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One Sector Models, Indeterminacy, and Productive Public Spending

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Abstract

This paper studies the influence of different modelling assumptions on the determinacy of the steady state in one—sector models of economic growth with externalities in the production function. We show that productive public spending subject to congestion, combined with variable capital utilization, can lead to indeterminacy at very low degrees of social increasing returns to scale. We perform a calibration of the model to the tax regimes observed in the USA. We shed some light on the conflicting effects of progressive taxation on the steady state stability reported in the literature. Finally, we extensively discuss the features of the model that lead to an indeterminate rather than an explosive steady state once the saddle—path stability is broken.

Abstrakt

Tato studie se zabývá vlivem rozdílných modelových předpokladů na určitelnost stacionárních stavů v jednosektorovém modelu ekonomického růstu s externalitami v produkční funkci. Ukazujeme, že efektivní veřejné výdaje za předpokladu možného přehlcení, kombinované s měnícím se kapitálovým využitím, mohou vést k neurčitelnosti stacionárního stavu při velmi nízkých stupních rostoucích společenských výnosů z rozsahu. Model kalibrujeme na základě existujících daňových režimů v USA. Osvětlujeme problém v literatuře uváděných rozporuplných efektů progresivního zdanění na stabilitu stacionárního stavu. Závěrem extenzivně diskutujeme znaky modelu, které vedou po prolomení stability sedlové cesty k neurčenému stacionárnímu stavu namísto stacionárnímu stavu explozivnímu.

JEL Classification: E32, E62, H41
Keywords: indeterminacy, absolute instability, productive public spending, progressive taxation

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1 Introduction

Benhabib and Farmer (1994) showed that local indeterminacy (non–uniqueness of the perfect foresight trajectory in a small neighborhood of the steady state) can be obtained in a one–sector model in the presence of externalities. Indeterminacy relied on an unrealistically high degree of increasing returns to scale at the social level due to the presence of externalities, and the labor demand curve was upward sloping and steeper than the labor supply curve under indeterminacy. These undesirable properties were ameliorated by introducing the variable capital utilization, a standard feature of RBC models, in Wen (1998), and a non–separable utility function in Bennett and Farmer (2000). Both extensions generate indeterminate steady state with labor demand and supply crossing with standard slopes and the relatively low degree of increasing returns to scale that can be reconciled with the empirical estimates of Basu and Fernald (1997). Other approaches that make indeterminacy easier to achieve include multi–sector models, such as Benhabib and Farmer (1996) and Benhabib and Nishimura (1998), and an introduction of an external capital market which allows for perfect smoothing of consumption, see Lahiri (2001), Weder (2001), and Meng and Velasco (2003). Calibrated models with indeterminate steady states have been successfully used to describe fluctuations at the business cycles frequencies, c.f., Benhabib and Wen (2004).

Schmitt-Grohe and Uribe (1997) and Guo (1999), among others, studied the influence of taxation on indeterminacy. Schmitt–Grohe and Uribe find that a balanced budget and fixed government expenditure can be destabilizing (can lead to indeterminacy of the steady state), while Guo proves that progressive taxation leads to a higher likelihood of a saddle–path stable steady state. Slobodyan (2005) uses a model very similar to the one employed in this paper to study policy interventions which increase the probability of a sunspot–induced escape from the poverty trap. In all of these models, tax revenues do not influence households' utility or firms' productivity.

Cazzavillan (1996) introduces public spending that enters both the households' utility function and the firms' production function in a model with a simple flat tax. When households' utility function exhibits increasing returns in public spending, an indeterminate steady state becomes possible. This model uses fixed labor supply and thus, cannot be compared directly to the majority of models considered above. The same consideration applies to Park and Philippopoulos (2002) where a similar structure is used, but the government allocates the public good between households and firms optimally. The balanced growth path in the model is determinate. Zhang (2000) considers productive public spending which also affects households' utility. The model is mathematically equivalent to Benhabib and Farmer (1994), with public spending playing the role of labor effort. Finally, Bruha (2003) uses productive public spending subject to congestion in a two–sector open economy model with inelastic labor supply. Fiscal policy in the model consists of collecting flat rate taxes and allocating the tax revenue to productive public spending and transfers to households. The last model is closest to the one we are using in this paper; however, we concentrate on a one–sector model with elastic labor supply where stability can be studied analytically.

In the present paper, we introduce productive public spending financed by a progressive tax into a one–sector growth model with elastic labor supply and variable capital utilization due to Wen (1998). Variable capital utilization proved helpful in matching the stylized business cycles facts in both the "classical" RBC approach, see King and Rebelo (1999), and the multiple equilibria approach, see, for example, Benhabib and Wen (2004). Public spending (which could be thought of as paying for such public services as infrastructure, public utilities, and courts) is subject to congestion as in Barro and Sala–i–Martin (1992). We find that more productive public spending and more progressive taxes are both destabilizing and allow indeterminacy for a lower degree of returns to scale on a social level than in Wen. A one–sector structure allows us to get a clear intuitive explanation of these results.

The rest of the paper is organized as follows. Section 2 contains a description of our model. In Section 3, we discuss the stability of the steady state and the effect of different parameter values on its (in)determinacy. Section 4 provides some discussion on the calibrated parameter values and shows that indeterminacy could be observed for very low levels of externality, and Section 5 concludes.

