on the rate of capital deepening. The faster capital accumulation causes capital earnings to decline, the smaller the gains accruing to capital are [see (40)]. The closed economy welfare effects enjoyed by workers, $\tilde{w}_L^c$, are given by (see appendix D)

$$\tilde{w}_L^c = \frac{b}{(h^A + b)} \frac{(1 - t_k)}{(1 - t_L)} \frac{(\alpha_k - d)}{(1 - \alpha_k)} \left\{ \frac{h^A}{b} \frac{t_k}{(1 - t_k)} \frac{(\alpha_k - d)}{\alpha_k} \frac{\sigma_k}{(1 - \alpha_k)} - 1 \right\} \tilde{t}_k^1. \quad (44)$$

If capital deepening happens quickly and there is a large enough initial tax distortion, t_k^1 , it is in the interests of labor (at the margin) to substitute labor income for capital income as a tax base. Capital deepening increases before-tax wages rapidly enough to compensate workers for the higher tax rates on their income. The larger the initial distorting tax rate on capital income is, the larger is the aggregate welfare gain (43), and the less labor taxes have to rise to balance the budget.

5.2. Open economy

The aggregate welfare effect for the agents residing in a small open economy, $\tilde{w}^o$, is (see appendix D)

$$\begin{aligned} \tilde{w}^o = & \frac{h^R}{(b + h^R)} \frac{(\alpha_k - d)}{\alpha_k} \frac{1}{a_c} \frac{t_k(\alpha_k - d) - (\alpha_k/\sigma_D)}{(\alpha_k/\sigma_D) + ((1 - \alpha_k)/\sigma_k)} \tilde{t}_k^1 \\ & - (1 - s_{k1}^1) \frac{b}{(h^R + b)} \frac{(1 - t_k)(\alpha_k - d)}{a_c} \tilde{t}_k^1, \end{aligned} \quad (45)$$

where s_{kj}^i is the part of the capital stock in country j that is owned by residents of country i . Without foreign ownership of capital ($s_{k1}^1 = 1$) and with perfect substitutability in demand ($\sigma_D \rightarrow \infty$), the welfare effects for open and closed economies are given by similar expressions. In both cases, domestic capital deepening is welfare improving. The speeds of capital deepening, however, differ. While the accumulation speed determines the rate of capital deepening in the closed economy, in the open economy the reallocation speed is relevant for the rate with which capital accumulates. Using the

results from Theorem 2 on the relationship between the two adjustment speeds, welfare improving capital deepening occurs more rapidly in a small open economy than in a similar closed economy. Thus, the welfare gains associated with capital deepening are realized more rapidly and, therefore, the discounted welfare gains are larger in the open economy. Consequently, if under the assumptions above an economy becomes integrated into world markets, lowering capital taxes becomes an increasingly attractive policy option from a national welfare point of view. However, Theorem 2 indicates that the integration in world markets leaves the adjustment speed and the welfare gains relatively unaffected if investment is inelastic relative to saving.

Allowing for foreign ownership of domestic capital ($s_{k1}^1 < 1$), some of the gains accrue to foreigners and the residents of the open economy may actually lose.¹⁵ Moreover, even if the entire home capital stock is owned domestically, national welfare may decline due to terms of trade losses. If home goods and foreign goods are imperfect substitutes, domestic capital deepening depresses the terms of trade. With domestic ownership of capital, it is in the interest of a small country¹⁶ to discourage domestic capital accumulation by taxing capital income as long as [see (45)]

$$t_k < \frac{\alpha_k}{\alpha_k - d} \frac{1}{\sigma_D}. \quad (46)$$

Tariffs do not distort the labor–capital choice. Thus, imposing an optimal tariff is a more efficient and direct way to take advantage of monopoly power in world goods markets. If international agreements exclude tariffs, however, taxes on domestic factors of production provide an alternative way to affect the terms of trade at the expense of world welfare. Therefore, an efficient allocation of world resources calls for the international coordination of a wide range of tax instruments.

