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Indeterminacy and multiplicity of equilibria in a two-sector economy with a public-sector production

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Abstract

We introduce government production of both output-augmenting and utility-enhancing public services into an exogenous growth model with a detailed government sector, and calibrate the model to Bulgarian data for the period following the introduction of the currency board arrangement (1999-2016). We show that in contrast to the case without government output, e.g., Vasilev (2009), when the economy features saddle-path stability, the presence of a second sector leads to equilibrium indeterminacy in the model. When public sector production adds to private sector output, the setup exhibits "sink" dynamics, and equilibrium paths are determined by "animal spirits." These results are in line with the findings in the literature, e.g., Benhabib and Farmer (1994, 1996) and Farmer (1999), and have major implications for policy-making and welfare.

Keywords: Equilibrium indeterminacy, animal spirits, two-sector model, government production, Bulgaria

JEL Classification Codes: E32, E22, E37

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1 Introduction and Motivation

In the standard real business cycle model, as Cooley and Prescott (1995) have pointed out, changes in hours account for two-thirds of the cyclical output volatility. Those hours, however, are assumed to be supplied in the private sector only, and thus the private-public sector labor choice is ignored. This study adds to the literature by distinguishing between the two types of hours: after all, central governments in EU countries are the biggest employers at a national level, and public employment is a significant share of total employment. This paper also adds to earlier research by focusing on the endogenous public-private sector labor choice, and the public sector production technology as an alternative way to produce goods and services. Furthermore, we show that in an exogenous growth model, where public-sector hours and wages are endogenously-determined, and where utility-enhancing public services are produced using hours and capital, the artificial economy features indeterminacy and multiplicity of equilibria.

The source of the indeterminacy result is due to the fact that total output in our framework is the sum of private-sector production and public-sector output. Also, the public sector is treated differently than the official sector, as taxes are based on public-sector wages only, and not on public capital. Thus the presence of a government sector generates externalities in production, and increasing returns to scale (IRS). Also, Farmer (1999) has shown that the presence of IRS can produce indeterminate equilibria, as long as the increasing returns are large enough. In this model this is exactly the case, as government output in Bulgaria is one-sixth of total production. Bulgaria was chosen in this paper as it is an EU member state with a substantial government production, and thus a good testing ground for the theory developed in this paper. We show that in contrast to the case without government output, *e.g.*, Vasilev (2009), when the economy features saddle-path stability. When public sector output augments private production, the setup exhibits global stability ("sink" dynamics), and equilibrium paths are determined by "animal spirits."¹ These results are in line with the findings in the literature, *e.g.*, Benhabib and Farmer (1994, 1996) and Farmer (1999), and have major implications for policy-making and welfare.

¹When habits enter additively, the model again features saddle-path stability.

The rest of the paper is organized as follows: Section 2 presents the model setup and defines the equilibrium system. Section 3 describes the data used and the calibration procedure. Section 4 characterizes the model economy's long-run behavior. Section 5 evaluates the model stability. Section 6 discusses the results, and Section 7 concludes.

2 Model Description

There is a representative (aggregate) household which derives utility out of consumption and leisure. The time available to households can be spent in productive use - working in the private- or the public sector, or as leisure. The government provides utility-enhancing public goods, and taxes consumption spending and levies a common tax on all income, in order to finance government consumption, government investment spending, government transfers, and spending on the government wage bill. On the production side, there is a representative firm, which hires labor and capital to produce a homogenous final good, which could be used for consumption, investment, or government purchases.

2.1 Household

There is an infinitely-lived aggregate household, which maximizes its expected utility function, as in Vasilev (2015c, 2016b,d):²

$$\max_{\{c_t, n_t^p, n_t^g, k_{t+1}^p\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \ln c_t + \theta_p \ln(1 - n_t^p) + \theta_g \ln(1 - n_t^g) + \gamma \ln s_t^g \right\} \quad (2.1)$$

where E_0 denotes household's expectations as of period 0, c_t denotes household's private consumption in period t , n_t^p and n_t^g refers to private- and public-sector labor supply, $\theta_p, \theta_g > 0$ measures the importance of leisure for each type of labor services, $0 < \beta < 1$ is the discount factor, $0 < \gamma < 1$ is the relative weight that the household attaches to public services.³

²This is the resulting utility function of an aggregate household, where individuals are either a "private-sector" or "public-sector" type, and search for work into that sector only. As a result of the search, only a proportion of each type are chosen to work in each sector. After aggregation, and in the presence of certain insurance markets, e.g. Merz (1995), consumption across types is equalized, and the utility of leisure is separable in the two types of labor hours.

