Taxing Land Rent in an Open Economy

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Summary

This paper analyzes the effects of a land rent tax on capital formation and foreign investment in a life-cycle small open economy with endogenous labor-leisure choices. Differently from the previous literature, the consequences of land taxation critically depend on how the tax proceeds are used by the government. A land tax depresses capital formation, crowds out foreign investment and pulls up national wealth and consumption when consumers are lump-sum compensated for the tax. If the proceeds from taxation were used for financing un-productive government expenditure, land taxation would be neutral in its effects on capital stock, nonhuman wealth and labor. When the tax proceeds are used to reduce labor taxes, the land tax exerts ambiguous effects on capital stock and manhours, and spurs nonhuman wealth accumulation.

Keywords: Land Taxation, Labor Supply, Capital Accumulation, Overlapping-generations

JEL: E21, E62, H22

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1 Introduction

In a non-altruistic OLG closed economy, where land serves as an input as well as an asset, and land and labor are inelastically supplied, a tax on land rent is associated with higher capital stock and output per person in the steady state. This result is discovered by Feldstein (1977). The rationale for this result is that a land tax hike, by initially reducing the value of land, diverts savings away from land into real capital, therefore spurring capital accumulation and temporarily output growth. The increase in capital stock in turn lowers the real interest rate (whose fall, if sufficiently strong, may even induce a rise in the land price in the after-shock equilibrium) and raises the marginal productivity of land as well as the wage rate. Steady state financial wealth, consumption and welfare rise.[1]

The positive effect of the land rent tax on capital formation, which can be denominated the "Feldstein effect", is grounded in the portfolio choices. Since capital and land are the only assets of the economy, any "flight from

[1] The primary purpose of the Feldstein (1977) analysis was to demonstrate that within an intertemporal setting, where the supply of capital is endogenous through saving decisions, the Ricardian proposition that a tax on pure rent is unshifted is violated. Calvo-Kotlikoff-Rodriguez (1979) demonstrate that the Feldstein findings depend on the non-Ricardian (in the demographic sense) structure of the economy considered, by showing that in a Barro-Ramsey economy a tax on land rent is fully capitalized in the price of land and no tax shifting occurs as originally predicted by Ricardo. See also Kotlikoff-Summers (1987).

land", determined by the land rent tax, is by necessity a "flight into real capital".[2]

In a finite-lived small open economy facing a perfect world capital market and having a fixed labor supply, savings diverted from land by a rise in land taxation are not canalized into real capital. This is shown by Eaton (1988) who discovers that within such an economy a compensated land tax leaves capital stock, domestic output and non-land input prices unaffected. The land tax however reduces the price of land, crowds out foreign investment and hence raises national income as well as consumption and welfare of nationals.[3]

There is nothing surprising in these findings. In fact, even if the economy analyzed by Eaton (1988) is in principle a three-asset economy (as net foreign assets are introduced in the asset menu of savers in addition to physical capital and land), it *de facto* works as a two-asset economy, as capital stock is tied down by the given world interest rate. Within a small open economy with perfect capital mobility, the portfolio mechanism discovered by Feldstein is still in existence but implies that the "flight from land" necessarily determines a "flight into foreign assets", given the capital stock black-out.

The purpose of this paper is to analyze the effects of a land rent tax on capital formation and foreign investment within a life-cycle small open economy where capital stock is unblocked from the world interest rate uni-

[2] The "Feldstein effect" is independent of alternative uses of land tax revenues. Whether land tax proceeds are lump-sum transferred to consumers or spent to increase unproductive government spending or used to reduce labor taxes is inconsequential for the qualitative consequences of the land tax on the resource allocation.

[3] The effects of land taxation is only one of the multiple issues investigated by Eaton (1988).

lateral peg by considering endogenous labor-leisure choices. By extending the analysis provided by Eaton (1988), we investigate whether the direction of the "flight from land" can involve real capital other than net foreign assets, when the world interest rate fixes capital intensity, but no longer capital stock as both capital and labor are endogenously determined.

We discover that the consequences of land rent taxation differ substantially from those predicted by Feldstein (1977) and Eaton (1988) and critically depend on how the tax proceeds are used by the government.

Land taxation does not spur capital accumulation as in a closed economy, but instead depresses capital formation and economic growth when consumers are lump-sum compensated for the tax. In this case, as in Eaton (1988), the "Feldstein effect" takes the morphology of foreign investment displacement as a mirror-like reflection of the land value fall; when labor supply is endogenous, however, capital stock bears part of the burden of the macroeconomic adjustment in an anti-Feldstein direction. Labor and domestic output are reduced by the shock, while nonhuman wealth and national income are increased. The cause of the rise in financial wealth and consumption lies in the intergenerational redistribution of resources that affects the pattern of the life-cycle savings of an individual and, as a result, the aggregate savings in the economy.