Theorem 4. The welfare gains from lower taxes on capital income that are enjoyed by residents of small open economies exceed the gains that are enjoyed by residents of similar closed economies if the ratio σ_x/σ_c is finite, goods are perfect substitutes ($\sigma_D \rightarrow \infty$), and the domestic capital stock is owned by domestic residents. Under the above assumptions, if the ratio σ_x/σ_c becomes larger, the divergence between the gains of open and closed economies becomes smaller and vanishes if the ratio σ_x/σ_c becomes infinitely large. If goods are

¹⁵When the entire domestic capital stock is owned by foreigners, national welfare gains (45) reflect the domestic labor gains. With slow capital relocation or a small initial tax rate t_k^1 , domestic residents lose, just as labor does in a closed economy with a small accumulation rate and a small initial tax rate [see (44)].

¹⁶We do not consider retaliation by the rest of the world. A proper treatment requires game-theoretic considerations that are beyond the scope of this paper.

imperfect substitutes and σ_D becomes smaller, the gains of a small open economy decrease. If the elasticity σ_D becomes small enough, open economy gains fall below the closed economy gains and become negative.

6. Numerical simulations

This section evaluates the quantitative significance of alternative capital mobility assumptions for the effects of the cut in capital income taxes that was examined in the previous section. The specific parameter values required to carry out the simulation analysis are presented at the end of table 1.¹⁷ The initial tax rates on capital income (net of depreciation) and labor income are respectively 50 percent and 20 percent. With a balanced budget, a net capital share in GNP of 23 percent and a labor share of 70 percent, government expenditure equals 25.5 percent of GNP. The ratios of net and gross investment to GNP are close to the historical values observed for the United States [see Summers (1981)]. Given the gross investment share and the government expenditure share, private consumption amounts to 64.5 percent of GNP.

The results presented in table 1 assume perfect substitutability between home goods and foreign goods. Tables 2 and 3 explore the effects of imperfect substitutability between goods by adopting substitution elasticities in demand σ_D of two and one, respectively. The first column in each of the three tables corresponds to a benchmark simulation. The benchmark value of two for the installation elasticity is close to Summers' (1981) implicit estimate of 2.17. The unitary elasticity of marginal instantaneous utility adopted in the benchmark corresponds to logarithmic instantaneous utility as in Lipton and Sachs (1983). The other columns in the tables examine the sensitivity of the welfare effects with respect to alternative assumptions about the installation elasticity, σ_x , the utility elasticity, σ_c , and the substitution elasticity between capital and labor, σ_k . The second column examines the effect of perfect mobility of physical capital by assuming a zero installation elasticity corresponding to infinitely elastic investment. Infinitely elastic saving is explored in the sixth column. The other columns represent a broad range of empirical estimates.¹⁸

Turning to the simulation results that assume perfect substitutability between goods, table 1 reveals that, with less than perfectly elastic investment and domestic ownership of capital, open economy results are quite similar to closed economy effects. In an open economy, the welfare gains are only marginally larger. Even if financial capital is perfectly mobile, the owners of domestic capital gain substantially on account of windfall gains. Only in the

¹⁷We do not need information on the rate of time preference and the growth rate to derive the welfare and incidence effects summarized in the tables. Information on these parameters is required, however, to find the rates of adjustment.

¹⁸See Judd (1985) for references to the relevant empirical literature.

Table 1

Welfare effects for a permanent decrease in the tax on capital income in the home country from 50 percent to 49.5 percent ($\bar{t}_k^1=0.01$) with perfect substitution between tradables ($\sigma_D \rightarrow \infty$) (relative change in welfare, in percent).

Cases	Benchmark ^a	σ_x					σ_c					σ_k			
		0	1/2	1	4	0	1/2	2	4	8	1/4	4			
Relative change in welfare residents of:															
Closed economy [$\tilde{w}^c$]	0.060	0.132	0.096	0.079	0.041	0.064	0.062	0.056	0.049	0.039	0.026	0.094			
Small open economy with domestically owned capital [$\tilde{w}^o(s_{k1}^1=1)$]	0.064	0.195	0.110	0.087	0.043	0.064	0.064	0.064	0.064	0.064	0.027	0.106			
Small open economy with foreign owned capital [$\tilde{w}^o(s_{k1}^1=0)$]	-0.056	0.195	0.031	-0.012	-0.096	-0.056	-0.056	-0.056	-0.056	-0.056	-0.051	-0.048			
Relative change in welfare owners domestic capital in:															
Closed economy [$\tilde{w}_k^c$]	0.940	0.436	0.687	0.807	1.069	0.909	0.925	0.968	1.013	1.080	0.620	1.190			
Small open economy [$\tilde{w}_k^o$]	0.909	0.000	0.594	0.750	1.054	0.909	0.909	0.909	0.909	0.909	0.594	1.169			
Relative change in welfare domestic labor in:															
Closed economy [$\tilde{w}_L^c$]	-0.074	0.086	0.006	-0.032	-0.115	-0.064	-0.069	-0.083	-0.097	-0.118	-0.064	-0.073			
Small open economy [$\tilde{w}_L^o$]	-0.064	0.225	0.036	-0.013	-0.110	-0.064	-0.064	-0.064	-0.064	-0.064	-0.059	-0.055			