2 The Model

Our deterministic continuous–time model with infinitely living agents extends upon those of Benhabib and Farmer (1994), Wen, and Guo. There is a continuum of $[0,1]$ of identical households maximizing the welfare functional

$$\int_0^\infty (\log C_t - A\frac{N_t^{1+\chi}}{1+\chi})e^{-\rho t}dt,\ A>0, \tag{1}$$

where C and N are household consumption and working hours, $\chi > 0$. Households own capital and run firms, and their budget constraint is given by

$$\dot{K_t} = (1-\tau)Y_t - C_t - \xi u_t^\theta K_t,\ K(0) \text{ given}, \tag{2}$$

where Y_t is the firm's output (equal to household income), τ the tax rate, and K_t the household's capital stock. Capital depreciation rate depends on the capital utilization rate u_t. Choosing $\theta > 1$ guarantees interior equilibrium with $u_t < 1$, see Wen. The constant relative progression tax system's tax rate is given as

$$\tau = 1 - \Psi\left(\frac{\overline{Y}_t}{Y_t}\right)^\phi,\ \Psi \in [0,1],\ \phi \in [0,1). \tag{3}$$

Parameters ϕ and Ψ determine the slope and the level of tax schedule. ϕ greater than 0 means "progressive" tax because in this case, the marginal tax rate is higher than the average one, see Benabou (2002) and Guo. In a symmetric equilibrium where every household has the same amount of capital, supplies the same number of hours, and uses the same capital utilization rate, the tax rate τ would equal $1-\Psi$.

The production function of every firm is given by

$$Y_t = \left(\frac{G_t}{\overline{u_t}\overline{K_t}}\right)^{\eta}\left[\left(\overline{u_t}\overline{K_t}\right)^{\alpha}\overline{N}^{1-\alpha}\right]^{\sigma}(u_tK_t)^{\alpha}N^{1-\alpha}, \tag{4}$$

where $\eta > 0$ and $\sigma > 0$. Public spending is productive (η is positive) and is taken as a given by every household. $\overline{K}$ and $\overline{N}$ are economy–wide averages of K and N per firm and are also taken as a given by the households. Public spending is subject to congestion, as in Barro and Sala–i–Martin (1992). The government balances its budget at every point in time and does not issue debt.

The necessary conditions for optimality are given as

$$\begin{aligned}
ACN^{\chi} &= (1-\phi)(1-\alpha)\Psi\left(\frac{\overline{Y}}{Y}\right)^{\phi}\frac{Y}{N}, && \text{(5a)}\\
(1-\phi)\alpha\Psi\left(\frac{\overline{Y}}{Y}\right)^{\phi}\frac{Y}{u} &= \xi\theta u^{\theta-1}K, && \text{(5b)}\\
\dot{C} &= C\left((1-\phi)\alpha\Psi\left(\frac{\overline{Y}}{Y}\right)^{\phi}\frac{Y}{K}-\rho-\xi u^{\theta}\right), && \text{(5c)}\\
\lim_{t\to\infty} e^{-\rho t}\frac{K}{C} &= 0, && \text{(5d)}
\end{aligned}$$

plus the capital accumulation equation (2). In a symmetric equilibrium $\overline{Y} = Y$, $\overline{K} = K$, $\overline{N} = N$, and $G = (1-\Psi)Y$. Switching to logs ($c = log(C)$, $k = log(K)$, $y = log(Y)$) and using (5a), (5b), and (4) to express y as a function of c and k one gets

$$y = w - (v-1)k - sc,$$

with values of w, v, and s given in the Appendix, equation (14). In the log variables, the two differential equations describing the optimal solution are

$$\begin{aligned}
\dot{c} &= \Psi\alpha(1-\phi)(1-\frac{1}{\theta})\exp(w-vk-sc)-\rho, && \text{(6a)}\\
\dot{k} &= \Psi(1-\frac{\alpha(1-\phi)}{\theta})\exp(w-vk-sc)-\exp(c-k). && \text{(6b)}
\end{aligned}$$

Finally, changing the coordinates to

$$\begin{aligned}
x &= \exp(w-vk-sc), && \text{(7a)}\\
z &= \exp(c-k), && \text{(7b)}
\end{aligned}$$

we get the system of equations presented below,

$$\dot{x} \quad = \quad x \times \left\{ -\Psi \left[v(1 - \frac{\alpha(1-\phi)}{\theta}) + s\alpha(1-\phi)(1-\frac{1}{\theta}) \right] x + vz + s\rho \right\}, \tag{8a}$$

$$\dot{z} \quad = \quad z \times \left\{ \Psi \left[\alpha(1-\phi)(1-\frac{1}{\theta}) - (1 - \frac{\alpha(1-\phi)}{\theta}) \right] x + z - \rho \right\}. \tag{8b}$$

By construction, x and z are nonnegative; therefore, only the first quadrant of the (x, z) space should be considered. We study the stability properties of the positive steady state $(x^*, z^*) = \left(\frac{\rho}{(1-\phi)(\theta-1)} \frac{\theta}{\Psi\alpha}, \frac{\rho}{(1-\phi)(\theta-1)} \frac{\theta-\alpha(1-\phi)}{\alpha} \right)$.

3 Stability Conditions

Our model has one predetermined variable (k) and one free (c).[1] Other non–predetermined variables controlled by the households, u and N, are functions of c and k in the interior equilibrium which is assumed here. Therefore, a steady state (x^*, z^*) is determinate, indeterminate, and absolutely unstable (explosive) if the Jacobian of (8) evaluated at the steady state has one, two, and zero eigenvalues with negative real parts.

