FISCAL COMPETITION IN SPACE AND TIME: AN ENDOGENOUS-GROWTH APPROACH

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Abstract

Is tax competition good for economic growth? The paper addresses this question by means of a simple model of endogenous growth. There are many small jurisdictions in a large federation and individual governments benevolently maximise the welfare of immobile residents. Investment is costly: Quadratic installation and de-installation costs limit the mobility of capital. The paper looks at optimal taxation and long-run growth. In particular, the effects of variations in the cost parameter on economic growth and taxation are considered. It is shown that balanced endogenous growth paths do not always exist and effects of changes in installation costs are ambiguous.

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Fiscal Competition in Space and Time: An Endogenous-Growth Approach

Daniel Becker and Michael Rauscher* [*]

1 The Issue

Tax competition has been an important issue in public economics in the past two decades. Static models have shown that there is a tendency for underprovision of services provided by the public sector emerging from fiscal externalities when the tax base is mobile and the use of non-distorting taxes is restricted. See Wilson (1999) for an overview. This paper attempts to extend this literature to an economic-growth context and poses the question whether an increase in the intensity of competition for a mobile tax base enhances economic growth.

When there is competition for a mobile tax base like capital, the taxing power of governments is limited by the threat of capital owners to withdraw their capital if they consider the tax rates to be too high. Most models of tax competition assume that capital flight is cost-free and capital mobility therefore is perfect. Wildasin (2003) has shown how a dynamic formulation of an otherwise standard model of tax competition can be used to incorporate the more realistic case of imperfect capital mobility. In his model, firms face adjustment costs of the type suggested by Hayashi (1982) and Blanchard/ Fischer (1989, ch. 2.4) in their macroeconomic growth models. An instantaneous relocation of the capital stock as a response to a tax increase does then not occur as long as the adjustment cost function is convex. Instead, capital flight is a time consuming process where the speed of adjustment to a new steady state can be taken as a measure for capital mobility. Wildasin's article is concerned with an economy that approaches a static long-run equilibrium and it shows that the capital tax rate is positive and that it increases with increasing adjustment cost. The present paper, in contrast, looks at a model of endogenous growth where the steady state is a balanced growth path. It will be seen that not all results carry over from exogenous-growth to endogenous-growth models.

Endogenous growth in this paper is sustained by the provision of public services to firms. We follow the approach taken by Barro (1990) and model a public sector that uses tax revenue to provide a flow of services to firms. Hence, we analyse an AK-type growth model. Mainly because public inputs are not modelled as a stock

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variable, there are no transitional dynamics for the evolution of output and physical capital.[1] The set of instruments at hand of the policymaker is restricted and distorting taxes become desirable. In particular, capital owners cannot be taxed lump-sum. Thus redistribution has to be financed by distorting taxes. The central question will then be how the choice of tax rates is influenced by the degree of tax competition and how this affects growth.

The analysis of endogenous growth in open economies has been mainly concerned with the issue of convergence, i.e. the question if countries tend to converge to a common growth rate and how this uniform growth rate is reached by an individual country, see for example Rebelo (1992). Another central question is the relationship between savings and investment. As has been shown by Turnovsky (1996) for a small open economy with endogenous growth, the presence of adjustment-costs allows for different growth rates of physical capital and financial assets. This is not only interesting by itself but has also consequences for taxation. In equilibrium, the after-tax returns of physical capital and financial assets must be equalized. When the interest rate earned by financial assets is exogenous to decision-makers, this also determines the after-tax return of physical capital and the set of available tax policies in equilibrium is heavily constrained by the model-setup. Adjustment costs however drive a wedge between the rates of return of financial assets and physical capital such that the choice of arbitrary tax policy is possible and an interesting problem even in a small open economy. While our modelling of endogenous growth is close to Turnovsky (1996), we extend his model by considering the implications of tax competition for the choice of public policy as in Wildasin (2003).

The literature on tax competition and growth is still rather small. A major complication is the fact that optimising governments use private-sector first-order conditions as constraints. This implies there are second derivatives in the optimality conditions. This problem can be solved in static models of tax competition. In dynamic growth models matters are often less simple. However, in some models, particularly those with benevolent governments and purely redistributive taxation, second derivatives cancel out if it is assumed that workers do not save. This is the modelling strategy followed in this paper. Other papers on growth and tax competition include Lejour/Verbon (1997), Razin/Yuen (1999) and Rauscher (2005). Lejour/Verbon (2005) look at a two-country model of economic growth. Besides the conventional fiscal externality leading to too-low taxes they identify a growth externality. Low taxes in one country increase the growth rate in the rest of the world. If this effect dominates the standard fiscal externality due to competition for a mobile tax base, uncoordinated taxes will be too high. This contrasts the

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[1] Models of public policy and growth that address the importance of modelling public capital as a stock variable include Futagami et al. (1993) and Turnovsky (1997).

finding of the standard static tax-competition models that taxes tend to be too low. Razin/Yuen (1999) look at a more general model that also includes human-capital accumulation and endogenous population growth. They come to the conclusion that optimum taxes should be residence-based, capital taxes should be abolished along a balanced growth path, and taxes will be shifted from the mobile to the immobile factor of production if the source principle is applied in a world of tax-competing jurisdictions. Their results extend those derived by Judd (1985) and are in accordance with the standard economic intuition. The underlying assumption is that the government's set of tax instruments is large enough such that distortion-free taxation becomes feasible. Rauscher (2005) uses an ad-hoc model of limited inter-jurisdictional capital mobility and comes to the conclusion that the effects of increased mobility are ambiguous. A central parameter in this context is the elasticity of intertemporal substitution, which does not only affect the magnitude of the economic growth rate, but also the signs of the comparative static effects.

In the centre of our approach to model tax competition and growth are public inputs as the source for sustainable growth and adjustment costs causing imperfect mobility of capital. We consider a continuous-time infinite-horizon framework. As in most other models of tax competition, we look at a federation consisting of a large number of very small jurisdictions that have no power to affect economic variables determined on the federal level. In the present analysis, the only variable determined on the federal level will be the interest rate. Given the interest rate, governments choose their policies, which are then announced to the private sector. The private sector consists of a continuum of identical agents acting under conditions of perfect competition. In the first step of the analysis, individual economic agents will maximise utility given the interest rate and the economic policies announced by the government. In the next step, governments will decide about policies taking as given the interest rate and the first-order conditions of the private sector. Finally, the interest rate itself will be determined.