^aBenchmark parameter values are: gross investment share $a_I=0.10$; depreciation share $d=0.07$; labor share $1-\alpha_k=0.70$; capital income tax rate $t_k=0.5$; labor income tax rate $t_L=0.2$; substitution elasticity $\sigma_k=1$; elasticity marginal utility $\sigma_c=1$; installation elasticity $\sigma_x=2$.

Table 2

Welfare effects for a permanent decrease in the tax on capital income in the home country from 50 percent to 49.5 percent ($\tilde{\tau}_k^1=0.01$) with imperfect substitution between tradables ($\sigma_D=2$) (relative change in welfare, in percent).

Cases	σ_x				σ_c				σ_k			
	Benchmark ^a	0	1/2	1	4	0	1/2	2	4	8	1/4	4
Relative change in welfare residents of:												
Closed economy	0.060	0.132	0.096	0.079	0.041	0.064	0.062	0.056	0.049	0.039	0.026	0.094
[$\tilde{w}^c$]												
Small open economy with domestically owned capital	-0.018	-0.049	-0.029	-0.023	-0.012	-0.018	-0.018	-0.018	-0.018	-0.018	-0.008	-0.027
[$\tilde{w}^o(s_k^1=1)$]												
Small open economy with foreign owned capital	-0.132	-0.049	-0.102	-0.116	-0.146	-0.132	-0.132	-0.132	-0.132	-0.132	-0.085	-0.168
[$\tilde{w}^o(s_k^1=0)$]												
Relative change in welfare owners domestic capital in:												
Closed economy	0.940	0.436	0.687	0.807	1.069	0.909	0.925	0.968	1.013	1.080	0.620	1.190
[$\tilde{w}_k^c$]												
Small open economy	0.865	0.000	0.554	0.705	1.016	0.865	0.865	0.865	0.865	0.865	0.583	1.068
[$\tilde{w}_k^o$]												
Relative change in welfare domestic labor in:												
Closed economy	-0.074	0.086	0.006	-0.032	-0.115	-0.064	-0.069	-0.083	-0.097	-0.118	-0.064	-0.073
[$\tilde{w}_L^c$]												
Small open economy	-0.152	-0.056	-0.117	-0.134	-0.168	-0.152	-0.152	-0.152	-0.152	-0.152	-0.098	-0.193
[$\tilde{w}_L^o$]												

^aSee note to table 1.

Table 3

Welfare effects for a permanent decrease in the tax on capital income in the home country from 50 percent to 49.5 percent ($\bar{t}_k^1=0.01$) with imperfect substitution between tradables ($\sigma_D=1$) (relative change in welfare, in percent).

Cases	σ_x				σ_c				σ_k			
	Benchmark ^a	0	1/2	1	4	0	1/2	2	4	8	1/4	4
Relative change in welfare residents of:												
Closed economy [$\tilde{w}^c$]	0.060	0.132	0.096	0.079	0.041	0.064	0.062	0.056	0.049	0.039	0.026	0.094
Small open economy with domestically owned capital [$\tilde{w}^o(s_k^1=1)$]	-0.085	-0.220	-0.135	-0.111	-0.060	-0.085	-0.085	-0.085	-0.085	-0.085	-0.041	-0.123
Small open economy with foreign owned capital [$\tilde{w}^o(s_k^1=0)$]	-0.194	-0.220	-0.204	-0.199	-0.190	-0.194	-0.194	-0.194	-0.194	-0.194	-0.116	-0.254
Relative change in welfare owners domestic capital in:												
Closed economy [$\tilde{w}_k^c$]	0.940	0.436	0.687	0.807	1.069	0.909	0.925	0.968	1.013	1.080	0.620	1.190
Small open economy [$\tilde{w}_k^o$]	0.828	0.000	0.521	0.668	0.983	0.828	0.828	0.828	0.828	0.828	0.573	0.993
Relative change in welfare domestic labor in:												
Closed economy [$\tilde{w}_L^c$]	-0.074	0.086	0.006	-0.032	-0.115	-0.064	-0.069	-0.083	-0.097	-0.118	-0.064	-0.073
Small open economy [$\tilde{w}_L^o$]	-0.224	-0.253	-0.235	-0.230	-0.218	-0.224	-0.224	-0.224	-0.224	-0.224	-0.134	-0.292