If instead the resources from taxation were used for financing unproductive government expenditure, land taxation would be neutral in its effects on capital stock and aggregate wealth, because no income redistribution between living generations and still unborn generations occurs. Welfare of nationals is not affected by the land tax. In this case the fall in the land price stemming from higher taxation only implies a reduction in foreign investment.

When the tax proceeds are used to reduce labor income taxes, land taxation exerts ambiguous effects on capital stock and manhours, while it raises domestic wealth and aggregate consumption.

2 The model

Consider a small open economy populated by finite-lived consumers. This economy produces a single tradable good, which is perfectly substitutable with the foreign-produced good, and has access to a perfect world capital market. Domestic production is obtained by using capital, land and labor. Domestic assets, namely real capital and land, are partly owned by nationals and partly by foreigners.[4]

The consumers' behavior is obtained by using the OLG demographics with uncertain lifetime and no bequest motives formulated by Yaari (1965) and Blanchard (1985), extended to incorporate endogenous labor-leisure choices, as in Phelps (1994, ch. 16).[5] Agents face a constant mortality rate θ. New cohorts are born continuously. As the birth rate is assumed to equal the death rate, population, composed of cohorts of different ages, remains constant and hence can be normalized to one.

Assuming logarithmic preferences, the demand-side of the economy is

[4]It could be alternatively assumed without altering the equilibrium that the stock of capital and land are owned entirely by domestic residents, who could always borrow abroad to bring about the current portfolio allocation.

[5]The analysis of Eaton (1988) is instead based on the Samuelson-Diamond specification of the overlapping-generations structure.

described by the following aggregate relationships[6]

$$\dot{C} = (r^* - \rho)C - \alpha\theta(\theta + \rho)V^d \tag{1a}$$

$$1 - L = \frac{(1-\alpha)C}{\alpha(1-\tau)w} \tag{1b}$$

$$C + \dot{V}^d = r^* V^d + (1-\tau)wL + Z \tag{1c}$$

where C is aggregate consumption, V^d financial wealth of nationals, L labor hours, w real wage, Z lump-sum transfers from the government, r^* the given world interest rate, ρ the exogenous rate of time preference, τ the labor income tax rate and $\alpha \in (0,1)$ a preference parameter.

Equation (1a) describes the law of motion of consumption. It derives from the Blanchard-Yaari intertemporal arbitrage condition asserting that the rate of return on nonhuman wealth, r^*, must equal the rate of return on consumption, given by the subjective discount rate plus the relative change in consumption plus a premium proportional to the wealth-consumption ratio.[7] Equation (1b) is a Cobb-Douglas labor supply, while relation (1c) represents consumers' aggregate budget constraint.

Financial wealth of domestic residents is composed of two perfectly substitutable assets, i.e. physical capital K^d and unimproved land T^d; that is

[6]The derivation of sub-system (1) is described in Appendix A of the Mathematical Supplement.

[7]As the stock of financial wealth held by nationals is assumed to be strictly positive, the steady state equilibrium requires $r^* > \rho$. This condition guarantees that individuals save initially more and have an increasing profile of consumption.

$$V^d = K^d + qT^d$$

where q is the price of land.

After-tax rates of return of perfectly substitutable assets must satisfy the following relationship

$$r^* = \frac{(1-\lambda)R}{q} + \frac{\dot{q}}{q} \tag{2}$$

where λ is a proportional tax rate on land rent, R represents the land reward and perfect foresight has been assumed.

Domestic output Y is produced by competitive firms through the following well-behaved and linearly homogeneous production function:

$$Y = F(K, T, L)$$

where K and T represent total capital stock and land, respectively. Factors of production are complementary in the Edgeworth sense.

Total capital and land are defined as

$$K = K^d + K^f \tag{3a}$$

$$T = T^d + T^f \tag{3b}$$

where K^f and T^f are capital and land owned by foreigners, respectively.

First-order conditions for maximum profit entail

$$F_K(K, T, L) = r^* \tag{4a}$$

$$F_T(K, T, L) = R \tag{4b}$$

$$F_L(K, T, L) = w \tag{4c}$$

The economy has a fixed endowment of unimproved land, $\widetilde{T}$, fully used in production. Land endowment is normalized to one, i.e. $\widetilde{T}= 1$.