The next section of this paper will present the assumptions of the model regarding production technology and the frictions that limit the mobility of capital. Sections 3 and 4 will look at the behaviour of the private sector and of the government, respectively. Section 5 closes the model by determining the interest rate and derives the central result by investigating the impact of capital mobility on the long-run economic-growth path. Section 6 summarises.

2 Definition of Variables and Characterisation of Technology

Let us consider a federation consisting of a continuum of infinitely small identical jurisdictions, also labelled 'regions', on the unit interval. There is perfect competition in all markets and single jurisdictions do not have any market power vis-à-vis the rest of the federation. The private sector takes prices and policies announced by regional governments as given. Regional governments take variables determined on the federal level as given. As is always the case in models of tax competition, there is a distinction between ex ante objectives and ex post outcomes of actions taken to achieve the objectives. Ex ante, jurisdictions may be willing to use policy instruments to affect the allocation of mobile tax bases. Ex post, however, it turns out that all jurisdictions have acted in the same way and that the interjurisdictional allocation of the tax base is unaffected despite the efforts taken in the first place.

There are three types of agents in this model: workers, entrepreneurs, who own physical capital and other assets, and governments.

- Workers are immobile across jurisdictions and inelastically supply one unit of labour per person in the perfectly competitive labour market of their home region at the current wage rate, which they take as exogenously given. Workers do not save and, thus, do not own physical capital or other assets.
- Capitalist producers own capital, hire labour, produce, save, and consume the unsaved share of their incomes. Saving yields an interest rate, which is determined on the federal capital market and which they take as exogenously given. If they want to transform their financial assets and invest in a particular jurisdiction, they face installation costs. If they want do withdraw physical capital, they have to bear de-installation costs. With these costs, federal financial assets and local physical capital are imperfectly malleable and, thus, capital is imperfectly mobile.
- Governments charge taxes and provide a productive input. They are benevolent and maximise the utility of immobile residents. This includes the possibility of income redistribution.

As all jurisdictions are identical, let us consider a representative jurisdiction. There are three factors of production: capital, labour, and a publicly provided input, denoted $K(t)$, $L(t)$, and $G(t)$, respectively, where t denotes time. For the sake of a simpler notation, the time argument will be omitted when this does not generate ambiguities. Output, $Q(t)$, is produced by means of the three factors where marginal productivities are positive and declining. Moreover, we assume that the production function, $\Phi(.,.,.)$, is linearly homogenous in (K,G) and in (K,L). An example is the Cobb-Douglas function

$$Q = \Phi(K,G,L) = K^{1-\alpha} G^{\alpha} L^{\alpha} \tag{1}$$

with $0 < \alpha < 1$. The size of the labour force is normalised to one. Each worker inelastically supplies one unit of labour, i.e. L=1. Thus, (1) can be rewritten

$$Q = F(K,G) \equiv \Phi(K,G,1) \tag{1a}$$

where $F(.,.)$ is a neoclassical constant-returns-to-scale production function measuring output per employee. A worker's income is the wage rate, $w(t)$, which is determined on the regional labour market. Moreover, let us introduce a production function in intensity terms,

$$f(g) \equiv F(1,g) \quad \text{where} \quad g \equiv G/K \tag{1b}$$

with $f'(g)>0$ and $f''(g)>0$, primes denoting derivatives of univariate functions. Regarding the marginal productivities we have

$$\Phi_K = F_K = f - gf', \tag{2a}$$

$$\Phi_G = F_G = f', \tag{2b}$$

$$\Phi_L = F - KF_K = Kgf', \tag{2c}$$

where subscripts denote partial derivatives and arguments of functions have been omitted for convenience.

Regarding the other two factors of production, we assume:

- <u>Capital.</u> $K(t)$ is the quantity of a composite capital good consisting of physical capital, human capital, and knowledge capital. Initially, each jurisdiction is endowed with $K(0)=K_0$. Capital depreciates at a constant exogenous rate m. Let $I(t)$ be the rate of gross investment as a share of the capital stock. Then capital accumulation evolves according to

  $$\dot{K} = (I - m)K, \tag{3}$$

  dots above a variable denoting its derivative with respect to time. Capital is mobile, albeit at a finite speed. As mentioned, there is a capital market on the federal level, yielding an interest rate $r(t)$, which is exogenous to individual capital owners and to governments of individual jurisdictions, but endogenously determined by demand and supply on the federal level. Assets and physical capital are imperfectly malleable. Transforming financial capital into physical capital and vice versa is costly. We follow Wildasin (2003) in the specification of the installation cost function. Installation costs are defined as

  $$c(I)\,K \quad \text{with} \quad c(0) = 0 \quad \text{and} \quad c''(.) > 0.$$

  The installation cost per unit depends on the rate of investment as a share of capital, i.e. on the speed of gross accumulation. As c' is positive for negative values of I, this function also covers the possibility of de-installation costs. For the derivation of explicit results in the forthcoming sections of the paper we assume a quadratic shape of c such that

$$c(I)K = \frac{b}{2} I^2 K \,, \tag{4}$$

i.e. $c'(I)=bI$ and $c''(I)=b$, where the constant positive parameter b measures the barriers to mobility. b=0 represents perfect mobility and malleability. If b goes to infinity, capital becomes absolutely immobile. For the interpretation of some of the results to be derived in the following sections, it is useful to introduce the absolute rate of investment, J. Using $I=J/K$ in equation (4) yields

$$c(I)K = c\left(\frac{J}{K}\right)K = \frac{b}{2}\frac{J^2}{K} \,. \tag{4'}$$

- <u>The public-sector input.</u> The government provides a productive input at a rate $G(t)$. This may be interpreted as physical infrastructure such as roads and ports, but also institutional infrastructure including the legal framework in which economic transactions take place. For the sake of simplicity, we treat this good as a flow variable, which is provided anew in each period. Inter-jurisdictional spill-overs are excluded. The provision of the public input is financed by taxes. There are two types of fiscal instruments, a source tax on capital, the tax rate being θ,[2] and a redistributive lump-sum transfer going to the immobile factor of production. We assume that the government chooses a constant tax rate and allocates a constant share of the budget, 1-s, to redistribution. Thus,

  $$G = s\theta K \,, \tag{5}$$

  where $s > 0$ ($s > 1$ implies lump-sum taxation of immobile residents) Equation (5) directly implies

  $$g = s\theta \,. \tag{5'}$$

  The underlying assumption that the budget is balanced in each period seems to be restictive, but real-world governments are indeed subject to within-period budget constraints. A prominent example is the European Growth and Stability Pact, which restricts the policy makers' discretion to borrow. Equation (5) is a possibility of introducing such a restriction in a simple way.