^aSee note to table 1.

second column, when investment is infinitely elastic, do open economy distributional consequences significantly differ from those in a similar open economy. With perfectly mobile physical capital in a small open economy, the real value of domestic capital does not increase at all and the larger economy-wide gains accrue only to domestic labor.

If terms of trade effects are allowed for by adopting the finite demand elasticities in table 2 and table 3, a small open economy loses due to terms of trade losses. Although capital gains somewhat less, labor suffers most of these terms of trade losses.

If all domestic capital is foreign owned, replacing taxes on capital by taxes on labor is in the national interests only if physical capital is (almost) perfectly mobile and terms of trade effects are absent (i.e. the second and third columns in table 1).

7. Conclusions

This study examined the main determinants of the incidence and efficiency of capital income taxes. Using an analytical solution for a two-country intertemporal equilibrium model, it analyzed the sensitivity of the tax effects with respect to several structural features of an economy.

Section 4 found that even for a small open economy, perfect international mobility of financial capital is not a sufficient condition for complete shifting of capital income taxes. Only if both physical and financial capital can costlessly flow among countries, does capital escape the entire tax burden.

Section 5 established the conditions under which decreasing capital income taxation is particularly attractive for open economies. These conditions are perfectly mobile physical and financial capital, close substitutability between home and foreign goods, and domestic ownership of home capital. If investment is inelastic with respect to Tobin's Q , welfare gains in open and closed economies are quite similar. If home goods and foreign goods are imperfect substitutes, or foreigners own capital in the home country, the efficiency gains in an open economy can be smaller than the gains in a similar closed economy. The open economy may even suffer welfare losses.¹⁹

Numerical simulations presented in section 6 suggested that the integration of an economy in world financial markets may affect the welfare and incidence results only marginally. This finding is in contrast to the claim made by Feldstein and Horioka (1980) that perfectly mobile financial capital is sufficient to dramatically alter the closed economy incidence results.²⁰ The

¹⁹In Bovenberg (1984), domestic capital deepening may yield welfare losses due to interaction with trade distortions.

²⁰Bovenberg (1984) analyzes the sources of financing for the domestic capital deepening that is induced by reducing capital income taxes. It is found that the adjustment path affects the long-run ownership of capital. With inelastic investment causing slow international capital relocation, the increase in domestic saving anticipating future terms of trade losses may suffice to finance domestic capital deepening. These results are consistent with the empirical relation between domestic saving and domestic investment found by Feldstein and Horioka (1980).

study also qualified the steady-state analysis in Mutti and Grubert (1985). They concluded that it takes much less than perfect capital mobility to substantially modify the incidence results derived in standard models of closed economies. Our analysis suggested that inertia in the investment process slows down the transition to such an extent that the dynamic shifting in a closed economy can be a reasonable approximation for the shifting process in an open economy. Thus, for a realistic assessment of capital income taxes in open economies, the reallocation process of physical capital during the transition period should be explicitly considered.

Appendix A: The linearized model

This appendix presents the log-linearized equations of the model presented in section 2. The equation number in square brackets refers to the corresponding equation in section 2. The superscripts and subscripts i and j represent either of the two countries. First, the static equations (i.e. the equations without time derivatives) are presented:

$$\tilde{x}_f^j = \alpha_{I1}^j \tilde{x}_1^j + (1 - \alpha_{I1}^j) \tilde{x}_2^j, \quad [(1)] \quad (A.1)$$

$$\tilde{p}_I^j = \alpha_{I1}^j \tilde{p}_1 + (1 - \alpha_{I1}^j) \tilde{p}_2, \quad [(5)] \quad (A.2)$$