³The particular form of the leisure terms does not matter quantitatively for the results obtained in this paper.

The household starts with an initial stock of private physical capital $k_0^p > 0$, and has to decide how much to add to it in the form of new investment. The law of motion for private physical capital is

$$k_{t+1}^p = i_t + (1 - \delta^p)k_t^p \quad (2.2)$$

and $0 < \delta^p < 1$ is the depreciation rate. Next, the real interest rate is r_t , hence the before-tax capital income of the household in period t equals $r_t k_t^p$. In addition to capital income, the household can generate labor income. Hours supplied to the representative firm are rewarded at the hourly wage rate of w_t^p , and an hour worked in the public sector is remunerated at the rate of w_t^g , so total pre-tax labor income equals $w_t^p n_t^p + w_t^g n_t^g$. Lastly, the household owns the firm in the economy and has a legal claim on all the firm's profit, π_t .

Next, the household's problem can be now simplified to

$$\max_{\{c_t, n_t^p, n_t^g, k_{t+1}^p\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \ln c_t + \theta_p \ln(1 - n_t^p) + \theta_g \ln(1 - n_t^g) + \gamma \ln s_t^g \right\} \quad (2.3)$$

s.t.

$$(1 + \tau^c)c_t + k_{t+1}^p - (1 - \delta^p)k_t^p = (1 - \tau^y)[w_t^p n_t^p + w_t^g n_t^g + r_t k_t^p + \pi_t] + g_t^t, \quad (2.4)$$

where τ^c is the tax on consumption, τ^y is the proportional income tax rate ($0 < \tau^c, \tau^y < 1$), levied on both labor and capital income, and g_t^t denotes government transfers. The household takes the two tax rates $\{\tau^c, \tau^y\}$, government spending categories, $\{g_t^c, g_t^i, g_t^t\}_{t=0}^{\infty}$, profit $\{\pi_t\}_{t=0}^{\infty}$, government capital and public services $\{k_t^g, s_t^g\}_{t=0}^{\infty}$, the realized technology process $\{A_t\}_{t=0}^{\infty}$, prices $\{w_t^p, w_t^g, r_t\}_{t=0}^{\infty}$, and chooses $\{c_t, n_t^p, n_t^g, k_{t+1}^p\}_{t=0}^{\infty}$ to maximize its utility subject to the budget constraint.⁴ After plugging the process followed by habits into the utility

⁴Note that by choosing k_{t+1}^p the household is implicitly setting investment i_t optimally.

function, the constraint optimization problem generates the following optimality conditions:

$$c_t : \frac{1}{c_t} = \lambda_t(1 + \tau^c) \quad (2.5)$$

$$n_t^p : \frac{\theta_p}{1 - n_t^p} = \lambda_t(1 - \tau^y)w_t^p \quad (2.6)$$

$$n_t^g : \frac{\theta_g}{1 - n_t^g} = \lambda_t(1 - \tau^y)w_t^g \quad (2.7)$$

$$k_{t+1}^p : \lambda_t = \beta E_t \lambda_{t+1} [1 + (1 - \tau^y)r_{t+1} - \delta^p] \quad (2.8)$$

$$TVC : \lim_{t \rightarrow \infty} \beta^t \lambda_t k_{t+1}^p = 0 \quad (2.9)$$

where λ_t is the Lagrangean multiplier attached to household's budget constraint in period t . The interpretation of the first-order conditions above is as follows: the first one states that for each household, the marginal utility of consumption equals the marginal utility of wealth, corrected for the consumption tax rate. The second and third equations state that when choosing labor supply optimally, at the margin, each hour spent by the household working for the firm or the government should balance the benefit from doing so in terms of additional income generates, and the cost measured in terms of lower utility of leisure. The fourth equation is the so-called "Euler condition," which describes how the household chooses to allocate private physical capital over time. The fourth condition is called the "transversality condition" (TVC): it states that at the end of the horizon, the value of physical capital should be zero.

2.2 Firm problem

There is a representative firm in the economy, which produces a homogeneous final product. The price of output is normalized to unity. The production technology is Cobb-Douglas and uses both physical capital, k_t^p , and labor hours, n_t^p , to maximize static profit

$$\Pi_t = A_t (k_t^p)^\alpha (n_t^p)^{1-\alpha} - r_t k_t^p - w_t^p n_t^p, \quad (2.10)$$

where A_t denotes the level of technology in period t . Since the firm rents the capital from households, the problem of the firm is a sequence of static profit maximizing problems. In equilibrium, there are no profits, and each input is priced according to its marginal product,

i.e.:

$$k_t^p : \alpha \frac{y_t}{k_t^p} = r_t, \quad (2.11)$$

$$n_t^p : (1 - \alpha) \frac{y_t}{n_t^p} = w_t^p. \quad (2.12)$$

In equilibrium, given that the inputs of production are paid their marginal products, $\pi_t = 0$, $\forall t$.