From equation (5'), the following result follows immediately

Lemma 1

All first derivatives of the production function F(.,.) are constant.

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[2] Other papers like Judd (1985, 1999) and Lejour/Verbon (1997) introduce taxes on capital income rather than on capital itself. But as long as taxation is linear, the two instruments are equivalent.

This follows directly from (2a) and (2b). The next section solves the optimisation problem faced by the private sector. Afterwards, the behaviour of the government will be considered.

3 Saving, Investment and Production in the Private Sector

As workers in this model do nothing besides inelastically supplying labour, the dynamics of the economy are driven by entrepreneurs and capital owners. In order to save on notation, we do not distinguish between these two types but assume that there is a homogenous group of capitalist producers. They hire labour, they save, and they invest. Moreover, unlike workers, capital owners are mobile and can choose to live where they want. If they are not satisfied with their domicile, they can vote with their feet like in Tiebout (1956) and move to another jurisdiction that offers better conditions. In contrast to the Tiebout model, mobile capitalists in our model do not demand local public goods. Thus, they are not willing to pay taxes to contribute to such goods. They will settle in the jurisdictions that tax them at the lowest rates. Real-world examples are Monaco and the Swiss cantons Zug, Schwyz, and Nidwalden, which levy very low taxes and attract millionaires from other parts of the country and from the rest of the world.[3] In a competitive world with many identical jurisdictions, there is a race to the bottom such that capitalists ultimately do not pay any taxes anywhere. Hence, capital income can only be taxed at source. The perfect mobility of capitalists has another important implication for the model. Since capitalists vote with their feet, they are not interested in participating in the political process. They do not show up at the ballot box and, thus, their interests are not taken into account by the policy maker.

The representative capitalist producer has two sources of income. On the one hand, she retains the share of output not being paid as wages to workers. On the other hand she has an interest income from her stock of saved assets, $A(t)$. There is a perfect asset market in the federation such that all assets yield the same rate of interest, $r(t)$, to their bearers. There are two possibilities to spend the income. It can be consumed or it can be saved. Moreover, savings (assets) can be transformed into physical capital, however only at a cost, the cost function being defined by (4). The rate of accumulation of assets is output minus the wage payments going to workers minus tax payments minus consumption minus investment into physical capital minus costs of investing into physical capital plus interest income from assets accumulated in the past. In algebraic terms:

$$\dot{A} = \Phi(K, G, L) - wL - \theta K - C - IK - c(I)K + rA \,. \tag{6}$$

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[3] According to a report in the "Neue Zürcher Zeitung" from September 23, 2005, 13 percent of the ca. 3300 citizens of the the village of Walchwil in Zug are millionaires, and other villages in Zug, Schwyz, and Nidwalden report similar, though slightly lower, percentages.

Since all jurisdictions are identical, there will be no lending and borrowing ex post, i.e. A=0. In particular, $A(0)$=0. Ex ante, however, capitalists consider the possibility of borrowing and lending according to (6). Extreme Ponzi games are excluded, i.e. the present value of assets in the long run must be non-negative

$$\lim_{t\to\infty} e^{-rt} A \geq 0 .$$

A representative capitalist producer maximises the present value of her utility. Utility is derived from consumption, $C(t)$, only and is of the constant-elasticity-of-substitution type with σ being the rate of intertemporal substitution. The discount rate, δ, is positive and constant and the time horizon is infinite. Thus, the individual's objective is to maximise

$$\int_0^\infty e^{-\delta t} u(C) dt \qquad \text{with} \qquad u(C) = \frac{C^{1-\frac{1}{\sigma}} - 1}{1 - \frac{1}{\sigma}}$$

subject to (3), (6), the initial endowments, K_0 and A_0, the tax rate θ, and the public expenditure, $G(t)$, the latter two having been announced by the government. Note that an individual capitalist-producer does not take the government's budget constraint, (5), into account. The decision maker's control variables are $C(t)$ and $L(t)$. The corresponding Hamiltonian is

$$H = u(C) + \lambda\big(\Phi(K,G,L) - wL - \theta K - C - IK - c(I)K + rA\big) + \mu(I-m)K$$

where $\lambda(t)$ and $\mu(t)$ are the shadow prices, or co-state variables, of financial and physical capital, respectively. The canonical equations are

$$\dot{\lambda} = (\delta - r)\lambda , \tag{7a}$$

$$\dot{\mu} = (\delta + m - I)\mu - (\Phi_K - \theta - I - c)\lambda , \tag{7b}$$

where subscripts denote partial derivatives and Φ_K will be replaced by F_K in the remainder of the investigation. See equation (2a). Complementary slackness at infinity requires

$$\lim_{t\to\infty} e^{-\delta t} \lambda A = 0 ,$$

$$\lim_{t\to\infty} e^{-\delta t} \mu K = 0 ,$$

and, hats above variables denoting growth rates and using (2) to substitute for $\hat{K}$, these conditions imply that

$$\hat{\lambda} + \hat{A} < \delta \qquad \text{for} \qquad t \to \infty , \tag{8a}$$

$$\hat{\mu} + I - m < \delta \qquad \text{for} \qquad t \to \infty . \tag{8b}$$

First-order conditions are

$$w = \Phi_L , \tag{9a}$$

which is the standard marginal-productivity result for a competitive labour market,

$$u' = \lambda, \tag{9b}$$

and

$$\mu = (1 + c')\lambda . \tag{9c}$$

Condition (8a) is a standard labour-demand equation. From (9b), we can derive the standard Ramsey-type growth equation with $\hat{C}$ as the growth rate of consumption

$$\hat{C} = \sigma(r - \delta). \tag{10}$$

Equation (9c) states there is a wedge between the shadow prices of financial capital on the federation level and local physical capital. Plausibly, this wedge depends on the marginal cost of installation. From (9c), one can derive a condition that links the rates of returns in the two markets for capital. Taking time derivatives of the shadow prices, inserting (7a) and (7b), and using (9c) again to eliminate λ/μ, we have

$$\dot{I} = \frac{1}{c''}\left((1 + c')r - (F_K - m - \theta - c) - (I - m)c'\right). \tag{11}$$

The condition for a steady state, i.e. for $\dot{I} = 0$, is

$$F_K - m - \theta - c + (I - m)c' = (1 + c')\, r . \tag{12}$$

This is a capital-market indifference condition. On the right-hand side, we have the interest rate augmented by a term that contains the marginal mobility cost. If the marginal productivity of capital in the jurisdiction under consideration equals $(1+c')r$, an investor is indifferent whether or not to install an additional marginal unit of capital in this jurisdiction. On the left-hand side, we have the marginal productivity of capital, net of taxes and other costs to be borne by the investor. The first term is the gross productivity from which the rate of depreciation and the tax rate are subtracted. Without mobility cost, this would constitute the net productivity of capital after taxes. With mobility cost, two additional terms emerge. The first one is c. Mobility costs are proportional to capital, i.e. cK. Thus, additional capital raises installation costs. The final term on the left-hand side may be interpreted as an inter-temporal benefit from a larger capital stock. If $I>m$, the capital stock grows and this implies lower future installation costs per unit of newly installed capital, J. See equation (4').