$$\tilde{x}_f^j = (1/\sigma_x^j)(\tilde{q}_j - \tilde{p}_I^j), \quad [(15)] \quad (A.3)$$

$$\tilde{x}_1^j - \tilde{x}_2^j = -\sigma_I^j(\tilde{p}_1 - \tilde{p}_2), \quad [(3)] \quad (A.4)$$

$$\tilde{y}_j = \alpha_k^j \tilde{k}_j, \quad [(7)] \quad (A.5)$$

$$\tilde{p}_L^j = (\alpha_k^j/\sigma_k^j) \tilde{k}_j + \tilde{p}_j, \quad [(9)] \quad (A.6)$$

$$\tilde{c}_f^i = \alpha_{c1}^i \tilde{c}_1^i + (1 - \alpha_{c1}^i) \tilde{c}_2^i, \quad [(2)] \quad (A.7)$$

$$\tilde{p}_c^i = \alpha_{c1}^i \tilde{p}_1 + (1 - \alpha_{c1}^i) \tilde{p}_2, \quad [(6)] \quad (A.8)$$

$$\tilde{c}_f^i = -(1/\sigma_c^i)(\tilde{p}_c^i + \tilde{\mu}_i), \quad [(20)] \quad (A.9)$$

$$\tilde{c}_1^i - \tilde{c}_2^i = -\sigma_H^i(\tilde{p}_1 - \tilde{p}_2), \quad [(4)] \quad (A.10)$$

$$\tilde{Q}_i = \tilde{q}_i + \tilde{\mu}_i, \quad [(22)] \quad (A.11)$$

$$\begin{aligned}
(1 - t_L^i)(1 - \alpha_k^i)\tilde{t}_L^i &= -(1 - t_k^i)(\alpha_k^i - d^i)\tilde{t}_k^i \\
&+ (t_L^i - t_k^i)(1 - \alpha_k^i)\tilde{p}_L^i + t_k^i(\tilde{y}_i + \tilde{p}_i) \\
&- t_k^i d^i(\tilde{p}_I^i + \tilde{k}_i) \\
&- \{t_k^i(\alpha_k^i - d^i) + t_L^i(1 - \alpha_k^i)\} \{ \alpha_{G1}^i \tilde{p}_1 + (1 - \alpha_{G1}^i) \tilde{p}_2 \},
\end{aligned}
\tag{23} \quad (\text{A.12})$$

$$a_y^j \tilde{y}_j = \sum_{i=1}^2 a_I^i a_y^i \alpha_{Ij}^i (\tilde{x}_j^i + \tilde{k}_i) + \sum_{i=1}^2 a_c^i a_y^i \alpha_{cj}^i \tilde{c}_j^i. \tag{24} \quad (\text{A.13})$$

The dynamic equations are log-linearized around the initial steady state. In order to express the elasticities in terms of observable shares, the following steady-state relations are used. Imposing the balanced-growth conditions on (11) and (21), respectively:

$$g(x_f^i) = n, \tag{A.14}$$

$$r = \beta. \tag{A.15}$$

Substituting (A.14) and (A.15) into (16) and using (15) to eliminate $g'(x_f^i)$ yields:

$$b = [(1 - t_k^i)p_i f'(k_i) + t_k^i p_I^i \delta_f^i - p_I^i x_f^i] / q_i. \tag{A.16}$$

Using the definition for the share of after-tax cash-flow in production, z_i ,

$$z_i = (1 - t_k^i)\alpha_k^i - a_I^i + t_k^i d^i, \tag{A.17}$$

the following implicit balanced-growth expression for q_i is arrived at:

$$z_i/b = q_i k_i / p_i y_i. \tag{A.18}$$

Substitution (15) into (A.18), the corresponding expression for $g'(x_f^i)$ is

$$(g'(x_f^i)x_f^i)/b = a_I^i/z_i. \tag{A.19}$$

Relation (A.15) is used in log-linearizing (21) to arrive at

$$\dot{\mu}_i = -\beta \tilde{r}. \tag{21} \quad (\text{A.20})$$

Using (A.19) in the log-linearized version of (11) yields:

