TESTING FOR TAX SMOOTHING
IN A GENERAL EQUILIBRIUM MODEL OF GROWTH

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November 22, 1999

Abstract: This paper constructs and formally tests a general equilibrium model of long-term growth and endogenous fiscal policy. In this model policymakers find it optimal to keep the income tax rate constant over time. Tax revenues finance public consumption and public production services, with the latter generating long-term growth. Surprisingly, despite its popularity amongst theorists, there have thus far been no formal econometric tests of this Barro-type general equilibrium model. We find that data from 22 OECD economies uniformly reject this model over the period 1960-1996.

Keywords: Fiscal policy and private agents, Optimal taxation, Growth.
JEL classification: H3, H21.

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* We thank Tryphon Kollintzas, Sajal Lahiri, Campbell Leith, Thomas Moutos, Lee Redding, Ron Smith and Harald Uhlig for discussions and comments. We have also benefited from comments of seminar participants at the IESG 1999 Easter Mini-Conference at the University of Warwick, and the ESEM 1999 Conference at the University of Santiago de Compostella. All errors are ours.

1. INTRODUCTION

General equilibrium models of economic growth have studied the role of fiscal policy in the growth process. The main idea of Barro [1990] is that some government-provided services work as a positive externality to private firms. For this reason, at the aggregate level, there are no diminishing returns, and hence the economy is capable of long-term (endogenous) growth. Then, if government services are financed by distortionary taxes, this raises questions regarding the optimal size of government and the associated optimal tax rate.

Within the framework of optimizing governments, one of the most popular policy results is that the income tax rate should be constant over time (see e.g. Barro [1990], Barro and Sala-i-Martin [1992, 1995], Alesina and Rodrik [1994], Benhabib and Velasco [1996] and Devereux and Wen [1998]).[1] The idea is that tax policy is distorting and therefore the optimizing fiscal authorities allocate this policy over time to minimize its negative effects. Basically, this means that the tax rate should change only if there are unanticipated shocks, i.e. the tax rate should follow a random walk independently of the state of the economy or the properties of the underlying shocks

[1] The result that the optimal tax rate is constant over time is not general. Although a survey of the literature on what model specification can give a constant tax rate is beyond the scope of this paper, we wish to say that in Barro [1990] the optimal tax rate that maximizes the utility of the representative agent is constant over time (it is equal to the productivity of public services) and there are no time-inconsistency issues (i.e. the absence of commitment is irrelevant). Benhabib and Velasco [1996] have shown that optimal tax rates under commitment are no longer constant once we use more general production functions like CES. That is, as in Chamley [1986], it is optimal to tax capital heavily in the short-run and reduce its taxation in the future. However, when Benhabib and Velasco [1996] solve for equilibria without commitment, the optimal tax rate is constant. Park and Philippopoulos [1999] have shown that once we add public consumption services in the utility function, the optimal tax rate under commitment ceases to be constant even if the production function is Cobb-Douglas as in Barro [1990]. This offers an alternative to more general functional forms for the production function. In any case, here we solve for optimal fiscal policy in the absence of commitment technologies on the part of policymakers. This is the natural thing to do since we want to empirically test the model.

(i.e. tax rates are not state-contingent). This is a form of the classic tax-smoothing result of Barro [1979].[2]

Surprisingly, despite its popularity amongst theorists, there has been no formal testing of the above Barro-type model. Therefore, the purpose of this paper is to construct, and *formally* test, a general equilibrium model of long-term growth and endogenous fiscal policy, in which policymakers find it optimal to keep the income tax rate at a constant positive rate all the time. Tax revenues are used to finance government production services (which provide production externalities to firms) and government consumption services (which provide direct utility to households).

The paper is organized as follows. In Section 2, we set up an endogenous growth model, in which a benevolent government chooses a path of distorting income taxes to finance the provision of public services. In doing so, the government acts as a Stackelberg leader *vis-à-vis* households and firms. The general equilibrium is Markov-perfect so that optimal tax policy is time consistent. We obtain a closed-form solution which consists of behavioral relations for private consumption-to-, private capital-to-, government production services-to- and government consumption services-to-output ratios.