In the derivation of the optimal rate of investment, we follow Turnovsky (1996). Using the quadratic shape of the investment cost function, (4), we can rewrite (11) such that

$$\dot{I} = \frac{1}{2}\left(-I^2 + 2(r + m)I - \frac{2}{b}(F_K - m - \theta - r)\right). \tag{11'}$$

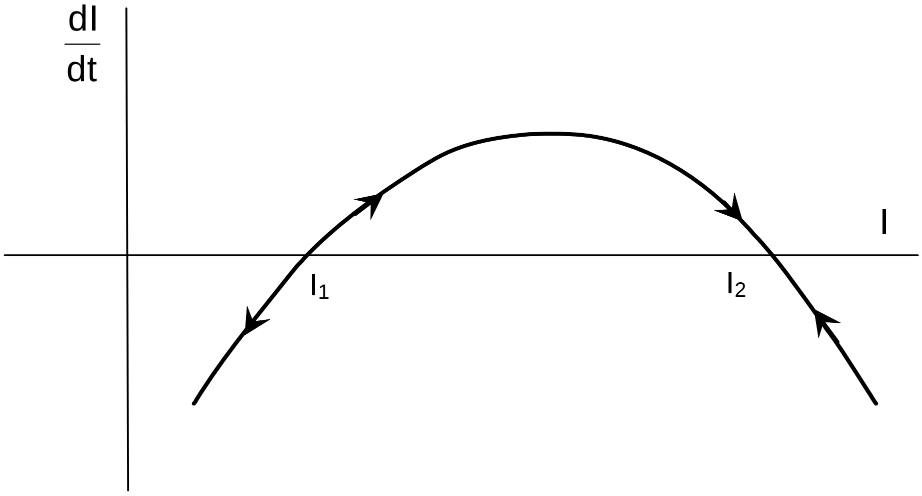

Figure 1: Investment Dynamics

This is a quadratic differential equation that can be represented as a hump-shaped curve in a phase diagram with a stable and an unstable equilibrium. See Figure 1. The condition for a steady state with $\dot{I} = 0$ is

$$I_{1,2} = r + m \pm \sqrt{(r+m)^2 - \frac{2}{b}(F_K - m - \theta - r)}, \qquad (13)$$

where the smaller value, I_1, corresponds to the unstable equilibrium in Figure 1 and the larger one, I_2, to the stable equilibrium. An imaginary solution would imply a fluctuating path of capital accumulation. One can show that I_2 as well as an imaginary solution would violate the transversality condition.[4] Noting that I_1 is an instable solution of (11'), it follows that there are no transitional dynamics. This implies

Proposition 1

The optimal rate of investment is constant along the optimal trajectory, with

$$I_1 = r + m - \sqrt{(r+m)^2 - \frac{2}{b}(F_K - m - \theta - r)}. \qquad (13')$$

Imaginary solutions are excluded.

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[4] Note that I is constant in the steady state. Thus (8c) implies $\hat{\mu} = \hat{\lambda}$. Using this in (7b) yields the condition that $I_1 < r+m$. This is violated by I_2 and by any imaginary solution to (13) because its real part would be $r+m$.

Constancy follows from Lemma 1, which states that F_K is constant. Condition (13') shows that the optimum rate of investment, as expected, is increasing in the marginal productivity of capital and decreasing in the depreciation rate, the interest rate, and the cost parameter b. It should be noted that the marginal productivity of capital is determined by g via (2a) and that, ex post, g is determined by (5'). Thus F_K depends on the tax rate as well. Moreover we have

Finally, to fully characterise the savings behaviour of the private sector, the initial level of consumption needs to be determined. Using (1a), (9a), (2c), (3), (4), and (10) in (6) yields

$$\dot{A} = \left(F_K - \theta - I_1 - \frac{b}{2} I_1^2 \right) K(0) e^{(I_1 - m)t} - C(0) e^{\sigma(r-\delta)t} + rA .$$

In an intertemporal steady-state equilibrium with identical jurisdictions, there is no lending and borrowing, i.e. $A = 0 = \dot{A}$ for all t. This implies equal growth rates of the capital stock and of consumption,

$$I_1 - m = \sigma(r - \delta), \tag{14}$$

and the starting value of C is:

$$C(0) = \left(F_K - \theta - I_1 - \frac{b}{2} I_1^2 \right) K(0) . \tag{15}$$

Equation (14) determines, together with (13'), the equilibrium interest rate as an implicit function of the parameters of the model and of the tax rate. Equation (15) states that consumption is positively related to initial capital endowment and capital productivity and negatively related to the tax rate, the rate of investment, and the installation cost.

4. Government Behaviour and Taxation

The government maximises the welfare of immobile residents. Immobile residents are workers. Their wage rate is $gf'K$ and their transfer income $(1-s)\theta K$. See equations (9a), (2c), and (5). The government takes the interest rate as exogenously given. In particular, it does not consider condition (14), which determines the equilibrium interest rate when, ex post, all governments have chosen the same tax policies. Let us assume that workers have the same preference parameters as the capitalists. Thus, the government's objective is to maximise

$$W^L = \int_0^\infty e^{-\delta t} \frac{\left[\left(gf' + (1-s)\theta \right) K_0 e^{(I_1 - m)t} \right]^{1-\frac{1}{\sigma}} - 1}{1 - \frac{1}{\sigma}} dt . \tag{16}$$

We impose a limit on taxation. The maximum to be charged from capitalist producers is their period income, i.e. output minus wage payments. Using (2c), we have

$$\theta < F_K . \tag{17}$$

The condition for the objective function, (16), to be finite is

$$r + m - I_1 = (1-\sigma)r + \sigma\delta > 0 , \tag{18}$$

and it is assumed for the remanider ofthe investigation that the parameters of the model are such that the condition is satisfied.[5] Note this is the same condition as that derived from complementary slackness at infinity for the private sector. See Footnote 4.