Government uses revenues from taxing land rents and labor income to finance lump-sum transfers to consumers and unproductive public spending G; that is

$$\lambda RT + \tau wL = Z + G \tag{5}$$

The current account gives the rate of accumulation of foreign investment:

$$\dot{B}= C+ \dot{K} +G - Y + r^* B \tag{6}$$

where B denotes foreign investment, i.e. the value of capital and land held by foreigners, defined as

$$B = K^f + qT^f \tag{7}$$

The full model of the economy is obtained by combining the optimality conditions for consumers and firms together with the equilibrium condition on factor markets and the relevant equations of accumulation.

Our study of the macroeconomic consequences of land taxation is only concerned with a situation of steady state equilibrium.

3 Land taxation and resource allocation

Three alternative policy-experiments concerning the effects of a parametric change in λ are studied: one in which the government distributes the revenues from taxation to consumers in a lump-sum fashion, one in which the additional tax proceeds are used for financing an increase in public expenditure, and one in which land tax revenues are employed to reduce the labor income tax rate.

3.1 Lump-sum distribution of land tax revenues

In this experiment, the rise in the land tax is accompanied by the lump-sum distribution of the land tax proceeds. Government expenditure and the labor income tax rate are fixed at $\tilde{G}$ and $\tilde{\tau}$ respectively.

In the present economy, the marginal productivity of capital is fixed by the world interest rate according to equation (4a). From (4a), we obtain

$$\bar{L} = l(\bar{K}), \quad l' > 0 \tag{8}$$

where overbars denote long-run values and $l' = -\dfrac{F_{KK}}{F_{KL}} > 0$.

Substituting (8) into (1b) for $\bar{L}$, we can express consumption in terms of capital stock and the labor income tax rate as follows

$$\bar{C} = c(\bar{K}, \tilde{\tau}), \quad c_{\bar{K}} < 0, \ c_{\tilde{\tau}} < 0 \tag{9}$$

where $c_{\bar{K}} = -\dfrac{\alpha(1-\tilde{\tau})\left[(1-\bar{L})\Phi - F_L F_{KK}\right]}{(1-\alpha)F_{KL}} < 0$, $c_{\tilde{\tau}} = -\dfrac{\alpha(1-\bar{L})F_L}{(1-\alpha)} < 0$ and $\Phi = F_{KK}F_{LL} - F_{KL}^2 > 0$.

From equation (1a), the Blanchard-Yaari consumption function is derived

$$\bar{C}= \frac{\alpha\theta(\theta+\rho)}{(r^{*}-\rho)}\left(\bar{K}+\bar{q}-\bar{B}\right) \tag{10}$$

where $\bar{K}+\bar{q}-\bar{B}=\bar{V}^{d}$.

The current account balance implies that

$$\bar{C}+\widetilde{G}= r^{*}\left(\bar{K}+\bar{q}-\bar{B}\right)+F_{L}\ \bar{L}\ +\lambda F_{T} \tag{11}$$

Substituting (10) into (11) for $\bar{K}+\bar{q}-\bar{B}$ and using (8), we obtain

$$\bar{C}= \frac{\alpha\theta(\theta+\rho)}{[\alpha\theta(\theta+\rho)-r^{*}(r^{*}-\rho)]}\left[h(\bar{K},\lambda)-\widetilde{G}\right] \tag{12}$$

where $h(\bar{K},\lambda)=F_{L}\ \bar{L}\ +\lambda F_{T}$, $h_{\bar{K}}=-\frac{\left[(1-\lambda)\ \bar{L}\ \Phi+F_{L}F_{KK}\right]}{F_{KL}}$, $h_{\lambda}=F_{T}>0$ and $\alpha\theta(\theta+\rho)>r^{*}(r^{*}-\rho)$.

Differentiating equations (9) and (12) yields

$$\frac{d\ \bar{K}}{d\lambda}=\frac{\alpha\theta(\theta+\rho)F_{T}}{\Delta}$$

$$\frac{d\ \bar{C}}{d\lambda}=\frac{\alpha\theta(\theta+\rho)F_{T}c_{\bar{K}}}{\Delta}$$

where $\Delta=[\alpha\theta(\theta+\rho)-r^{*}(r^{*}-\rho)]\,c_{\bar{K}}-\alpha\theta(\theta+\rho)h_{\bar{K}}$.

Saddle-point stability of the steady state equilibrium is satisfied as long as $\Delta<0$.[8] Thus a compensated rise in the land tax leads to lower capital stock and higher consumption. The reduction of capital goes together with a contraction of labor hours from (8), while the rise in consumption is accompanied by an expansion of national wealth from (10). The reduction of

[8] The dynamic properties of the model are discussed in Appendix B of the Mathematical Supplement.

capital implies that the before-tax return on land falls, while the wage rate rises.[9] The price of land falls more than the capitalized amount of the tax because of the reduction of the marginal productivity of land. Moreover, since domestic wealth $\bar{K} + \bar{q}$ is reduced and national wealth $\bar{K} + \bar{q} - \bar{B}$ is increased, a reduction of foreign investment takes place.