[2] Using a partial equilibrium model, Barro [1979] showed that when government expenditures are exogenous, and if it is optimal to keep tax revenues constant over time, the public debt inherits the properties of the state of the economy. That is, the public debt smoothes out intertemporal tax distortions. In Lucas and Stokey [1983], the smoothing device is returns to bonds. In Chari *et al.* [1994], it is revenues from capital income taxes and returns to bonds (this paper also surveys the literature). In our model, it is endogenous government expenditures. That is, when the budget is balanced, and if it is optimal to keep the tax rate constant over time, government expenditures inherit the properties of the state of the economy. We therefore adopt the term “tax smoothing”, even if we do not include public debt. The important thing is whether it is optimal for policymakers to keep the tax rate constant. What is the specific device that smoothes out tax distortions over time and across states of nature is less important.

This closed-form general equilibrium solution enables us, in Section 3, to *formally* test the cross-equation restriction implied by the interaction between optimizing private agents and optimizing fiscal authorities. Our empirical testing is conducted using annual data from all OECD economies, where full data sets are available, over the period 1960-1996. We find that the data resoundingly reject the empirical validity of the model.[3] It therefore appears that the popular Barro [1990]-type general equilibrium model, in which it is optimal for policymakers to keep the tax rate constant over time so as to smooth out its distortive effects on growth, is not supported by the data. In other words, testing based on partial equilibrium models has over-favored the tax-smoothing hypothesis of policymaking. Our findings are consistent with the findings of e.g. Jones *et al.* [1993] and Chari *et al*. [1994] for the U.S.. Finally, in Section 4 we discuss our conclusions and related research.

How is our work related to the relevant literature? There are three strands. First, there is a big empirical literature that uses regression analysis to investigate how growth is affected by the structure of public expenditure (e.g. public consumption vs. public production services) and the associated public finance decisions. See, e.g. Devarajan *et al.* [1996] and Kneller *et al.* [1999] and the references cited therein. However, in this literature there is no testing of theoretical cross-equation restrictions and also the government's actions are treated as exogenous. Second, there has been a tremendous amount of empirical interest in tax smoothing in the context of partial equilibrium models. See, e.g. Serletis and Schorn [1999] and the references cited therein. However, there has been no testing of the general equilibrium renditions of

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[3] There are papers that have added more structure to the model we test here. For instance, Devereux and Wen [1998] have added electoral motives. Since we reject the basic model, it seems likely that versions of this model, that imply more cross-equation restrictions, would also be rejected.

these models, and in particular the cross-equation restrictions implied by the interaction between private agents and policymakers.[4] Third, it is well-known that RBC models have also incorporated fiscal policy. In e.g. Christiano and Eichenbaum [1992], Baxter and King [1993], McGrattan [1994] and Stokey and Rebelo [1995], policy is exogenous. In e.g. Jones *et al*. [1993], Chari *et al*. [1994] and Ambler and Paquet [1996] policy is endogenously chosen as in our paper. However, most of these models (with the notable exception of Christiano and Eichenbaum [1992]) are “tested” with the use of calibration techniques following the RBC tradition. In contrast, here we obtain closed-form analytical solutions and hence can use *formal* econometric techniques to directly test the implications of the theory.

2. THE THEORETICAL MODEL

Consider a closed economy with a private sector and a government. The private sector consists of a representative household and a representative firm. The household consumes, works and saves in the form of capital. The firm uses capital and labor to produce a single good. The government finances the provision of public services by taxing the households’ income. We assume discrete time, infinite time-horizons and certainty. The government is benevolent and acts as a Stackelberg leader *vis-à-vis* the private sector.

We solve for Markov strategies, and hence Markov-perfect general equilibria. Markov strategies depend only on the current value of the relevant state variables. In turn, Markov-perfect equilibria are sub-game perfect, and hence time consistent. This

[4] For an exception without government production services, see Malley and Philippopoulos [1999a].

is important because since taxes are distorting, optimal policy is inherently time-inconsistent.[5]

2.1 *Behavior of Households*

The representative household maximizes intertemporal utility:

$$\sum_{t=0}^{\infty} b^t u(c_t, g_t) \tag{1a}$$

where c_t and g_t are respectively private and government consumption at time t, and $0 < b < 1$ is the discount rate. The utility function is increasing and concave in its two arguments, and also satisfies the Inada conditions. For simplicity, we assume that $u(.)$ is additively separable and logarithmic. Thus,

$$u(c_t, g_t) = \log c_t + d \log g_t \tag{1b}$$

where $d \geq 0$ is the weight given to government consumption services relative to private consumption.