Maximising (16) with respect to the government's policy parameters, θ and s, and subject to (17) yields.

Proposition 2

The optimal tax-and-expenditure policy of the government in the equilibrium is characterised by

$$f' = 1, \tag{19a}$$

$$\theta = b(r + m - I_1)^2 \tag{19b}$$

and the equilibrium interest rate is determined by

$$b = \frac{2(F_K - r - m)}{(r + m - I_1)^2 + (r + m)^2} \qquad \text{if } \theta \leq F_K , \tag{19c}$$

$$b = \frac{2(r + m)}{(r + m - I_1)^2 - (r + m)^2} \qquad \text{if } \theta = F_K , . \tag{19d}$$

where $r + m - I_1 = (1-\sigma)r + \sigma\delta$ can be used to eliminate I_1.

For the derivation of these results, see the appendix. Conditions (19a-d) can be interpreted as follows.

- Equation (19a) states that the marginal productivity of government expenditure is unity. This is a standard result in tax-competition models with lump-sum tax instruments. See, e.g., Zodrow/Mieszkowski (1986, p. 363). The underlying intuition to explain this result in our model is the following one. In a first step, capital is taxed and the tax revenue is added to labour income. Out of this gross income, workers pay a lump-sum tax that is used to finance the

[5] Condition (18) follows from noting that the growth rate of the integrand is $\left(-\delta + \left(1 - \frac{1}{\sigma}\right)(I_1 - m)\right)$. This growth rate must be negative. Using (14) to substitute for σ and I_1, respectively, one obtains (18).

publicly provided good. Thus, the cost of producing one unit of G is exactly one unit of GDP. Since $f'=\Phi_G$ is the marginal productivity of G, $f'=1$ is nothing else but the rule that the marginal productivity of a factor should equal the marginal cost of employing it.

- Equation (19b) determines the optimum tax rate. It is non-negative: capital subsidies are not feasible.[6] Ceteris paribus, the larger b, the larger is θ in (19b). For a given interest rate, the government of a jurisdiction chooses the tax rate such that it goes to infinity as investment costs become prohibitive. The reasoning behind this is intuitive: as de-installation of capital becomes more costly, the possibility to evade taxes shrinks and the government can exploit an increasingly inelastic tax base.

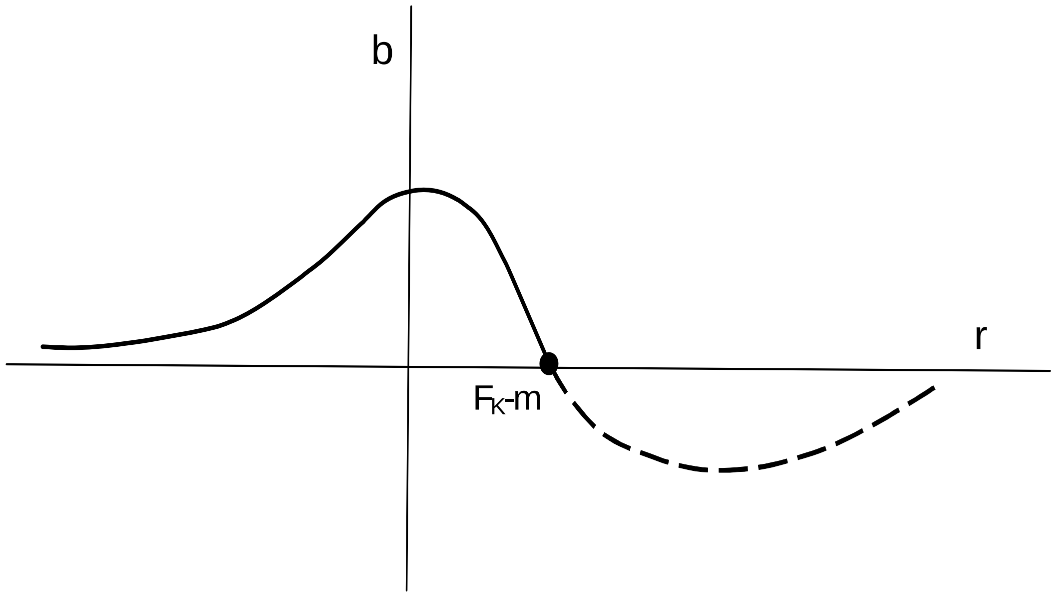

Figure 2: Equilibrium interest rate and capital mobility for unconstrained θ

- Equation (19c) determines the interest rate in the growth equilibrium with an unconstrained optimal tax. The appendix explores the properties of (19c). They are depicted in Figure 2. It is seen that $r < F_K - m$ if installation costs are positive. Moreover it is seen that an equilibrium interest rate does not exist if b is above a certain threshold value which is the maximum of the $b(r)$ function. The reason is that for large values of b a small country's government would choose an extensively high tax rate. The underlying reason is the small-

6 θ does not depend on the lump-sum tax rate, τ. This is due to the fact that $f'=1$ has been used in the derivation of (18b). If there is a restriction on lump-sum taxation, $f'=1$ cannot be used and (18b) is changed to (A8) in the appendix and then θ does depend on τ.

country assumption. An indvidual government neglects the impact of its tax policy on the interest rate. If all countries do this, the asset market equilibrium collapses. A sensible threshold on the tax rate is (17) and its impact will be discussed in due course. so large that since it does not consider its impact on the interest rate. The upward-sloping part of the $r(b)$ curve left of the maximum indicates the possibility of multiple growth equilibria. For each b, there are two values of r satisfying condition (19c). However, the lower of the two values of r is irrelevant here.[7]) The maximum of the $b(r)$ function is attained for the following value of r:

$$r = F_K - m - \sqrt{\frac{F_K^2 + \left((1-\sigma)\left(F_K - m\right) + \sigma\delta\right)^2}{1 + (1-\sigma)^1}}\,. \qquad (20)$$

This follows from setting dr/db=0 in equation (A7).[8] Moreover, one can show that the tax rate in this point may be larger or less than the dritical value, F_K. See the Appendix.