The Jacobian evaluated at the positive steady state is given by

$$J^* = \begin{bmatrix} -\Psi[v(1-\frac{\alpha(1-\phi)}{\theta}) + s\alpha(1-\phi)(1-\frac{1}{\theta})]x^* & vx^* \\ \Psi[\alpha(1-\phi)(1-\frac{1}{\theta}) - (1-\frac{\alpha(1-\phi)}{\theta})]z^* & z^* \end{bmatrix}.$$

Determinant of J^* equals $-\Psi(s+v)\alpha(1-\phi)(1-\frac{1}{\theta})x^*z^*$. Assumptions on parameters ($\phi < 1$, $\theta > 1$) mean that $\det(J^*)$ is positive *iff* $s + v < 0$. In this case the steady state (x^*, z^*) can be indeterminate or absolutely unstable, depending on the value of $Tr(J^*)$. Using values of s and v given in the Appendix, we get

$$s + v = \frac{\theta(1+\chi)(1-\alpha(1+\sigma))}{\alpha(\theta-1) + \chi(\theta-\alpha) - \eta(1+\chi)(\theta-1) - \sigma\left[\theta(1-\alpha) + \alpha(1+\chi)\right]}. \tag{9}$$

[1]The change of variables (c, k) to (x, y) is non–singular as long as $C > 0$, $K > 0$, and $s + v \neq 0$. As shown below, $s + v = 0$ is the necessary condition for the Jacobian at the steady state to be non–hyperbolic (to have zero or a purely imaginary eigenvalue). Therefore, both (6) and (8) remain hyperbolic as long as the change of variables is non–singular. In this case, they are also C^0 equivalent, and C^0 equivalence preserves local stability properties, in particular sinks remain sinks. See Guckenheimer and Holmes (1997, Section 1.7) for details and definitions. Therefore, if the steady state is indeterminate in (6), it is also indeterminate in (8), and we can study local stability in either one.

The numerator is positive for $\sigma \leq \frac{1}{\alpha} - 1$. Given that α is usually calibrated at 0.3÷0.4, this constraint is not binding for reasonable values of σ. The denominator of (9) equals $\alpha(\theta-1)+\chi(\theta-\alpha) > 0$ for $\sigma = \eta = 0$ and is a decreasing function of both σ and η. Therefore, (9) is negative [and $\det(J^*)$ is positive] in the region of the (σ, η) space above the downward sloping straight line **A** in Figure 1A.

Let us turn our attention to $Tr(J^*)$. Calculations (given in the Appendix) demonstrate that it equals

$$\frac{\rho\theta}{\alpha(1-\phi)} \times \frac{\alpha\,(1+\sigma)\left[(1+\chi)\left(1-\frac{\alpha(1-\phi)}{\theta}\right)-(1-\alpha)(1-\phi)\right]-(1+\chi)\left(1-\frac{\alpha(1-\phi)}{\theta}\right)\eta}{\alpha(\theta-1)+\chi(\theta-\alpha)-\eta(1+\chi)(\theta-1)-\sigma\left[\theta(1-\alpha)+\alpha(1+\chi)\right]}.$$

The denominator is the same as in (9) times a positive number. When $\sigma = \eta = 0$, the numerator equals $\rho\theta\alpha\left[\chi\left(1-\frac{\alpha(1-\phi)}{\theta}\right)+\alpha(1-\phi)\left(1-\frac{1}{\theta}\right)+\phi\right] > 0$. Therefore, the numerator equals zero along line **B** in Figure 1A, which crosses the σ axis at $(0,-1)$ and is upward sloping. It is positive above line **B**.

The region of the (η, σ) space generating an indeterminate steady state $[\det(J^*) > 0,\ Tr(J^*) < 0]$ is the area below the line $\sigma = \frac{1}{\alpha} - 1$, above line **A**, and above line **B**.[2] Line **A** crosses the η axis to the right of line **B** for any parameter values (see Appendix for the proof). Therefore, a minimum value of $\sigma = \sigma_{\min}$ exists at which indeterminacy is first achieved. For smaller values of σ, the steady state is either determinate or explosive. The point of intersection of lines **A** and **B**, $(\eta^*, \sigma_{\min})$, corresponds to a minimum degree of increasing returns to scale that is necessary to generate the indeterminate steady state, $IRS_{\min} > 1$. For values of (η, σ) that correspond to $IRS < IRS_{\min}$, the steady state can be determinate or explosive, but all three outcomes — indeterminate, determinate, and the explosive steady state — are possible for $IRS > IRS_{\min}$.[3]

Notice that for some values of η, it is possible to move from an indeterminate to an explosive steady state by *lowering* σ and *decreasing* the returns to scale. For large η, fixing σ at 0 (constant returns to scale at the social level) generates

[2] Intersection with opposite signs — above the line $\sigma = \frac{1}{\alpha} - 1$ and below lines **A** and **B** — is an empty set.

[3] This is true if line **A** is steeper than the iso–IRS line in Figure 1A. Calculations in the Appendix show that this is indeed true for all reasonable parametrizations.

an explosive, rather than a determinate, steady state. This behavior is similar to the one observed in the Benhabib and Farmer (1994) model, where for β large enough, relatively small values of α result in the explosive steady state.

Given the values of externality parameters (η, σ), stability of the steady state depends on three other parameter values: χ, θ, and ϕ. Stability does not depend on ρ, which is a usual outcome with this functional form of variable capital utilization, and on Ψ, one minus the symmetric equilibrium tax rate.

The increase in χ (less elastic labor supply) moves the points of intersection of line **A** with both axes upward, thus increasing the region of the (η, σ) space where the steady state is determinate. Line **B** rotates clockwise, expanding the area of the indeterminacy region relative to that of the explosive one. Tedious derivations show that the effect on $IRS_{\min}$ is positive. The results are similar to those reported previously: for example, Schmitt-Grohe and Uribe (1997) show that higher χ makes indeterminacy of the steady state less likely to be obtained.