$$z_j(\dot{\tilde{k}}_j/b) = a_I^j \tilde{x}_f^j. \quad [(11)] \quad (A.21)$$

Using (A.18) and (A.19) to eliminate q_i and $g'(x_f^i)$ in the elasticities in the log-linearized version of (16) and using (A.3) to eliminate $\tilde{x}_f^i$

$$\begin{aligned} z_j\{(\dot{\tilde{q}}_j/b) - (\beta/b)\tilde{r} - \tilde{q}_j\} &= (a_I^j - t_k^j d^j) \tilde{p}_I^j \\ &\quad - (1 - t_k^j) \alpha_k^j \tilde{p}_j + (1 - t_k^j) \alpha_k^j \{(1 - \alpha_k^j)/\sigma_k^j\} \tilde{k}_j \\ &\quad - (1 - t_k^j)(\alpha_k^j - d^j) \tilde{t}_k^j. \end{aligned} \quad [(16)] \quad (A.22)$$

Notation of steady-state shares:

$a_y^j = p_j y_j / (p_1 y_1 + p_2 y_2)$,	share of country j in world production,
$(1 - \alpha_k^j)$,	share of gross labor income in value of production in country j ,
$\alpha_{cj}^i = p_j c_j^i / p_c^i c_f^i$,	value share of good j in composite consumption by residents of country i ,
$\alpha_{Ij}^i = p_j x_j^i / p_I^i x_f^i$,	value share of good j in composite investment in country i ,
$a_I^j = p_I^j x_f^j k_j / p_j y_j$,	value share of gross investment in production in country j ,
d^j ,	value share of replacement investment in production in country j ,
α_{Gj}^i ,	value share of good j in public demand in country i ,
s_{kj}^i ,	share of the capital stock installed in country j that is owned by residents of country i ,
$a_c^i = p_c^i c_f^i / p_i y_i$,	value share of consumption by residents in country i in production in country i ,
z_j ,	share of after-tax cash flow in production in country j .

For these shares the following relations hold:

$$\begin{aligned} z_j &= (1 - t_k^j) \alpha_k^j - a_I^j + t_k^j d^j, \\ a_y^i a_c^i &= a_y^i (1 - t_L^i) (1 - \alpha_k^i) + \sum_{j=1}^2 a_y^j s_{kj}^i z_j. \end{aligned}$$

Notation of parameters:

σ_c^i ,	elasticity of marginal instantaneous utility for residents in country i ,
σ_H^i ,	substitution elasticity between the two goods in consumption demand by residents in country i ,
σ_x^j ,	elasticity of marginal productivity of the composite capital good in installation in country j ,
σ_I^j ,	substitution elasticity between the two goods in installation in country j ,
σ_k^j ,	substitution elasticity between labor and capital in production in country j ,
β ,	annual rate of time preference,
n ,	annual rate of population growth,
$b = \beta - n$,	discounting parameter.

Appendix B: The accumulation system

The accumulation system is derived by taking the weighted sum of the dynamic relations given in appendix A, with the corresponding shares in world production, a_y^i , as weights. Imposing the symmetry conditions and substituting price equations (A.2) and (A.11) and investment demands (A.3), we arrive at

$$z(\dot{\tilde{k}}_A/b) = (a_I/\sigma_x)(\tilde{Q}_A - \tilde{p}_A - \tilde{\mu}_A), \quad (\text{B.1})$$

$$z(\dot{\tilde{q}}_A/b - (\beta/b)\tilde{r} - \tilde{Q}_A + \tilde{p}_A + \tilde{\mu}_A) = (1 - t_k)\alpha_k\{(1 - \alpha_k)/\sigma_k\}\tilde{k}_A, \quad (\text{B.2})$$

$$-(1 - t_k)(\alpha_k - d)\tilde{t}_k^A,$$

$$\dot{\tilde{\mu}}_A = -\beta\tilde{r}. \quad (\text{B.3})$$

Substituting (B.3) into (B.2), the rate of return is eliminated.