In this setup, the effects of land taxation on financial wealth and consumption deriving from the non-Ricardian demographic structure of the economy are not surprising, even if they are greatly simplified, compared to the closed economy, by the capital price invariance. What turns out to be rather unconventional in this open economy environment are the consequences upon the factors of production.

The rationale for the effects on financial wealth and consumption, and the reverse "Feldstein effect" on capital stock is as follows. When there are finite lives with new births, a higher compensated land tax, implying greater lump-sum transfers distributed by the government to consumers, causes a redistribution of income from those who consume more and save less (the "older" ones) to those who consume less and save more (the "younger" ones). This leads to higher aggregate savings and financial wealth accumulation is therefore spurred. The rise in financial wealth brings aggregate consumption up. Higher consumption induces a higher demand for leisure and a lower supply of labor. Manhours are therefore reduced. Since the marginal productivity of capital is given, and labor and capital are Edgeworth complements, lower labor hours imply lower capital stock.[10]

[9] This is because we have, once (8) is taken into account, that $\bar{R}= R(\bar{K})$ and $\bar{w}= w(\bar{K})$, where $R' = \dfrac{\bar{L}\,\Phi}{F_{KL}} > 0$ and $w' = -\dfrac{\Phi}{F_{KL}} < 0$.

[10] Although the drop of capital stock increases the wage rate, the consumption-to-wage

3.2 Compensatory increase in government expenditure

When land tax revenues are used to finance an increase in government expenditure, the implications of the land tax can be easily understood as follows. Equation (11) can be re-written by using the goverment budget constraint (5) as

$$\bar{C}= r^* \left(\bar{K} + \bar{q} - \bar{B}\right) + (1- \tilde{\tau})F_L \; \bar{L} + \tilde{Z} \tag{13}$$

where $\tilde{Z}$ represents the exogenous lump-sum transfers.

Using (13) together with (10), we obtain

$$\bar{C}= \frac{\alpha\theta(\theta + \rho)}{[\alpha\theta(\theta + \rho) - r^*(r^* - \rho)]} \left[j(\bar{K}, \tilde{\tau})+ \tilde{Z}\right] \tag{14}$$

where $j(\bar{K}, \tilde{\tau}) = (1- \tilde{\tau})F_L \; \bar{L}$, $j_{\bar{K}} = -\frac{(1- \tilde{\tau})(\bar{L} \; \Phi + F_L F_{KK})}{F_{KL}}$ and $j_{\tilde{\tau}} = -F_L \; \bar{L}<0$.

Equations (9) and (14), which jointly determine $\bar{K}$ and $\bar{C}$, are independent of λ and $\bar{G}$. Hence, a rise in the land tax rate accompanied by an increase in government spending leaves capital stock and consumption unchanged. Labor hours, national wealth, the before-tax land reward and the wage rate also remain unaffacted. As the gross land rental $\bar{R}$ is constant, the land price drops by exactly the fall in $1 - \lambda$. Hence, the land rent tax is fully capitalized in the price of land.

Since capital stock does not change and the price of land is reduced, foreign investment must fall in order to keep national wealth constant. Moreover, while domestic output remains constant, national income is increased.

ratio is driven up as consumption increases more than the wage rate.

The increase in national income is entirely absorbed by the government. Welfare of nationals remains unaltered.[11]

Thus, when the government budget is balanced through the endogenous adjustment of government expenditure, long-run capital stock becomes independent of the land tax, since the intergenerational redistribution of income seen above is absent and so are the effects on aggregate savings, financial wealth, consumption and welfare.

3.3 Compensatory reduction in τ

Suppose now that the increase in the land tax is matched by the endogenous change in the labor tax rate so as to keep the government budget balanced.

Using the government budget constraint (5) together with equations (4) and (8), we obtain

$$\frac{d\,\bar{\tau}}{d\lambda} = -\frac{F_T}{F_L\,\bar{L}} + \Pi\frac{d\,\bar{K}}{d\lambda}$$

where $\Pi = \dfrac{\left[\bar{\tau}\,(\bar{L}\,\Phi + F_L F_{KK}) - \lambda\,\bar{L}\,\Phi\right]}{F_L\,\bar{L}\,F_{KL}}$.[12]

From (9) and (12), after using the above expression for $\dfrac{d\,\bar{\tau}}{d\lambda}$, we get

$$\frac{d\,\bar{K}}{d\lambda} = -\frac{\alpha F_T\left[\theta(\theta+\rho)(\alpha-\bar{L}) - (1-\bar{L})r^*(r^*-\rho)\right]}{(1-\alpha)\,\bar{L}\,\Lambda}$$

$$\frac{d\,\bar{C}}{d\lambda} = \frac{(1-\bar{\tau})\alpha\theta(\theta+\rho)F_L F_T F_{KK}}{(1-\alpha)\,\bar{L}\,\Lambda F_{KL}}$$

[11] In this compensatory finance circumstance, the hypothesis of endogenous labor-leisure choices has no implications for the effects of λ on the resource allocation. Our findings confirm those obtainable in a small open economy with an inelastic labor supply.