The effect of higher θ is similar to that of the increase in χ: in the neighborhood of empirically relevant points where $\alpha(1+\sigma)-\eta>0$, Line **A** shifts up while **B** rotates clockwise. The effect on $IRS_{\min}$ is hard to interpret analytically, but it is likely to be small. Figure 1 in Wen (1998) demonstrates that the region of indeterminacy shrinks as δ decreases (and θ gets larger), which is compatible with our result.

Finally, an increase in ϕ — higher progressivity of the tax schedule — does not affect line **A**. Line **B** rotates clockwise around the point $(0, -1)$. Therefore, the region of (η, σ) space where the steady state is determinate does not change, but the indeterminate region increases at the expense of the explosive one. $IRS_{\min}$ decreases, thus making indeterminacy more likely. This outcome can be contrasted with Guo (1999), where more progressivity (higher ϕ) is stabilizing. However, in a two–sector model of Guo and Harrison (2001) the progressive tax schedule can be both stabilizing and destabilizing. See the next section for a more detailed discussion of the reasons for the differences between our and earlier results.

4 Discussion and Numerical Examples

4.1 Explaining Stability Conditions

As stated above, we are interested in values of parameters that lead to indeterminacy under a sufficiently low degree of increasing returns to scale. Plugging $G = (1-\Psi)Y$ into (4), using (5b) to eliminate u, and switching to logs, one gets

$$y = const + \frac{(\alpha(1+\sigma)-\eta)\left(1-\frac{1}{\theta}\right)}{1-\frac{\alpha(1+\sigma)}{\theta}-\eta\left(1-\frac{1}{\theta}\right)}k + \frac{(1-\alpha)(1+\sigma)}{1-\frac{\alpha(1+\sigma)}{\theta}-\eta\left(1-\frac{1}{\theta}\right)}n = const + \epsilon_k^y \cdot k + \epsilon_n^y \cdot n. \tag{10}$$

The aggregate returns to scale are given as the sum of elasticies of output with respect to k and n, $\epsilon_k^y + \epsilon_n^y$. Assuming $\sigma, \eta \ll 1$, this sum is approximately (to the first order) equal to $1 + \frac{1}{1-\alpha/\theta}\sigma$, and so productive public spending affects the degree of increasing returns to scale only to the second order in the (σ, η) space. This feature of the result is caused by the fact that productive public spending is subject to congestion. It amplifies the "returns to scale" effect of the variable capital utilization identified by Wen (1998).

Stability properties of the steady state can be for the most part inferred from (10) and static F.O.C.'s. Benhabib and Farmer (1999, p. 400) sketch the following mechanism leading to indeteminacy: If, starting from the steady state, agents' desire to increase consumption (possibly because of a belief in lower than the steady state return on capital) leads not only to lower investment but to a higher labor effort as well, the GDP increases and the investment eventually rises, bringing the return on capital back to its steady state value and so generating a different equilibrium trajectory. Thus, (in)determinacy of the model's steady state depends on the static equilibrium condition (5a) with u and Y plugged in:

$$c = const + \epsilon_k^y \cdot k + (\epsilon_n^y - 1 - \chi) \cdot n. \tag{11}$$

The steady state is not determinate whenever $\epsilon_n^y - 1 - \chi > 0$.[4] Let us consider

[4] This is, of course, the same condition as the celebrated $\beta + \chi - 1 > 0$ in Benhabib and Farmer (1994) or (22) in Wen (1998).

the effects of different parameter values on the stability.

First, note that $\frac{\partial}{\partial\eta}\epsilon_n^y > 0$, and so a higher η makes co–movement between consumption and labor effort easier: Higher labor elasticity of output is the primary channel through which productive public spending influences determinacy of the steady state. Second, $\frac{\partial}{\partial\theta}\epsilon_n^y < 0$ for a realistic scenario where $\alpha(1+\sigma) > \eta$. As the steady state depreciation rate is inversely proportional to θ, faster depreciation increases ϵ_n^y. One thus sees that the effect of η is similar to Wen's "elasticity effect" of θ. Third, a higher α reduces ϵ_n^y thus making determinacy more likely. Fourth, a higher χ generates a stronger reduction of consumption through the income effect when labor effort increases, and higher labor elasticity of output is needed to engineer the resulting *increase* of consumption necessary to break the saddle–path stability. Finally, progressivity of the tax schedule ϕ does not affect ϵ_n^y nor the elasiticity of equilibrium consumption with respect to labor, and thus does not enter the condition for saddle–path stability.

The way different parameter values influence stability in the non–determinate region is more involved. Let us consider only the regions close to the Hopf bifurcation boundary. In the case of indeterminacy trajectories, they spiral into the steady state, while in the explosive case they spiral out of it. The difference between the indeterminate and the explosive steady state is, therefore, that of a degree: when agents decide to invest less and consume more (and so to work more because $\epsilon_n^y - 1 - \chi > 0$), how fast will they start scaling back their consumption? With an initial jump in consumption (and labor), capital accumulates, and its marginal product changes. If this change is too small, the system will never get back: the steady state is explosive. Sensitivity of the marginal product of capital to the value of K is proportional to ϵ_k^y, and so parameter changes that increase ϵ_k^y will tend to make the steady state indeterminate rather than explosive.

As is obvious from (10), ϵ_k^y is increasing in σ and decreasing in η; therefore, a higher σ moves the system into the indeterminate region, while a higher η could mean an explosive one. This conjecture is exactly confirmed by the

Fig. 1A. Furthermore, ϵ_k^y is increasing in θ, which is again consistent with the analysis in the previous section which stated that a higher θ means more of the indeterminate and less of the explosive region.