2.3 Government

In the model setup, the government is levying taxes on labor and capital income, as well as consumption, in order to finance spending on government purchases, government investment, and government wage bill.

The government combines labor and capital to provide public services (government output) using a production function as in Vasilev (2016a):

$$s_t^g = (k_t^g)^{\alpha_g} (n_t^g)^{1-\alpha_g} \quad (2.13)$$

where s_t^g is the amount of government services produced, k_t^g is public capital, n_t^g is public employment, and α_g is the capital share in the government production function. In addition, government capital evolves as follows:

$$k_{t+1}^g = g_t^i + (1 - \delta^g) k_t^g, \quad (2.14)$$

where $0 < \delta^g < 1$ is the depreciation rate of public sector capital, and $k_0^g > 0$ is given.

Next, the government budget constraint is as follows:

$$g_t^c + g_t^i + g_t^t + w_t^g n_t^g = \tau^c c_t + \tau^y [w_t^p n_t^p + w_t^g n_t^g + r_t k_t^p + \pi_t] \quad (2.15)$$

Tax rates, government consumption-to-output ratio, government investment-to-output ratio, and government transfers-to-output ratio would be chosen to match the average share in data, and government wages would be determined residually in each period so that the government budget is always balanced.⁵

⁵In this way, we will have a negative relationship between public sector wages and employment, hence that would be the effective labor demand curve for public sector labor services.

2.4 Dynamic Competitive Equilibrium (DCE)

For a given process followed by technology $\{A_t\}_{t=0}^{\infty}$ average tax rates $\{\tau^c, \tau^y\}$, initial capital stocks $\{k_0^p, k_0^g\}$, the decentralized dynamic competitive equilibrium is a list of sequences $\{c_t, i_t, k_t^p, n_t^p, n_t^g\}_{t=0}^{\infty}$ for the household, a sequence of government purchases, government investment and transfers $\{g_t^c, g_t^i, g_t^t\}_{t=0}^{\infty}$, government capital and public services $\{k_t^g, s_t^g\}_{t=0}^{\infty}$, and input prices $\{w_t^p, w_t^g, r_t\}_{t=0}^{\infty}$ such that (i) the household maximizes its utility function subject to its budget constraint; (ii) the representative firm maximizes profit; (iii) government budget is balanced in each period; (iv) all markets clear.

3 Data and Model Calibration

To characterize business cycle fluctuations with an endogenous depreciation rate in Bulgaria, we will focus on the period following the introduction of the currency board (1999-2016). Quarterly data on output, consumption and investment was collected from National Statistical Institute (2017), while the real interest rate is taken from Bulgarian National Bank Statistical Database (2017). The calibration strategy described in this section follows a long-established tradition in modern macroeconomics: first, as in Vasilev (2016), the discount factor, $\beta = 0.982$, is set to match the steady-state private capital-to-output ratio in Bulgaria, $k^p/y = 13.964$, in the steady-state Euler equation. The labor share parameter, $1 - \alpha = 0.571$, is obtained as in Vasilev (2015b), and equals the average value of labor income in aggregate output over the period 1999-2016. This value is slightly higher as compared to other studies on developed economies, due to the overaccumulation of physical capital, which was part of the ideology of the totalitarian regime, which was in place until 1989. Then, assuming that government production technology is more labor intensive, we set the capital share in government services $\alpha_g = 0.400$.⁶ Next, the average income tax rate was set to $\tau^y = 0.1$. This is the average effective tax rate on income between 1999-2007, when Bulgaria used progressive income taxation, and equal to the proportional income tax rate introduced as of 2008. Similarly, the tax rate on consumption is set to its value over the period, $\tau^c = 0.2$. Next, the relative weight attached to the utility out of public goods in the household's utility function, $\gamma = 0.231$, is set to match household's "observed preferences":

⁶Variation in this parameter do not affect the main results in the paper.

that in the steady-state consumers would consume private and public goods in the same proportion as in data.⁷ Next, the household will supply one-third of their time endowment to working. This is in line with the estimates for Bulgaria (Vasilev 2015a) as well over the period studied. Looking at the breakdown across sectors, public sector employment ($n^g = 0.067$) makes one-fifth of total employment, and private employment ($n^p = 0.267$) is four-fifths of total. The relative weight attached to leisure are then calibrated to match steady-state hours. Next, the steady-state depreciation rate of physical capital in Bulgaria, $\delta = 0.013$, was taken from Vasilev (2016c). It was estimated as the average quarterly depreciation rate over the period 1999-2014. Public sector depreciation rate was set to $\delta^g = 0.004$, and public capital stock is computed as $k^g = g^i/\delta^g$. Table 1 below summarizes the values of all model parameters used in the paper.