[12] If a Cobb-Douglas production function were used, Π would be unambiguously negative.

where $\Lambda = [\alpha\theta(\theta+\rho) - r^*(r^*-\rho)]\,(c_{\bar{K}} + \Pi c_{\bar{\tau}}) - \alpha\theta(\theta+\rho)h_{\bar{K}}$ and $\alpha > \bar{L}$.

Thus, a rise in the land tax exerts an ambiguous effect on capital stock and a positive effect on consumption, since $\Lambda < 0$, as a necessary and sufficient condition for having saddle-point stability of the steady state.[13] Also the effects on manhours, the pre-tax land reward and the wage rate are ambiguous. Financial wealth is instead pulled up by the rise in land taxation.

The ambiguity of the land tax effects on capital and labor depends on two contrasting effects that are at work in this case-study. These effects derive from the OLG demographics with new entries, on the one hand, and the consumption-leisure substitution effect, on the other hand.

The rise in λ, by inducing a reduction of the wage income tax, redistributes income between the living generations and the yet to be born ones. This mechanism, which works through a human wealth channel, leads to higher aggregate savings;[14] the stock of financial wealth is therefore expanded. Consequently, consumption is driven up and labor supply is reduced. On the other hand, the rise in λ, implying for a given capital stock an increase in the after-tax wage because of the fall of τ, brings about a fall in the leisure-consumption ratio. This causes a substitution away from leisure toward labor and consumption. The induced rise in labor supply stimulates capital from (8). Thus the overall effect of the land tax hike on equilibrium manhours and

[13] This is demonstrated in Appendix C of the Mathematical Supplement.

[14] Long-run aggregate human wealth is: $\bar{H} = \dfrac{(1-\bar{\tau})\,\bar{w} + \widetilde{Z}}{(r^*+\theta)}$ (see Appendix A of the unpublished Mathematical Supplement). From the definition of $\bar{H}$, it is clear that the intergenerational mechanism brought into action by the induced change in $\bar{\tau}$ is the same as the one activated by a change in lump-sum transfers (seen in Sub-section 3.1).

capital stock is determined by which of these two antitethic effects dominate.

From a mechanical perspective, it can be observed that, since consumption and the after-tax wage are increased by the fall in τ, the net effect of λ on labor and hence capital depends, according to (1b), on whether the consumption-to-after-tax-wage ratio increases or not. If the effect of the land tax on $\frac{\bar{C}}{(1-\bar{\tau})\,\bar{w}}$ is positive, namely consumption rises more than net wage, labor hours fall and capital stock is contracted, since the intergenerational redistributive effect dominates the substitution effect; in this case, the qualitative consequences on the whole system are the same as those seen in Subsection 3.1. If instead, the after-tax wage rate increases more than consumption, leisure is reduced while labor is stimulated as the magnitude of the substitution effect prevails over the magnitude of the intergenerational redistributive effect; the rise in manhours in turn increases capital stock. Foreign investment may either rise or fall.

4 Conclusions

This paper has investigated the consequences of taxing a fixed asset, i.e. unimproved land, on wealth accumulation and economic growth within a small open economy model that incorporates overlapping-generations with new births and an endogenous labor supply.

We have shown that the hypothesis of inelastic labor choices is non-innocuous for the economic growth neutrality of a land tax obtained by Eaton (1988), since in such a case capital stock is pinned down by the exogenous world interest rate. The consequences of land taxation upon the employment of production factors change substantially when labor-leisure choices become elastic. In fact, an endogenous labor supply removes the capital stock black-out and introduces permanent effects of land taxation on capital stock and labor hours, by making the interaction among financial assets (namely capital, land and foreign assets) fully operative.

We depart from the Feldstein (1977) and Eaton (1988) findings, firstly because the use of tax proceeds makes a fundamental difference for the final effects of land taxation on the resource allocation and secondly because of the consequences on capital accumulation and economic growth. While a pure "Feldstein effect" remains valid merely in terms of nonhuman wealth, a reverse "Feldstein effect" on capital stock is obtained, when consumers are lump-sum compensated for the tax; in this circumstance, foreign investment is crowded out, while national wealth and consumption rise.