The effect of increasing χ (less elastic labor) on indeterminacy could be surmised by looking at (11). For any given expansion of output, a higher χ means that consumption has to increase relatively less. Therefore, agents do not increase their consumption as fast after the initial consumption jump, which means we are more likely to see eventual return to the steady state. Again, the previous section's results confirm that a higher χ expands the indeterminate region and contracts the explosive one.

A more progressive tax schedule (higher ϕ) means that consumption increases more slowly for any given expansion of output, see (5a), while capital expands faster as the tax revenue is spent to increase total factor productivity.[5] As a result, consumption will respond less to capital accumulation after an initial jump, meaning the higher likelihood of an indeterminate steady state. Once again, this is exactly the behavior of the model confirmed in the previous section.

The above discussion helps to compare our results and those reported in earlier literature. Consider, for example, the one sector model of Guo (1999), where progressive labor taxes are stabilizing. In that paper, an equivalent of the equation (11) can be written as

$$c = const + (1 - \phi_n) \cdot \epsilon_k^y \cdot k + ((1 - \phi_n) \cdot \epsilon_n^y - 1 - \chi) \cdot n.$$

Obviously, ϕ_n — the progressivity parameter of the labor tax schedule — makes co–movement between consumption and labor more difficult and thus is stabilizing, in contast with our results. The reason for the discrepancy lies in Eq. (3). In our model, $\overline{Y}$ is the average *current* income in the economy, but it is the average *steady state* income in Guo. As a result, from a social perspective, the progressivity of Guo's tax system is higher than that here: A much larger

[5] Of course, the distortionary effect of a more progressive tax rate makes total output lower; however, only relative speed of consumption and capital change are relevant for this argument.

expansion of labor effort (and output as a result) is needed to sustain the initial jump in consumption because a larger share of the higher output is taken away in taxes, and less of it remains to support the desired expanded consumption. This effect of progressivity on the social level is not present in our model as the tax revenue to output ratio is constant in the symmetric equilibrium. The destabilizing effect of taxation in another one–sector model of Schmitt-Grohe and Uribe (1997) has the same explanation: As noted by Guo, the tax system in that paper is regressive on the social level and thus makes indeterminacy easier to achieve.

The presence of productive public spending financed by the tax revenue adds another dimension on which our results should differ from those in Guo or Schmitt–Grohe and Uribe. As noted previously, in our model a more progressive tax system leads to a relatively slower expansion of consumption when capital accumulates. The effect of relatively faster capital accumulation is not present in the papers cited above because the tax revenue does not contribute to the total factor productivity. As a result, we expect that in the non–determinate region, our model is more favorable to an indeterminate vs. explosive steady state than those of Guo or Schmitt–Grohe and Uribe.

4.2 Calibration of the Tax Schedule and Numeric Results

For the calibration exercise we use the same baseline parameters values as Wen (1998): $\alpha = 0.3$, $\chi = 0$, $\theta = 1.4$.

The calibration of the only remaining parameter, degree of progressivity of the tax schedule ϕ, can proceed along several paths. The first way is to use Internal Revenue Service data on individual tax returns. It lists average tax as a share of Adjusted Gross Income (AGI) for the returns that do claim income tax, and the share of returns with no tax, see IRS (Winter 2002). Assuming that all taxpayers are located in the middle of reported income brackets, we can derive the total amount of income tax paid by the taxpayers in this income bracket. Equation (3) then gives disposable income, $(1-\tau)Y = \Psi \overline{Y}_t^{\phi} Y_t^{1-\phi}$ or $\log(DPI) =$

$const + (1-\phi)\log(Y)$. Assuming that AGI=Y, it is then possible to estimate parameter ϕ from a simple linear regression. This estimate is necessarily very imprecise because income and AGI can differ significantly and calculating the extent of this difference is difficult. For the 2000 data, this calibration method gives ϕ from 0.046 (if the whole range of the data is used) to 0.066 (when data points with AGI below \$3,000 and above \$1,500,000 are excluded). Similar calibration by Englund and Persson (1982) using Swedish data gives ϕ equal to 0.47 (0.63) in 1971 (1979). The tax calculator TAXSIM developed by the NBER generates an average marginal tax of 0.23 for USA in 1991, see Feenberg and Coutts (1993). Finally, Easterly and Rebelo (1993) estimate the average marginal tax rate using the data on official tax rates, income distribution, and the actual amount of tax revenue collected. Depending on the specification used, they report an average marginal tax from 0.11 to 0.23 for the USA in 1984.

Another method of calibrating ϕ is as follows. We start from the assumption that income in the population has Gamma distribution with parameters α and β. Gamma distribution has been used to approximate the true distribution of income among households and was found to perform better than lognormal, see McDonald and Ransom (1979).

The Gini coefficient is the area between 45° line and the Lorenz curve representing the distribution of income. For continuous income distributions, it is given by

$$G = 1 - 2\int_0^\infty F_1(x)f(x)dx, \tag{12}$$

where

$$F_1(x) = \frac{1}{E[y]}\int_0^x yf(y)dy.$$

For details, see Kakwani (1977). If one assumes that the pre–tax income distribution f is Gamma with parameters α and β, the pre–tax Gini coefficient is given by

$$G_{in} = \frac{1}{\sqrt{\pi}}\frac{\Gamma(\alpha+\frac{1}{2})}{\Gamma(\alpha+1)},$$

see McDonald and Ransom (1979). With the constant residual progression tax, after–tax income of the agent with pre–tax income Y is given by $g(Y) = \Psi \overline{Y}_t^{\phi} Y_t^{1-\phi}$. Calculating the post–tax Gini index as in Kakwani (1977) then gives

$$G_{fin} = 1 - 2 \cdot \int_0^{\infty} f(r, \alpha, 1) \cdot F(r, \alpha + 1 - \phi, 1) dr. \tag{13}$$

Here $f(r, \alpha, \beta)$ and $F(r, \alpha, \beta)$ are, respectively, p.d.f and c.d.f. of the Gamma distribution with parameters α and β.