In each time-period t, the household rents its capital, k_t, to the firm and receives $r_t k_t$, where r_t is the gross return to capital. It also supplies inelastically one unit of labor services per unit of time and receives wage income, w_t. Further, it receives profits, p_t. Thus, the flow constraint of the household at t is:

$$k_{t+1} + c_t = (1 - q_t)(r_t k_t + w_t + p_t) \tag{2}$$

where $0 \leq q_t < 1$ is the income tax rate at t. The initial capital stock is given. Note that, for simplicity, there is full capital depreciation.

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[5] See Chamley [1986]. On the other hand, Markov-perfect equilibria exclude reputational strategies that can lead to *pareto* superior outcomes. See Benhabib and Velasco [1996].

The household acts competitively by taking prices, government services and tax policy as given. We solve this problem by using dynamic programming. From the household's viewpoint, the state at time t can be summarized by the beginning-of-period capital stock, k_t, and the current tax rate, q_t. Let $U(k_t;q_t)$ denote the value function of the household at time t.[6] This value function must satisfy the Bellman equation:

$$U(k_t;q_t) \equiv \max_{c_t,\, k_{t+1}} \left[\log c_t + d \log g_t + bU(k_{t+1};\, q_{t+1})\right] \tag{3}$$

subject to (2).

The first-order condition with respect to k_{t+1} and the envelope condition for k_t are respectively (see Stokey and Lucas [1989] and for applications Sargent [1987]):

$$\frac{1}{c_t} = bU_k(k_{t+1};q_{t+1}) \tag{4a}$$

$$U_k(k_t;q_t) = \frac{(1-q_t)r_t}{c_t}. \tag{4b}$$

2.2 Behavior of Firms

Following Barro [1990] and Barro and Sala-i-Martin [1995, p. 153], we assume that at the firm level, technology takes a Cobb-Douglas form. Thus, the production function of the representative firm at t is (written in intensive form):

$$y_t = Ah_t^{1-a} k_t^{a} \tag{5}$$

where h_t is government production services at t, $A > 0$ and $0 < a < 1$.

At any point of time, the firm maximizes profits, p_t:

$$p_t \equiv y_t - r_t k_t - w_t. \tag{6}$$

[6] Since the private agent acts competitively, he takes q_t and g_t as given.

The firm acts competitively by taking prices and government services as given. The standard first-order conditions that also imply zero profits are:

$$r_t = aAh_t^{1-a} k_t^{a-1} \tag{7a}$$

$$w_t = (1-a)Ah_t^{1-a} k_t^{a} . \tag{7b}$$

2.3 The Government Budget Constraint

Each time-period, the government runs a balanced budget by taxing the household's income at a rate $0 \le q_t < 1$.[7] Thus, since $g_t + h_t$ is total government expenditures, we have:

$$g_t + h_t = q_t\left(r_t k_t + w_t + p_t\right) . \tag{8a}$$

Without loss of generality, we assume that a share $0 \le b \le 1$ of total tax revenues is used to finance government production services h_t, and the rest $0 \le 1-b \le 1$ is used to finance government consumption services g_t.[8] Thus,

$$h_t = bq_t(r_t k_t + w_t + p_t) \tag{8b}$$

$$g_t = (1-b)q_t(r_t k_t + w_t + p_t) . \tag{8c}$$

2.4 Competitive Decentralized Equilibrium (given tax policy)

A Competitive Decentralized Equilibrium (CDE) is defined to be a sequence of allocations $\{k_{t+1}, c_t\}_{t=0}^{\infty}$, prices $\{r_t, w_t\}_{t=0}^{\infty}$ and fiscal policy $\{g_t, h_t, q_t\}_{t=0}^{\infty}$ such that: (i) households maximize utility and firms maximize profits given prices and policy; (ii)

[7] That is, there is no public debt. This is for simplicity because we want to obtain closed-form solutions. In any case, this assumption is not unusual in the relevant literature (see e.g. Barro and Sala-i-Martin [1992], Baxter and King [1993], McGrattan [1994], Ambler and Paquet [1996], Benhabib and Velasco [1996] and Devarajan *et al*. [1996]). Adding public debt would not change our main results (it would just make them "smoother", see Chari *et al*. [1994] and footnote 2 above). Also, by omitting public debt, we avoid well-known data measurement problems.

all markets clear via prices; (iii) the government budget constraint is satisfied. Note that since the share b is exogenous, only one of g_t, h_t, q_t can be independently set (see (8a)-(8c)). Here, we choose to express the CDE in terms of tax rates, $\{q_t\}_{t=0}^{\infty}$.