- Equation (19d) determines the interest rate in the growth equilibrium if the tax constraint is binding. The appendix derives the properties of (19d). The solution of (19d) is depicted in Figure 3. It is seen that $I_1<r+m$ and that I_1 is not defined within the interval $-m - b/2 < r < -m$. The two bending lines depict the $I_1(r)$ function outside this interval. I_1 is always negative because the tax rate θ=F_K reduces the income accruing to capitalist-producers to zero. In order to satisfy some consumption needs, they have to dis-invest and consume the capital stock. Since dis-investement is costly, they do this slowly and the rate of dis-investment is finite. The upward-sloping straight line is the equilibrium condition, $I_1=m+\sigma(r-\delta)$. See equation (14). In the case shown in Figure 3, this line intersects the $I_1(r)$ line, possibly twice. However, only the right-hand part of the $I_1(r)$ curve is relevant here. Note that equilibria do not always exist. If m is large and σ is small, the capital-market equilibrium line has an intercept close to m and is so flat that there are no points of intersetion with the $I_1(r)$ line. The underlying intuition is that capital owners want to withdraw their capital at rate that is incompatible with low discounting and low intertemporal substitution in consumption. Finally Figure 3 shows a shift in the $I_1(r)$ line generated by an increase in b. With higher b, dis-investment becomes more costly, thus, the rate of investment becomes less negative, and

[7] Assume that b has attained its maximum on the $b(r)$ curve. There is a unique equilibrium with a well-defined r. Now let us reduce b by a small amount. Each government, taking the interest rate and the other parameters of the model as given, will reduce the tax rate θ slightly. This has a positive effect on the interest rate. Thus, the part of the $b(r)$ curve to the right of the maximum is relevant here

[8] The proof is available from the authors on request.

the interest rate rises. In the extreme, $b \rightarrow \infty$ and I_1 approaches zero. Then $r \rightarrow \delta - m/\sigma$. Capital-owners cannot save their assets from taxation by dis-investing and are expropriated by the state.

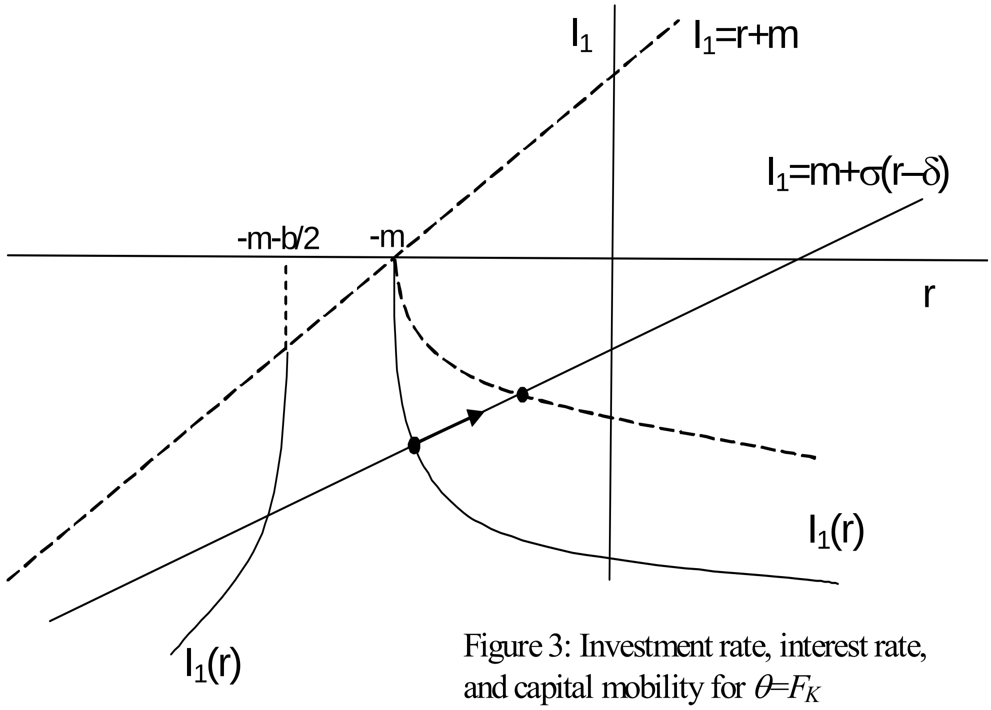

Figure 3: Investment rate, interest rate, and capital mobility for $\theta = F_K$

Figure 4 combines Figures 2 and 3 and shows the impact of changes in b on the equilibrium interest rate. For the $\theta = F_K$ case, we have $r \rightarrow -m$ for $b \rightarrow 0$ from (18d), $r \rightarrow \delta - m/\sigma$ for $b \rightarrow \infty$ and r being increasing in b in between. Moreover, one can show that the point of intersection between the two lines is determined by

$$m + r = \frac{F_K}{2}\left(1 - \frac{(r+m)^2}{(r+m-I_1)^2}\right),$$

which follows from equating (19c) and (19d). This is a cubic equation showing that multiple equilibria are possible. In Figure 4 the solid line repesents the un-constrained equilibrium and the dotted line represents the equilibrium constrained by $\theta = F_K$. Note that the unconstrained curve is shifted horizontally by changes in F_K whereas the other curve is unaffected by such a change. This implies that the point of intersection can be located in the increasing or in the decreasing segment of the solid line. Figure 4a shows the former case, Figure 4b the latter case. The arrows depict the effect of an increase in b, starting from zero at $r = F_K - $m. The interest rate is reduced initially. If the constraint is met, there is a discret change in the interest rate. Afterwards the interest rate rises since the rate of dis-investment is declining with increasing de-installation cost.