To calibrate ϕ, one then needs only two numbers: the pre–tax and post–tax Gini indices. Pre–tax Gini is used to determine α, and parameter ϕ is chosen so that (13) produces the empirically observed post–tax Gini index.

The data for this calibration method are taken from the Current Population Reports on consumer income by the US Census Bureau, see Jones and Weinberg (2000). US Census Bureau compiles data on consumer income together with several experimental measures of income, including pre–tax and post–tax income. Figure 7 in Jones and Weinberg (2000) contains Gini coefficients for pre–tax and post–tax household income from 1993 to 1998. The algorithm described above shows that the pre–tax income distribution can be approximated by the gamma distribution with α from 1.24 to 1.30, and the degree of progressivity of the tax, ϕ, varies from 0.086 to 0.103.

A similar calibration can be performed using data on specific taxes or transfers: the initial Gini index; progressivity (change in the Gini index associated with the tax or transfer); and intensity (share of the total income taxed away or transferred to individuals). The data for direct taxation in Hong Kong, the Philippines, Chile, Iran, Sri Lanka, and Canada around 1970 are taken from Lecaillon, Paukert, Morrisson, and Germidis (1984, Tables 43–48). Calculations give the value of ϕ from 0.008 (Iran) to 0.061 (the Philippines).[6]

For numerical examples, we use $\phi = 0.15$, which is about the mid–point of Easterly and Rebelo (1993) estimates, below the value generated by TAXSIM, and higher than the values calculated using pre–tax and post–tax Gini indices. A minimum degree of returns to scale implying indeterminacy of the steady state,

[6] Note that a constant marginal progression tax system transfers income to the poor agents. If one takes into account taxes *and transfers*, the calibrated value of ϕ becomes even higher.

$IRS_{\min}$, equals just 1.08. To get this rather low value the public spending has to be very productive, as η equals 0.10. Without public spending ($\eta = 0$) the steady state is determinate for IRS<1.12. Figures 1B–1D present the effect of changes in the basic parameters, θ, χ, and ϕ, on $IRS_{\min}$. Changing χ to a value often used in the literature, $\chi = 0.25$, increases $IRS_{\min}$ to 1.34 and requires even a larger elasticitiy of output with respect to public spending, $\eta \approx$0.15. Increase in θ corresponding to a decrease in the steady state depreciation rate from 0.1 to 0.08 has a small stabilizing effect by increasing the area of (η, σ) space producing the determinate steady state; $IRS_{\min}$ increases to 1.10. Finally, a reduction of ϕ from 0.15 to 0 (flat tax) increases $IRS_{\min}$ to 1.11, at the same time requiring much less productive public spending (η=0.03). IRS values of 1.1 and less are within the range of the empirical estimates, see Laitner and Stolyarov (2004); Basu and Fernald (1997); and Burnside, Eichenbaum, and Rebelo (1995).

As illustrated above, generating indeterminacy with very low degrees of increasing returns to scale requires a rather high public spending elasticity of output. Original estimates by Aschauer (1989) found very high (0.3 to 0.4) elasticities of output with respect to the flow of public services (proxied by public capital). Nadiri and Mamuneas (1994) proxied the flow of public capital (infrastructure) services by using the public capital stock augmented by the private capital utilization rates and found the cost elasticity of infrastructure capital in the range -0.11 to -0.21. Barro (1991) finds little support for any positive influence of public investment on economic growth, but suggests that this might be an outcome of governments' increasing the public investment to the point where its marginal contribution to the growth is about zero. Subsequent literature was inconclusive in pinpointing the elasticity of output with respect to public investment or public capital, see a survey in Gramlich (1994). Baier and Glomm (2001) calibrate their model so that the elasticity of output with respect to public capital equals 0.105.

There is no public capital in the current paper. In the symmetric equilibrium and for fixed K the flow of public services (equal to public spending) is proportional to $Y/u \sim u^{\theta-1}$, $\theta - 1 = 0.4$; therefore, Barro–like modelling of the flow of public services used here is "intermediate" between that of Aschauer (1989) (no dependence on the capital utilization rate) and of Nadiri and Mamuneas (1994) (linear dependence on the capital utilization rate). One thus believes that values of η about 0.1, needed to generate a large reduction in the $IRS_{\min}$, might be compatible with the available evidence. Of course, to correspond fully to the available empirical studies, one should model the process of public capital accumulation separately and then make assumptions regarding the flow of services derived from the stock of public capital; however, doing so would introduce another state variable into the model and thus greatly complicate it, not necessarily generating significantly different results, as local (in)determinacy depends on ϵ_n^y at the steady state alone.

What can we say about the slope of the labor demand curve when parameter values imply indeterminacy, say, near the point $(\eta^*, \sigma_{\min})$? In the symmetric equilibrium, if one (incorrectly) believes that capital utilization u is an independent variable rather than a function of (k, n) determined by (5b), equation (10) becomes

$$y = const + \frac{\alpha(1+\sigma) - \eta}{1-\eta}(u+k) + \frac{(1-\alpha)(1+\sigma)}{1-\eta} n,$$

in which case the perceived slope of the labor demand curve in log–log variables is given by $\frac{(1-\alpha)(1+\sigma)}{1-\eta} - 1$.[7] It is negative when $1 + \sigma < \frac{1-\eta}{1-\alpha}$: downward–sloping labor demand requires $\eta \lessapprox \alpha - \sigma$. The slope equals -0.17 at $(\eta^*, \sigma_{\min})$ for the baseline parametrization. It is still negative at (and in a neighborhood of) $(\eta^*, \sigma_{\min})$ for all the parameter changes presented at Figure 1 but change in χ: As χ increases, the area in the (η, σ) space, where both indeterminacy and downward–sloping labor demand coexist, shrinks and eventually disappears because both η and σ become very large at $(\eta^*, \sigma_{\min})$.