4 Steady-State

Once the values of model parameters were obtained, the steady-state equilibrium system solved, the "big ratios" can be compared to their averages in Bulgarian data. The results are reported in Table 2 on the next page. The steady-state level of output was normalized to unity (hence the level of technology A differs from one, which is usually the normalization done in other studies), which greatly simplified the computations. Next, the model matches consumption-to-output and government purchases ratios by construction; The investment ratios are also closely approximated, despite the closed-economy assumption and the absence of foreign trade sector. The shares of income are also identical to those in data, which is an artifact of the assumptions imposed on functional form of the aggregate production function. The after-tax return, where $\bar{r} = (1 - \tau^y)r - \delta$ is also relatively well-captured by the model. Lastly, given the absence of debt, and the fact that transfers were chosen residually to balance the government budget constraint, the result along this dimension is understandably not so close to the average ratio in data.

⁷This parameter plays no role in the model, as households take public services as given.

Table 1: Model Parameters

Parameter	Value	Description	Method
β	0.982	Discount factor	Calibrated
α	0.429	Capital Share	Data average
α_g	0.400	Capital share, government output	Set
θ_p	1.636	Relative weight attached to private sector hours	Calibrated
θ_g	1.543	Relative weight attached to public sector hours	Calibrated
γ	0.231	Relative weight attached to public services	Set
n	0.334	Total employment	Data average
n^g	0.067	Public sector employment	Data average
n^p	0.267	Private sector employment	Data average
w^g/w^p	1.200	Public-private sector wage ratio	Data average
g^{cy}	0.151	Government cons-to-output ratio	Data average
g^{iy}	0.025	Government investment-to-output ratio	Data average
g^{ty}	0.220	Government transfers-to-output ratio	Data average
δ^p	0.013	Depreciation rate on private physical capital	Data average
δ^g	0.004	Depreciation rate on public physical capital	Set
τ^y	0.100	Average tax rate on income	Data average
τ^c	0.200	VAT/consumption tax rate	Data average

5 Stability of Equilibrium Dynamics

The equilibrium system is now log-linearized around its unique deterministic steady-state, and after shutting down all stochasticity, and after some simplification, it can be represented by a system of three first-order difference equations in consumption, private- and public physical capital:

$$\begin{bmatrix} \hat{c}_{t+1} \\ \hat{k}_{t+1}^p \\ \hat{k}_{t+1}^g \end{bmatrix} = M \begin{bmatrix} \hat{c}_t \\ \hat{k}_t^p \\ \hat{k}_t^g \end{bmatrix} \quad (5.1)$$

Table 2: Data Averages and Long-run Solution

Variable	Description	Data	Model
y	Steady-state output	N/A	1.000
c/y	Consumption-to-output ratio	0.648	0.674
i/y	Investment-to-output ratio	0.201	0.175
k^p/y	Private capital-to-output ratio	13.96	13.96
k^g/y	Public capital-to-output ratio	2.000	2.000
s^g/y	Public-to-private output	0.160	0.149
g^c/y	Government consumption-to-output ratio	0.130	0.130
g^i/y	Government investment-to-output ratio	0.021	0.021
g^t/y	Government transfers-to-output ratio	0.220	0.220
$w^p n^p/y$	Pvt labor income-to-output ratio	0.571	0.571
$w^g n^g/y$	Pvt labor income-to-output ratio	0.171	0.142
$r k^p/y$	Pvt capital income-to-output ratio	0.429	0.429
\bar{r}	After-tax net return on capital	0.014	0.016

where the elements of matrix M are functions of the model parameters. There are three distinct and real characteristic roots, which for Bulgaria take the following values:

$$\mu_1 = 0.45, \mu_2 = 0.96, \mu_3 = 0.98 \quad (5.2)$$

Given that the reduced-form representation of the equilibrium system features three characteristic roots that are less than unity, the model features global stability (indeterminacy or sink dynamics).⁸ The following section provides some intuition for this result.