In order to find a dynamic system in the aggregate dynamic endogenous variables, $\tilde{Q}_A$ and $\tilde{k}_A$, and the aggregate exogenous variable $\tilde{t}_k^A$ only, the temporary equilibrium solution for the aggregate price $\tilde{p}_A + \tilde{\mu}_A$ is derived. Adding product market equilibria (A.13) and substituting the expressions for composite investment (A.1) and (A.3), composite consumption (A.7) and (A.9), production functions (A.5), and the prices (A.2), (A.8), and (A.11), the temporary equilibrium is found as

$$\tilde{\mu}_A + \tilde{p}_A = \frac{(a_I/a_c)\sigma_c}{\sigma_A}\tilde{Q}_A - \frac{\sigma_c\sigma_x}{a_c\sigma_A}(\alpha_k - a_I)\tilde{k}_A. \quad (\text{B.4})$$

The elasticities σ_A and σ_c are defined by (35) and (34), respectively. Using (B.4) to eliminate $\tilde{\mu}_A + \tilde{p}_A$ results in the accumulation system given in (27). The elasticity matrices C^A and D^A characterizing the system are given below:

$$C^A = b \begin{bmatrix} \{(a_I/a_c)\sigma_c/\sigma_A\}\{(\alpha_k - a_I)/z\} & (a_I/z\sigma_x)(\sigma_x/\sigma_A) \\ (z\sigma_x/a_I)\{(a_I/a_c)\sigma_c/\sigma_A\}\{(\alpha_k - a_I)/z\} & (\sigma_x/\sigma_A) \\ + \{(1-t_k)\alpha_k/z\}\{(1-\alpha_k)/\sigma_k\} & \end{bmatrix}, \quad (\text{B.5})$$

$$D^A = b \begin{bmatrix} 0 \\ -(1-t_k)(\alpha_k - d)/z \end{bmatrix}. \quad (\text{B.6})$$

Appendix C: The reallocation system

The reallocation system is derived by subtracting the dynamic relations (A.21) and (A.22) for the foreign country from the corresponding relations for the home country. Imposing the symmetry conditions and substituting price equations (A.2) and investment demands (A.3), we arrive at

$$z(\dot{\tilde{k}}_R/b) = (a_I/\sigma_x)\tilde{q}_R, \quad (\text{C.1})$$

$$z\{(\dot{\tilde{q}}_R/b) - \tilde{q}_R\} = (1-t_k)\alpha_k[-\tilde{p}_R + \{(1-\alpha_k)/\sigma_k\}\tilde{k}_R] - (1-t_k)(\alpha_k - d)\tilde{t}_k^R. \quad (\text{C.2})$$

In order to find a dynamic system in the relative dynamic endogenous variables, $\tilde{k}_R$ and $\tilde{q}_R$, and the relative exogenous variable $\tilde{t}_k^R$ only, the temporary equilibrium solution for the relative product price, $\tilde{p}_R$, is derived. To that end, the product market equilibria (A.13) are divided by the corresponding shares in world production. Subtracting the rewritten equilibrium expressions for the foreign good from the corresponding expression for the home good, and substituting relative product demands (A.4) and (A.10) and production functions (A.5), the temporary equilibrium is found as

$$\tilde{p}_R = -(\alpha_k/\sigma_D)\tilde{k}_R. \quad (\text{C.3})$$

The aggregate demand elasticity σ_D is defined by (30).

Using (C.3), the relative product price is eliminated from (C.2). This results in the reallocation system with the following elasticity matrices [see (27)]:

$$C^R = b \begin{bmatrix} 0 & (a_I/z\sigma_x) \\ \{(1-t_k)\alpha_k/z\}[\{(1-\alpha_k)/\sigma_k\} + \{\alpha_k/\sigma_D\}] & 1 \end{bmatrix}, \quad (\text{C.4})$$

$$D^R = b \begin{bmatrix} 0 \\ -(1-t_k)(\alpha_k-d)/z \end{bmatrix}. \quad (C.5)$$

Appendix D: Dynamic welfare effects

In the symmetric model with identical consumption shares, the consumption price index (A.8) is the same for all agents and equals the aggregate product price p_A . Thus, the real value of an endowment, reflecting intertemporal utility enjoyed by its owners, can be computed by deflating per capita endowment earnings by the aggregate product price and discounting these 'real' earnings by the discount factor $\beta - n = b$.