Models with indeterminate steady states are often used to explain business

[7] Of course, if one plugs in (5b), the slope of the *reduced form* labor demand equation becomes equal to $\epsilon_n^y - 1$ and is *positive* when the steady state is indeterminate as $\epsilon_n^y - 1 > \chi$. The situation is similar to, for example, the simplified model of Farmer (1997, p. 588), where labor demand is *downward* sloping when real money balances are taken as given, but is *upward* sloping in a reduced form equation with equilibrium real money balances substituted in.

cycles without recourse to strongly autocorrelated fundamental shocks, using *i.i.d.* sunspot shocks to drive the model instead, cf. Benhabib and Wen (2004). With *i.i.d.* sunspot shocks, the dynamic response of the model is dampened oscillations. In continuous time, if the two complex eigenvalues of the Jacobian at the steady state are given by $\alpha \pm i\theta$, then the period of the oscillations T is given by $2\pi\theta$. Wen (1998) believes that the frequency of oscillations equal to 0.2 cycles per year (0.05 per quarter), or T equal to 5 years, is compatible with the available data. Figure 1A presents iso–period lines for the baseline parametrization for T=5 and 10. As is obvious from Figure 1A, values of (η, σ) exist which generate an indeterminate steady state at a very low degree of increasing returns to scale and an implied period of dynamic response close to 5 years.

5 Conclusion

We showed that an introduction of productive public spending into a basic one–sector model with externalities, variable capital utilization, and a progressive tax schedule, allows a further reduction in the degree of returns to scale, at which the saddle–path stability of the steady state is broken, to values well within the range of the existing estimates. Moderately productive public spending favors indeterminacy because it increases the elasticity of output with respect to labor, while further increase in its productivity may lead to the explosive steady state as the capital elasticity of output becomes too small. One is able to obtain indeterminacy with a downward–sloping labor demand curve. The elasticity of output with respect to the flow of public capital services needed to generate these results is in the range identified by empirical estimates. Frequency of the dynamic response of the model to *i.i.d.* sunspot shocks is compatible with empirical observations. We further clarified the way progressive taxation influences the (in)determinacy of the steady state and successfully provided intuition regarding the relationship between indeterminate and explosive steady states in one–sector models that could be applied in a broader context.

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A Derivations

A.1 Values of w, s, and v

$$w = \frac{\theta(1+\chi)}{DEN} \times \left\{ \begin{array}{c} \eta \ln(1-\Psi) + \frac{\alpha(1+\sigma)-\eta}{\theta} \ln \frac{\Psi\alpha(1-\phi)}{\theta\xi} + \\ \frac{(1-\alpha)(1+\sigma)-\eta}{1+\chi} \ln \frac{\Psi(1-\alpha)(1-\phi)}{A} \end{array} \right\}, \tag{14a}$$

$$v = \theta \frac{\chi\left[1-\alpha(1+\sigma)\right]-\sigma}{DEN}, \tag{14b}$$

$$s = \theta \frac{(1-\alpha)(1+\sigma)}{DEN}, \tag{14c}$$

$$DEN = \theta\left[(1-\eta)(1+\chi)-(1-\alpha)(1+\sigma)\right]-(\alpha(1+\sigma)-\eta)(1+\chi) \tag{14d}$$

A.2 Calculation of $Tr(J^*)$

$$\begin{aligned} Tr(J^*) &= -\Psi[v(1-\frac{\alpha(1-\phi)}{\theta})+s\alpha(1-\phi)(1-\frac{1}{\theta})]x^*+y^* = \\ &= \frac{\rho}{\alpha(1-\phi)(1-\frac{1}{\theta})}\left[\left(1-\frac{\alpha(1-\phi)}{\theta}\right)(1-v)-s\alpha(1-\phi)(1-\frac{1}{\theta})\right]. \end{aligned}$$

First, let us calculate $(1-v)$:

$$\begin{aligned} & \frac{(1+\chi)\left[\theta(1-\eta)-\alpha(1+\sigma)+\eta\right]-\theta\left[(1-\alpha)(1+\sigma)+\chi\left[1-\alpha(1+\sigma)\right]-\sigma\right]}{DEN} \\ = & \frac{(1+\chi)\left[\theta(1-\eta)-\alpha(1+\sigma)+\eta\right]-(1+\chi)\theta\left[1-\alpha(1+\sigma)\right]}{DEN} = \\ = & \frac{\theta(1+\chi)(1-\frac{1}{\theta})(\alpha(1+\sigma)-\eta)}{DEN}. \end{aligned}$$

Then, $Tr(J^*)$ becomes equal to

$$\begin{aligned} & \frac{\rho}{\alpha(1-\phi)(1-\frac{1}{\theta})DEN} \times \\ & \times \left\{ \begin{array}{c} \theta\left(1-\frac{\alpha(1-\phi)}{\theta}\right)(1+\chi)(1-\frac{1}{\theta})(\alpha(1+\sigma)-\eta) - \\ -\theta(1-\alpha)(1+\sigma)\alpha(1-\phi)(1-\frac{1}{\theta}) \end{array} \right\} \\ = & \frac{\rho\theta}{\alpha(1-\phi)} \times \frac{\left(1-\frac{\alpha(1-\phi)}{\theta}\right)(1+\chi)(\alpha(1+\sigma)-\eta)-(1-\alpha)(1+\sigma)\alpha(1-\phi)}{DEN} \\ = & \frac{\rho\theta}{\alpha(1-\phi)\cdot DEN} \times \left\{ \begin{array}{c} \alpha(1+\sigma)\left[(1+\chi)\left(1-\frac{\alpha(1-\phi)}{\theta}\right)-(1-\alpha)(1-\phi)\right] - \\ -(1+\chi)\left(1-\frac{\alpha(1-\phi)}{\theta}\right)\eta \end{array} \right\}. \end{aligned}$$

A.3 Intersections with the η axis.