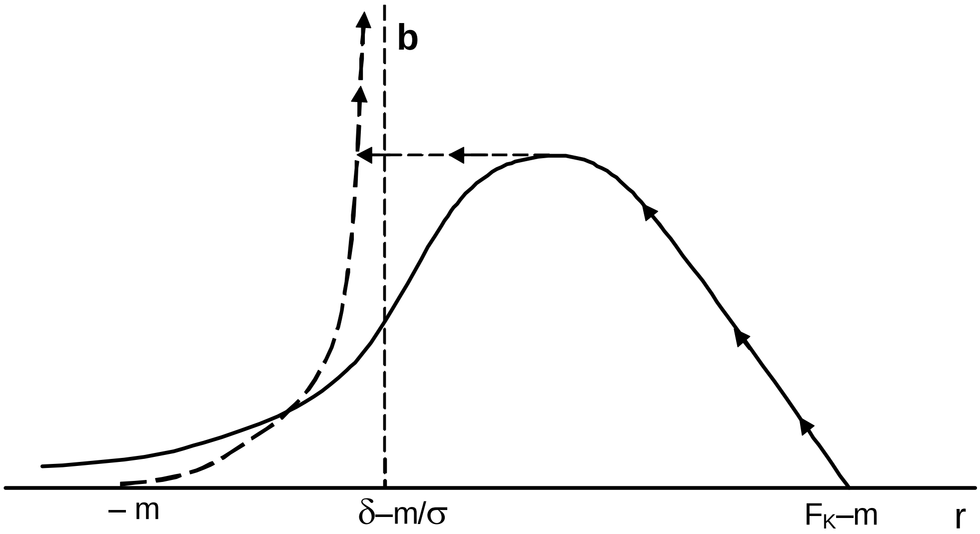

Figure 4a: The impact of *b* on *r*

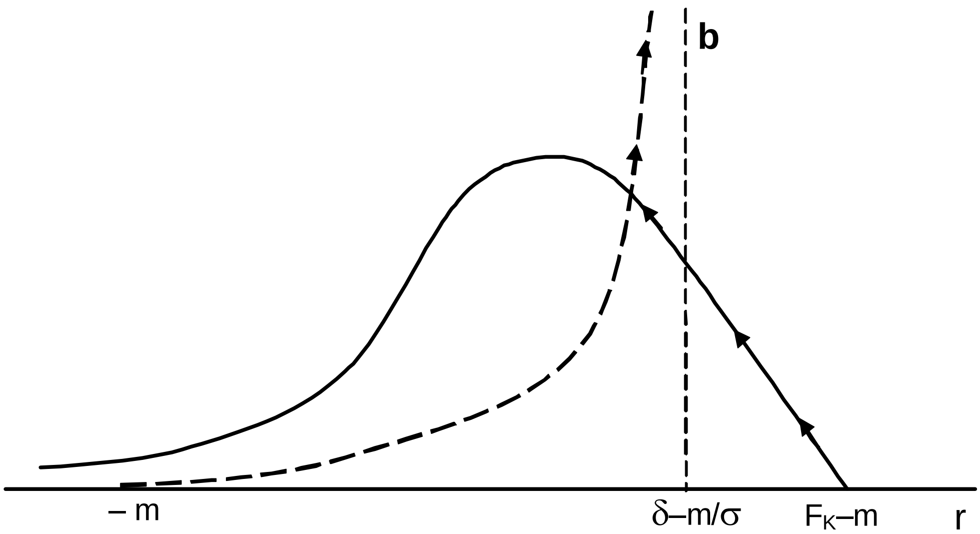

Figure 4b: The impact of *b* on *r*

The final question to be asked is related to the impact of installation cost on the tax rate. Does higher capital mobility lead to lower taxes? Differentiation of (19b) with respect to b yields

$$\frac{d\theta}{db} = (r+m-I_1)^2 + 2(1-\sigma)(r+m-I_1)\left(\frac{db}{dr}\right)^{-1} \quad (21)$$

where dr/db is taken from (A7) in the appendix. Since db/dr goes to zero close to the maximum of the $b(r)$ function, the second term on the right-hand side can dominate the first term, which is unambiguously positive. The sign of the second term is, however, indeterminate. Note that the second term vanishes for σ=1. In this case, θ=$b\delta^2$ and the tax rate is linear in b.

Since neither θ can be expressed explicitly as a function of b nor (21) can be solved to yield the shape of $\theta(b)$, we did some simulations using the parameters F_k=0.15, m=0.05, and δ=0.03 and different values of σ. The results are shown in Figure 5. It what has been conjectured earlier: non-monotonous behaviour of taxes in response to changes in capital mobility is possible.

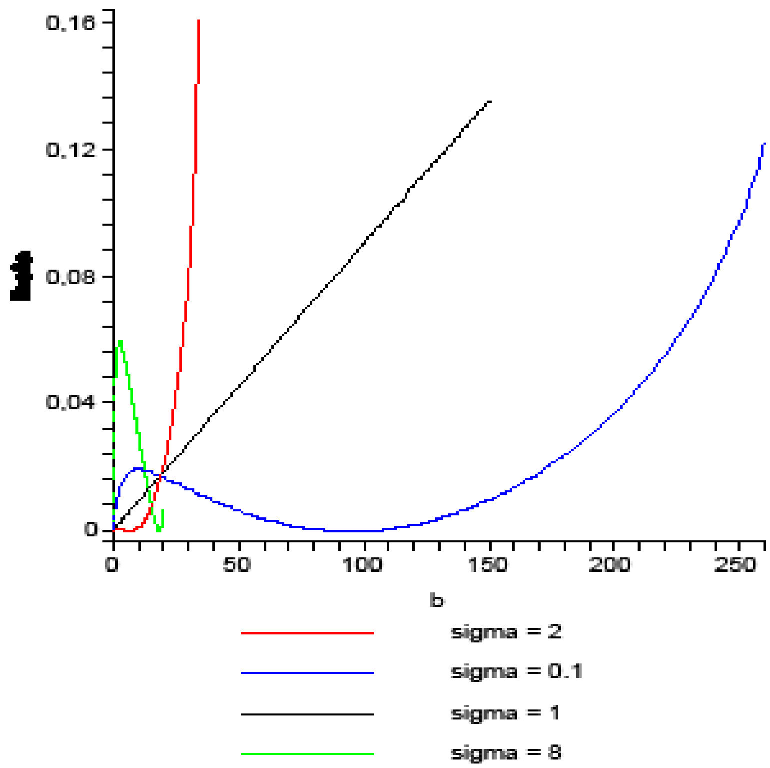

Figure 5: $\theta(b)$ for different values of σ

5. Final Remarks

The paper has addressed tax competition in a general-equilibrium endogenous growth model. It has been shown that

1. An equilibrium does not always exist. If installation costs and capital depreciation are large and the rate of discount and the elasticity of intertemporal substitution are small, an equilibrium does not exist since the tax rate becomes very high and capitalists want to reduce their capital stock at a rate that is incompatible with the smooth consumtion path implied by the low rate of discount and the small elasticity of intertemporal substitution
2. The impact of installation cost on the capital tax rate is ambiguous.

It is seen that the results of our endogneous-growth model differ substantially from those derived by Wildasin (2003) for a growth model that approaches a no-growth staedy state in the long run.