When the land tax is accompanied by the endogenous adjustment of government expenditure, no effects on capital stock, hours worked and non-human wealth are registered, whereas foreign investment is reduced by the fall in the land price. In this case the hypothesis of an endogenous labor supply is inconsequential for the effects of land taxation on the macroeconomic equilibrium.

Finally, a change in land taxation coupled with a compensatory change in the wage tax produces ambiguous effects on capital and manhours, while financial wealth and consumption rise.

MATHEMATICAL SUPPLEMENT

Appendix A

Microeconomics of the demand-side

Here, the microeconomic derivation of the aggregate behavior of consumers, namely equations (1) of the text, is provided.

Assuming that the individual utility is logarithmic in consumption, c, and leisure, $\widetilde{l} - l$ (where $\widetilde{l}$ is time endowment and l represents labor hours supplied), at each instant t a consumer born at time $s \leq t$ solves the following problem

$$\max \int_t^{\infty} \left\{ \alpha \ln c(s,j) + (1-\alpha) \ln \left[\widetilde{l} - l(s,j) \right] \right\} \exp[-(\theta+\rho)(j-t)] dj \quad \text{(A.1)}$$

subject to the instantaneous budget constraint

$$\frac{d}{dt} v^d(s,t) = (r^* + \theta) v^d(s,t) + (1-\tau) w(t) l(s,t) + z(s,t) - c(s,t) \quad \text{(A.2)}$$

and the solvency condition precluding Ponzi schemes

$$\lim_{j \to \infty} v^d(j,t) \exp[-(r^* + \theta)(j-t)] = 0 \quad \text{(A.3)}$$

where $v^d(s,t)$ and $z(s,t)$ denote nonhuman wealth and lump-sum transfers of a consumer born at time s; θ the mortality rate (exogenous), ρ the rate of time preference (exogenous), r^* is the world interest rate (exogenous), $w(t)$ hourly real wage, τ the proportional tax on labor income, and α a positive preference parameter.

The optimality conditions for the individual problem (A.1)-(A.3) are

$$c(s,t) = \alpha(\theta+\rho)[v^d(s,t) + h(s,t)]$$

$$\tilde{l} - l(s,t) = \frac{(1-\alpha)c(s,t)}{\alpha(1-\tau)w(t)}$$

$$\frac{d}{dt}c(s,t) = (r^* - \rho)c(s,t)$$

where $h(s,t)$ is the consumer's human wealth, given by

$$h(s,t) = \int_t^\infty [(1-\tau)w(j) + z(s,j)] \exp[-(r^*+\theta)(j-t)]dj$$

Aggregating over all the cohorts and omitting the time index, the demand-side of the model can be expressed as

$$C = \alpha(\theta+\rho)(V^d + H) \tag{A.4a}$$

$$1 - L = \frac{(1-\alpha)C}{\alpha(1-\tau)w} \tag{A.4b}$$

$$\dot{H} = (r^*+\theta)H - (1-\tau)w - Z \tag{A.4c}$$

$$C + \dot{V}^d = r^* V^d + (1-\tau)wL + Z \tag{A.4d}$$

where capital letters denote aggregate variables of the corresponding individual variables[15] and aggregate time endowment has been normalized to one.

By using equations (A.4a), (A.4c) and (A.4d), the Blanchard-Yaari equation of motion for consumption can be easily obtained:

$$\dot{C} = (r^* - \rho)C - \alpha\theta(\theta + \rho)V^d \tag{A.4a'}$$

Thus, the aggregate behavior of consumers can be described by the subsystem (A.4a'), (A.4b) and (A.4d) as indicated in Section 2 of the paper.

[15] Each aggregate variable is defined as

$$X(t) = \int_{-\infty}^{t} x(s,t)\lambda e^{\lambda(s-t)} ds$$

where $x(s,t)$ indicates a generic individual variable.

Appendix B

Lump-sum distribution of tax revenues: Analysis of stability

The short-run model can be written as

$$\dot{C}= (r^* - \rho)C - \alpha\theta(\theta + \rho)(K + q - B) \tag{B.1a}$$

$$\dot{q}= r^* q - (1 - \lambda)F_T(K, L) \tag{B.1b}$$

$$\dot{B}=\dot{K} + C + G - F(K, L) + r^* B \tag{B.1c}$$

$$1 - L = \frac{(1 - \alpha)C}{\alpha(1- \tilde{\tau})F_L(K, L)} \tag{B.1d}$$

$$F_K(K, L) = r^* \tag{B.1e}$$

Since we are considering the case of a lump-sum distribution of tax revenues, lump-sum transfers are obtained residually from the relationship: $Z = \lambda F_T(K, L)+ \tilde{\tau}\, F_L(K, L)L- \tilde{G}$.