Real human wealth owned by residents in country i , w_L^i , is given by the discounted after-tax real wages. The real wealth effect for human capital owned by residents in country i is

$$\tilde{w}_L^i = b \int_0^\infty \{ \tilde{p}_{Lt}^i - \tilde{p}_{At} + \tilde{t}_{Lt}^i \} e^{-bt} dt, \quad i=1,2. \quad (D.1)$$

The real value of the capital stock installed in country i , w_{ki} , is computed as the discounted after-tax real cash flow. Thus, the welfare effect for the owners of capital employed in country i is given by

$$\begin{aligned} \tilde{w}_{ki} = b \int_0^\infty [& \{ (1-t_k)/z \} \{ \tilde{y}_{it} + \tilde{p}_{it} - (1-\alpha_k)\tilde{p}_{Lt}^i \} \\ & - (a_I/z)\tilde{x}_{ft}^i - \tilde{p}_{At} - \{ (a_I-t_k d)/z \} (\tilde{k}_{it} + \tilde{p}_{It}^i) \\ & + \{ (1-t_k)(\alpha_k-d)/z \} \tilde{t}_k^i] e^{-bt} dt, \quad i=1,2. \end{aligned} \quad (D.2)$$

Using relations (A.2), (A.5), (A.6), (A.12), and (A.21), real earnings for labor and capital can be expressed in terms of real product prices, $\tilde{p}_i - \tilde{p}_A$, capital stocks, $\tilde{k}_i$, and exogenous variables only. Substituting

$$\tilde{p}_i - \tilde{p}_A = (-1)^{i+1} (1-a_y^i) \tilde{p}_R, \quad i=1,2, \quad (D.3)$$

$$\tilde{k}_i = \tilde{k}_A + (-1)^{i+1} (1-a_y^i) \tilde{k}_R, \quad i=1,2, \quad (D.4)$$

and temporary equilibrium (C.3) with the transition paths for the backward-looking dynamic endogenous variables $\tilde{k}_A$ [from (28) and 31)] and $\tilde{k}_R$ [from (29) and (36)], we arrive at the time paths for the real earnings of labor and capital.

Discounting these time paths according to (D.1) and (D.2), the real wealth effects are derived as

$$\tilde{w}_{ki} = \frac{(1-t_k)(\alpha_k-d)}{z} \left[\frac{b}{(h^A+b)} \tilde{t}_k^A + (-1)^{i+1} (1-a_y^i) \frac{b}{(h^R+b)} \tilde{t}_k^R \right], \quad i=1,2, \quad (\text{D.5})$$

$$\tilde{w}_L^i = \frac{a_c}{(1-\alpha_k)(1-t_L)} \tilde{w}_T^i - \frac{z}{(1-\alpha_k)(1-t_L)} \tilde{w}_{ki}, \quad i=1,2, \quad (\text{D.6})$$

where $\tilde{w}_T^i$ is the real value of the production factors employed in country i :

$$\begin{aligned} \tilde{w}_T^i = & \frac{h^A}{(h^A+b)} \frac{t_k(\alpha_k-d)}{a_c} \frac{(\alpha_k-d)}{\alpha_k} \frac{\sigma_k}{(1-\alpha_k)} \tilde{t}_k^A \\ & + (-1)^{i+1} (1-a_y^i) \frac{h^R}{(h^R+b)} \frac{(\alpha_k-d)}{\alpha_k} \frac{1}{a_c} \frac{\{t_k(\alpha_k-d) - (\alpha_k/\sigma_D)\}}{\{(1-\alpha_k)/\sigma_k\} + (\alpha_k/\sigma_D)} \tilde{t}_k^R, \\ & i=1,2. \end{aligned} \quad (\text{D.7})$$

The welfare effect for agents residing in country i , $\tilde{w}^i$, is given by the weighted sum of the real wealth effects corresponding to the endowments owned by domestic residents:

$$\tilde{w}^i = \frac{(1-t_L)(1-\alpha_k)}{a_c} \tilde{w}_L^i + \frac{z}{a_c} [\tilde{w}_{ki} + (-1)^{i+1} (1-s_{ki}^i) \tilde{w}_{kR}], \quad i=1,2. \quad (\text{D.8})$$

In this paper, only policy changes in the home country are considered. Thus, the exogenous policy variables are defined as

$$\tilde{t}_k^A = a_y^1 \tilde{t}_k^1, \quad (\text{D.9})$$

$$\tilde{t}_k^R = \tilde{t}_k^1. \quad (\text{D.10})$$

The effects for the closed and the open economy are found by letting the home share in world production, a_y^1 , approach one and zero, respectively.

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