6 Discussion

In this section we argue that the model discussed in this paper with informal sector is an isomorphic problem to a setup with increasing returns to scale and/or sector-specific externality. This is because total output in this framework is the sum of private-sector production and public-sector output. Private-sector output is produced using a Cobb-Douglas function,

⁸The results are robust to variations in model parameters.

which features constant returns to scale (CRS). In the government sector, production function also features CRS, but it is more labor intensive, so when we aggregate the two categories of output, we have increasing returns to scale (IRS). The existence of IRS in this setup is easy to justify, as a public sector is always an option, and official GDP figures try to impute the size of government output in national accounts. Also, the public sector is treated differently than the official sector, as taxes are based on public-sector wages only, and not on public capital. Thus the presence of a government sector generates externalities in production. Also, Farmer (1999) has shown that the presence of IRS can produce indeterminate equilibria, as long as the increasing returns are large enough. In this paper this is exactly the case, as the magnitude of the IR is represented by the size of the public sector relative to overall production, which in our calibration is 17%.

The other link to externalities is the two-sector modelling choice in our framework. In contrast to Benhabib and Farmer (1996), who model an economy with separate production processes for consumption and investment, in this paper consumption, investment, and government spending can be financed with proceeds from both private and public-sector production. The trade-off between producing private output and government output in our model is driven by the labor allocation decision. Even though the two technologies produce the same goods, there is a different treatment in the model between the two sectors. The other aspect of externality generated by the presence of the government sector in the model setup is that it is a non-competitive sector, as the wage rate in the public economy differs from the marginal productivity of labor in that sector; In equilibrium, the wage in the public sector will feature a time-varying mark-up over the the marginal productivity of labor. This pricing rule is obtained when we force the model to match in the steady-state the average observed wage ratio in data.

So even after shutting down aggregate uncertainty, extrinsic uncertainty (uncertainty that does not affect model primitives) may matter for equilibrium. In other words, knowledge of fundamentals in our model with government production, does not allow us to determine the equilibrium consumption path, as it will be determined by how people coordinate their expectations. For example, given certain beliefs, different allocations can be produced, even

though nothing fundamental has changed. These are also called self-fulfilling prophecies, which are at the core of the Keynesian view of business cycles. In some cases agents in the economy might be possessed by "animal spirits", either being under the influence of "irrational exuberance," or in other cases (such as the context of Bulgaria) agents in the economy might be suffering a severe form of pessimism about the future. The belief that the future will not be much better than today, which could be a trait of a conservative culture, turns out to be a powerful tool that can sustain low consumption and output in equilibrium. Indeed, if expected productivity is low, labor supply and investment will also be low, and thus the pessimistic belief will be validated, or "self-fulfilling".

A serious limitation of this theory that needs to be acknowledged, is that expectations are not directly observable, as they are not part of the primitives of the model. So there is still a lot of work to be done. One possible venue for further research could be the one pointed out in Farmer (1999): in particular, one reason for such beliefs to occur in our model could be the outcome of incomplete participation. In other words, despite the existence of complete set of markets, agents may not be allowed to transact and trade labor services in all of them, due to some frictions in the capital and labor markets. These imperfections keep the expected returns lower, and future consumption and output levels stay low. In order to achieve saddle-path stability in the economy, those rigidities in the factor markets need to be addressed first. Yet another possibility to break the multiplicity result is to attempt to support the positive expectations about the future, for example by lowering taxes and government spending, which as argued in King and Rebello (1990) and Vasilev (2016), would increase after-tax returns to the factors of production and stimulate consumption and investment.⁹ Such explorations, however, will be left for future research.

⁹Re-introducing progressive taxation in Bulgaria will not break the multiplicity result either - we experimented with the degree of progressivity featured by the progressive regime from before the introduction of proportional taxation, which is taken as the maximum degree of progressivity that the society was willing to accept). This negative result is in contrast to Guo and Lansing (1988) who argue that progressive taxation works as an automatic stabilizer.

7 Conclusions

We introduce government production of public services into an exogenous growth model augmented with a detailed government sector, and calibrate the model to Bulgarian data for the period following the introduction of the currency board arrangement (1999-2016). We show that in contrast to the case without government output, e.g., Vasilev (2009), when the economy features saddle-path stability, the presence of a second (government) sector leads to equilibrium indeterminacy in the model. The setup with government production exhibits "sink" dynamics, and equilibrium paths are determined by "animal spirits." These results are in line with the findings in the literature, e.g., Benhabib and Farmer (1994, 1996) and Farmer (1999), and have major implications for policy-making and welfare.

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