Equations (B.1d) and (B.1e) can be solved, once linearized around the steady state, for L and K in terms of the dynamic variable C to yield

$$L = n(C), \quad n' < 0 \tag{B.2a}$$

$$K = k(C), \quad k' < 0 \tag{B.2b}$$

where $n' = \dfrac{(1-\alpha)F_{KK}}{\Sigma} = l'k' = \dfrac{l'}{c_{\bar{K}}} < 0,\ k' = -\dfrac{(1-\alpha)F_{KL}}{\Sigma} = \dfrac{1}{c_{\bar{K}}} < 0,$
$\Sigma = \alpha(1-\tau)[(1-\bar{L})\Phi - F_L F_{KK}] > 0$ and $\Phi = F_{KK}F_{LL} - F_{KL}^2 > 0$.[16]

Substituting out the values of L and K from equations (B.2) into equations (B.1a)-(B.1c),[17] the model can be reduced to the following system of differential equations linearized around the steady state

$$\begin{bmatrix} \dot{C} \\ \dot{q} \\ \dot{B} \end{bmatrix} = \begin{bmatrix} j_{11} & -\alpha\theta(\theta+\rho) & \alpha\theta(\theta+\rho) \\ -(1-\lambda)Q' & r^* & 0 \\ j_{31} & -\alpha\theta(\theta+\rho)k' & r^* + \alpha\theta(\theta+\rho)k' \end{bmatrix} \begin{bmatrix} C-\bar{C} \\ q-\bar{q} \\ B-\bar{B} \end{bmatrix} \tag{B.3}$$

where

$j_{11} = r^* - \rho - \alpha\theta(\theta+\rho)k' > 0;$
$Q' = F_{TK}k' + F_{TL}n' = \dfrac{\bar{L}\ \Phi}{c_{\bar{K}}F_{KL}} < 0;$
$j_{31} = 1 - r^*k' - F_L n' + j_{11}k'.$

The transition matrix must have two positive eigenvalues associated with the jump variables C and q, and one negative eigenvalue associated with the predetermined variable B.[18]

[16] The expressions for l' and $c_{\bar{K}}$, given in Subsection 3.1, are:
$l' = -\dfrac{F_{KK}}{F_{KL}} > 0$ and $c_{\bar{K}} = -\dfrac{\alpha(1-\tilde{\tau})\left[(1-\bar{L})\Phi - F_L F_{KK}\right]}{(1-\alpha)F_{KL}} < 0.$

[17] Note that equation (B.2b) is employed, once linearized, to eliminate both K and $\dot{K}$ from equations (B.1a)-(B.1c).

[18] Since C adjusts on impact, K (hence L) jumps instantaneously as well, provided we assume, as in Mundell (1957) and Obstfeld (1989), that capital is instantaneously and costlessly mobile across borders. By considering foreign investment $B = K^f + qT^f$ a predetermined variable, we are implictly assuming that as q moves repentinely K^f adjusts instantaneously as well, but in an opposite direction so as to leave B unchanged on impact (note that T^f is also predetermined).

The determinant and the trace of the above Jacobian are

$$| J |= -r^*\alpha\theta(\theta+\rho)\left\{1-\frac{r^*(r^*-\rho)}{\alpha\theta(\theta+\rho)}-\frac{1}{c_{\bar{K}}}[l'F_L-\frac{(1-\lambda)\ \bar{L}\ \Phi}{F_{KL}}]\right\};$$

$$\mathrm{tr}(J)=3r^*-\rho>0.$$

The determinant must be negative as a necessary and sufficient condition for saddle-point stability since the trace is necessarily positive. This condition implies that, once the relationship $l'F_L - \frac{(1-\lambda)\ \bar{L}\ \Phi}{F_{KL}} = h_{\bar{K}} = -\frac{\left[(1-\lambda)\ \bar{L}\ \Phi + F_L F_{KK}\right]}{F_{KL}}$ is taken taken into account, the following inequality must hold

$$\Delta = [\alpha\theta(\theta+\rho) - r^*(r^*-\rho)]\, c_{\bar{K}} - \alpha\theta(\theta+\rho)h_{\bar{K}} < 0.$$

Therefore the condition $\Delta < 0$ ensures that the steady state equilibrium is saddle-point stable as stated in Subsection 3.1.