Line **B** intersects the η axis at

$$\eta = \alpha\frac{(1+\chi)(1-\frac{\alpha(1-\phi)}{\theta})-(1-\alpha)(1-\phi)}{(1+\chi)(1-\frac{\alpha(1-\phi)}{\theta})} = \alpha\left(1-\frac{(1-\alpha)(1-\phi)}{(1+\chi)(1-\frac{\alpha(1-\phi)}{\theta})}\right) < \alpha.$$

Line **A** intersects the η axis at

$$\eta = \frac{\alpha}{1+\chi} + \frac{\chi}{1+\chi}\frac{\theta-\alpha}{\theta-1} > \frac{\alpha}{1+\chi} + \frac{\chi}{1+\chi} > \frac{\alpha+\chi}{1+\chi} > \alpha.$$

A.4 Slope of line A

The iso–IRS line is defined as $\epsilon_k^y + \epsilon_n^y = IRS_{\min}$, where ϵ_k^y and ϵ_n^y are given by (10). The slope of this line is given by

$$-\frac{\left(1-\frac{1}{\theta}\right)(IRS_{\min}-1)}{1+\alpha\frac{IRS_{\min}-1}{\theta}},$$

while the slope of line **A** equals $-\frac{(1+\chi)\left(1-\frac{1}{\theta}\right)}{1-\alpha\left(1-\frac{1}{\theta}\right)}$. A comparison of the two values produces

$$\begin{aligned}-\frac{\left(1-\frac{1}{\theta}\right)(IRS_{\min}-1)}{1+\alpha\frac{IRS_{\min}-1}{\theta}} &> -\frac{(1+\chi)\left(1-\frac{1}{\theta}\right)}{1-\alpha\left(1-\frac{1}{\theta}\right)} \Leftrightarrow (IRS_{\min}-1)(1-\alpha) < \\ &< 1+\chi\left(1+\frac{IRS_{\min}-1}{\theta}\right).\end{aligned}$$

The last inequality is true as long as $IRS_{\min} < 2$, for example, but we are interested only in $IRS_{\min} \approx 1$. Therefore, line **A** is steeper than the iso–IRS line for all parameter values that might be reasonable.

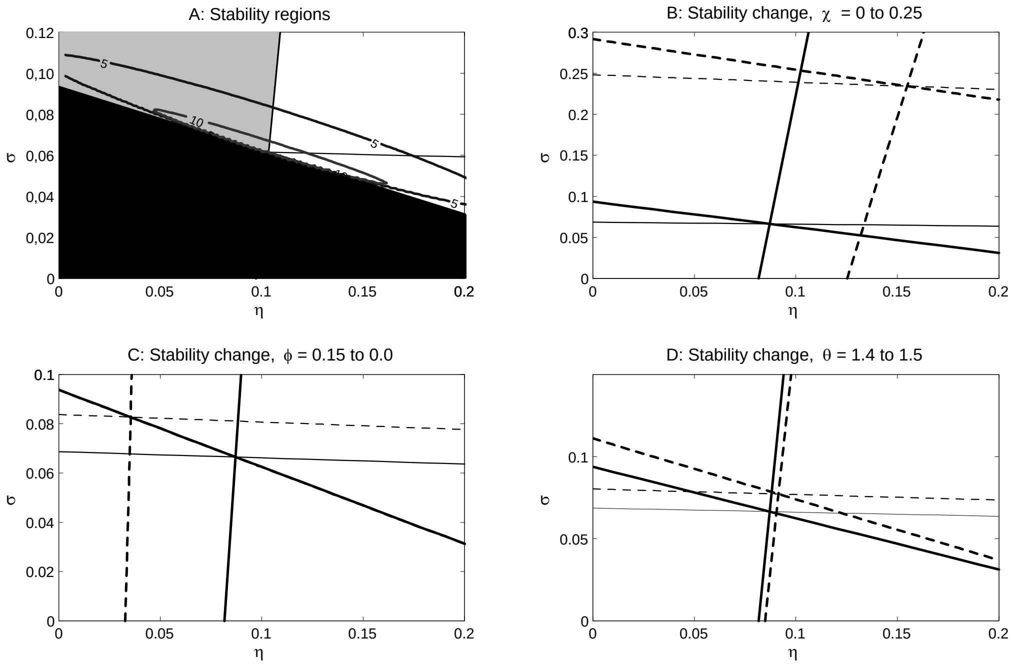

Figure 1: Panel A. Black area: saddle–path stability, gray: indeterminacy, white: explosive steady state. Iso–period lines corresponding to the period of dampened oscillations equal to 5 and 10 years are shown. Panel B. Stability regions before (solid lines) and after (dash lines) increase in χ. Thin approximately horizontal lines are iso–IRS lines, bold downward– and upward–sloping lines are Line **A** and **B**, respectively. Panel C. Same as Panel B, decrease in ϕ. Panel D. Same as Panel B, increase in θ.

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