Future research could aim at comparing tax competition to a coordinated tax policy. Given the algebraic complexities of the model, we conjecture that this will be possible only for specific assumptions about the parameters of the model, e.g. using a logarithmic utility function, which restricts the elasticity of intertemporal substitution to unity.

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Appendix

Derivation of (19a). Assuming that the integral in (16) is finite, the growth rate of the integrand must be negative. Then the integral can be rewritten:

$$W^L = \frac{\left[(gf'+(1-s)\theta)K_0\right]^{1-\frac{1}{\sigma}}}{\left(1-\frac{1}{\sigma}\right)\left(\delta-\left(1-\frac{1}{\sigma}\right)(I_1-m)\right)} - \frac{1}{\delta\left(1-\frac{1}{\sigma}\right)}.$$

Taking first derivatives with respect to s and θ and noting that $g=\sigma\theta$ (equation (5')), we have

$$\frac{\left[(gf'+(1-s)\theta)K_0\right]^{-\frac{1}{\sigma}} K_0\theta(gf''+f'-1)}{\delta-\left(1-\frac{1}{\sigma}\right)(I_1-m)} + \frac{\left[(gf'+(1-s)\theta)K_0\right]^{1-\frac{1}{\sigma}}\frac{\partial I_1}{\partial s}}{\left(\delta-\left(1-\frac{1}{\sigma}\right)(I_1-m)\right)^2} = 0 \quad \text{(A1)}$$

$$\frac{\left[(gf'+(1-s)\theta)K_0\right]^{-\frac{1}{\sigma}} K_0\left(s(gf''+f'-1)+1\right)}{\delta-\left(1-\frac{1}{\sigma}\right)(I_1-m)} + \frac{\left[(gf'+(1-s)\theta)K_0\right]^{1-\frac{1}{\sigma}}\frac{\partial I_1}{\partial \theta}}{\left(\delta-\left(1-\frac{1}{\sigma}\right)(I_1-m)\right)^2} = 0 \quad \text{(A2)}$$

Combining (A1) and (A2) yields

$$\frac{\theta(gf''+f'-1)}{s(gf''+f'-1)+1} = \frac{\frac{\partial I_1}{\partial s}}{\frac{\partial I_1}{\partial \theta}} \quad \text{(A3)}$$

Note that

$$\frac{\partial I_1}{\partial s} = \frac{-\theta gf''}{b\sqrt{(r+m)^2-\frac{2}{b}(F_K-m-\theta-r)}} \quad \text{(A4)}$$

and

$$\frac{\partial I_1}{\partial \theta} = \frac{-sgf''-1}{b\sqrt{(r+m)^2-\frac{2}{b}(F_K-m-\theta-r)}}, \quad \text{(A5)}$$

where (2a) has been used to substitute for F_K in the numerator. Using (A4) and (A5) in (A3) yields

$$\frac{\theta(gf''+f'-1)}{s(gf''+f'-1)+1} = \frac{\theta gf''}{sgf''s+1}. \quad \text{(A6)}$$

Simple calculus then leads to f'=1. Thus, condition (18a) has been derived.

Derivation of (19b). Use (14) to substitute for the square-root term in (A5). Using the result and (14), the latter to substitute for I_1, in (A2) gives

$$s(gf''+f'-1)+1 = \frac{(gf'+(1-s)\theta)(sgf''+1)}{b((1-\sigma)r+\sigma\delta)^2}$$

From f'=1 and $g=s\theta$, (18b) follows immediately. The second part of (18b) follows from (14).

Derivation of (19c). Take squares on both sides of (13') and use (18b) substitute for θ. Then, rearranging terms yields (18d).

Properties of (19c). From (18c), we have

$$r = F_K - m \quad \Leftrightarrow \quad b = 0 , \quad r < F_K - m \quad \Leftrightarrow \quad b > 0$$

$$r \to +\infty \quad \Rightarrow \quad b \to -0 , \quad r \to -\infty \quad \Rightarrow \quad b \to +0$$

Taking the derivative in (18c), noting that $dI_1/dr=\sigma$ yields

$$\frac{db}{dr} = -2\frac{(r+m-I_1)^2 + (r+m)^2 + 2(F_K - m - r)[(1-\sigma)(r+m-I) + r + m]}{\left[(r+m-I)^2 + (r+m)^2\right]^2} \tag{A7}$$

For db/dr=0, we get a quadratic equation in r, which implies that the $b(r)$ function has two extrema, a maximum for $r < F_K - m$ and a minimum for $r > F_K - m$.

Values of θ in the maximum of the $b(r)$ function. It is shown by two examples that θ can be larger or less than F_K. To illustrate the first possibility, assume that σ=1. Then (20) changes to

$$r = F_K - m - \sqrt{F_K^2 + \delta^2} \ .$$

Using this in (19c) and inserting into (19b) yields

$$\theta = \frac{\delta^2 \sqrt{F_K^2 + \delta^2}}{F_K^2 + \delta^2 - F_K \sqrt{F_K^2 + \delta^2}} \ .$$

From the fact that the denominator is less than δ^2, it follows that $\theta > F_K$. The opposite case can be shown for an example, where the parameters of the model are such that the second term in the numerator in the square root in (20) vanishes, i.e. $\delta = -(1-\sigma)(F_K - m)/\sigma$, which is possible for large values of σ even if $F_K - m > 0$. Then,

$$r = F_K\left(1 - \left(1 + (1-\sigma)^2\right)^{-2}\right) - m$$

and the tax rate turns out to be (to be completed)

Derivation of (19d). Using F_K for θ in (13') yields

$$I_1 = r + m - \sqrt{(r+m)^2 + \frac{2(r+m)}{b}}\ . \qquad \text{(A8)}$$

Taking squares and solving for b, one obtains (19d).

Properties of (19d). The argument of the square-root in (A8) is negative if $-m - b/2 < r < -m$. Then there is no real-valued solution to (A8). On the boundaries of this interval, $I_1 = r+m$. Outside this interval, $I_1 < r+m$. Closer inspection of (A8), using de l'Hospital's rule, yields that I_1 goes to $-\infty$ if r goes to $\pm\infty$. Differentiation of (A8) yields

$$\frac{dI_1}{dr} = 1 - \frac{r + m - \frac{1}{b}}{\sqrt{(r+m)^2 + \frac{2(r+m)}{b}}}\ . \qquad \text{(A9)}$$

This derivative explains the shape of the $I_1(r)$ curve in Figure 3.

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