Appendix C

Compensatory reduction in τ: Analysis of stability

The complete short-run model is given by

$$\dot{C} = (r^* - \rho)C - \alpha\theta(\theta + \rho)(K + q - B) \tag{C.1a}$$

$$\dot{q} = r^* q - (1 - \lambda)F_T(K, L) \tag{C.1b}$$

$$\dot{B} = \dot{K} + C + G - F(K, L) + r^* B \tag{C.1c}$$

$$1 - L = \frac{(1 - \alpha)C}{\alpha(1 - \tau)F_L(K, L)} \tag{C.1d}$$

$$F_K(K, L) = r^* \tag{C.1e}$$

$$\tau = \tau(K) \tag{C.1f}$$

where $\tau' = \Pi = \dfrac{\left[\bar{\tau}\ (\bar{L}\ \Phi + F_L F_{KK}) - \lambda\ \bar{L}\ \Phi\right]}{F_L\ \bar{L}\ F_{KL}}$.

Equation (C.1f) has been obtained by solving the government budget constraint for τ.[19]

Equations (C.1d) and (C.1e) can be solved, after linearizing around the steady state and taking (C.1f) into account, for L and K in terms of C as follows

[19] The exogenous effect of λ on τ has been omitted for simplicity.

$$L = v(C), \quad v' < 0 \tag{C.2a}$$

$$K = \kappa(C), \quad \kappa' < 0 \tag{C.2b}$$

where $v' = l'\kappa' = \dfrac{l'}{(c_{\bar{K}} + \Pi c_{\bar{\tau}})} < 0$, $\kappa' = \dfrac{1}{(c_{\bar{K}} + \Pi c_{\bar{\tau}})} < 0$,
$c_{\bar{K}} = -\dfrac{\alpha(1-\widetilde{\tau})\left[(1-\bar{L})\Phi - F_L F_{KK}\right]}{(1-\alpha)F_{KL}} < 0$, $c_{\bar{\tau}} = -\dfrac{\alpha(1-\bar{L})F_L}{(1-\alpha)} < 0$
and $\Phi = F_{KK}F_{LL} - F_{KL}^2 > 0$.

Substituting out the values of L and K from equations (C.2) into equations (C.1a)-(C.1c), the model can be reduced to the following system of differential equations linearized around the steady state

$$\begin{bmatrix} \dot{C} \\ \dot{q} \\ \dot{B} \end{bmatrix} = \begin{bmatrix} j_{11} & -\alpha\theta(\theta+\rho) & \alpha\theta(\theta+\rho) \\ -(1-\lambda)Q' & r^* & 0 \\ j_{31} & -\alpha\theta(\theta+\rho)\kappa' & r^* + \alpha\theta(\theta+\rho)\kappa' \end{bmatrix} \begin{bmatrix} C-\bar{C} \\ q-\bar{q} \\ B-\bar{B} \end{bmatrix} \tag{C.3}$$

where

$j_{11} = r^* - \rho - \alpha\theta(\theta+\rho)\kappa' > 0;$
$Q' = F_{TK}\kappa' + F_{TL}v' = \dfrac{\bar{L}\,\Phi}{(c_{\bar{K}} + \Pi c_{\bar{\tau}})F_{KL}} < 0;$
$j_{31} = 1 - r^*\kappa' - F_L v' + j_{11}\kappa'.$

The transition matrix must admit two positive eigenvalues associated with C and q and one negative eigenvalue associated with B.

Since the trace of the coefficient matrix in (C.3) is positive, the determinant, given by
$$\mid J \mid = -r^*\alpha\theta(\theta+\rho)\left\{1 - \frac{r^*(r^*-\rho)}{\alpha\theta(\theta+\rho)} - \frac{1}{(c_{\bar{K}} + \Pi c_{\bar{\tau}})}[l'F_L - \frac{(1-\lambda)\,\bar{L}\,\Phi}{F_{KL}}]\right\},$$

must be negative. This condition is satisfied if the following expression

$$\Lambda = [\alpha\theta(\theta+\rho) - r^*(r^*-\rho)]\,(c_{\bar{K}} + \Pi c_{\bar{\tau}}) - \alpha\theta(\theta+\rho)h_{\bar{K}} < 0$$

is, as stated in Subsection 3.3, negative.[20]

[20] Note that the relationship $l' F_L - \dfrac{(1-\lambda)\,\bar{L}\,\Phi}{F_{KL}} = h_{\bar{K}}$ has been used.

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(liii) This paper was circulated at the International Conference on “Climate Policy – Do We Need a New Approach?”, jointly organised by Fondazione Eni Enrico Mattei, Stanford University and Venice International University, Isola di San Servolo, Venice, September 6-8, 2001

(liv) This paper was presented at the Seventh Meeting of the Coalition Theory Network organised by the Fondazione Eni Enrico Mattei and the CORE, Université Catholique de Louvain, Venice, Italy, January 11-12, 2002

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