We start with equilibrium economy-wide output. Equations (7a), (7b) and (8b) imply:

$$y_t = r_t k_t + w_t + p_t = A^{\frac{1}{a}} (bq_t)^{\frac{1-a}{a}} k_t \tag{9}$$

so that our model is a version of Rebelo's [1991] AK model. That is, at the aggregate level, output is linear in the capital stock. Note that as in Barro [1990] and Barro and Sala-i-Martin [1995], A is here a function of fiscal policy, q_t. Hence, there is a role for the government.[9]

Using (9) into (1)-(4), Appendix A shows that, for Markov tax strategies, optimal private consumption, c_t, and the end-of-period capital stock, k_{t+1}, are:[10]

$$c_t = (1-ab) A^{\frac{1}{a}} (1-q_t)(bq_t)^{\frac{1-a}{a}} k_t \tag{10a}$$

$$k_{t+1} = abA^{\frac{1}{a}} (1-q_t)(bq_t)^{\frac{1-a}{a}} k_t \tag{10b}$$

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[8] See also Turnovsky and Fisher [1995] and Devarajan *et al*. [1996] for the exogenous decomposition of government expenditures between different types of public services.

[9] Equation (9) implies that the realized economy-wide return to capital is $\partial y_t / \partial k_t = A^{1/a} (bq_t)^{1-a/a}$. On the other hand, using (8b) and (9) into (7), the return that drives consumption/saving decisions is $r_t = aA^{1/a} (bq_t)^{1-a/a}$. Since $0 < a < 1$ and $q > 0$, $r_t < \partial y_t / \partial k_t$. That is, the open access characteristics of public production services create externalities and so the decentralized growth rate is sub-optimally low. This justifies government action.

[10] The fact that the competitive private agent's decisions are obtained as the policy solutions to a dynamic programming problem, in combination with the requirement that fiscal policy variables are Markov, makes the competitive equilibrium a recursive one. In other words, allocations and factor prices are functions of the current value of the relevant state variables. In turn, the problem of the government becomes also recursive and its strategies are Markov (see Appendix A).

which are closed-form solutions for private optimal decisions in a CDE, given Markov tax policy. As it is well-known, we obtained a closed-form solution due to logarithmic preferences, a Cobb-Douglas production function and full capital depreciation.[11]

We also present g_t and h_t in a CDE. Using (9) into (8b) and (8c), we have:

$$h_t = b(Aq_t)^{\frac{1}{a}} b^{\frac{1-a}{a}} k_t \tag{10c}$$

$$g_t = (1-b)(Aq_t)^{\frac{1}{a}} b^{\frac{1-a}{a}} k_t \, . \tag{10d}$$

In summary, equations (10a), (10b), (10c) and (10d) give respectively c_t, k_{t+1}, h_t and g_t in a CDE. This is for any feasible tax policy, q_t.

2.5 Endogenous Policy and Markov-perfect General Equilibrium

We assume that the government is benevolent and acts as a Stackelberg leader *vis-à-vis* private agents. That is, the government chooses q_t to maximize (1a)-(1b) subject to (10a)-(10d). Then, the resulting Markov strategy for q_t, in combination with (10a)-(10d), will give a Markov-perfect general equilibrium.

From the government's viewpoint, the state at time t is the predetermined economy-wide capital stock, k_t. Let $V(k_t)$ denote the value function of the government at time t. This value function must satisfy the Bellman equation:

$$V(k_t) = \max_{q_t}\left[\log c_t + d \log g_t + bV(k_{t+1})\right] \tag{11}$$

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[11] Observe that c_t and k_{t+1} increase with predetermined capital, k_t, while the effect of the current tax rate, q_t, depends on the sign of $(1-a-q_t)$. In particular, if the tax rate is relatively low, $0 < q_t < 1-a < 1$, then c_t and k_{t+1} increase with q_t. If the tax rate is relative high, $1-a < q_t < 1$, then c_t and k_{t+1} decrease with q_t. Thus, for given q_t, the effect of the income tax rate on the economy's consumption and growth is an inverse U-curve (see also Barro [1990] and Alesina and Rodrik [1994]).

where c_t, k_{t+1} and g_t follow (10a), (10b) and (10d) respectively.

Appendix B shows that the solution to (11) implies that it is optimal for the government to keep the income tax rate, q_t, or equivalently via (8a) the total government expenditures-to-output ratio $\frac{g_t + h_t}{y_t}$, constant over time. In particular, the Markov strategy of the government is:

$$0 < 1 - a < q_t = \frac{(g_t + h_t)}{y_t} = 1 - a + \frac{ad(1-b)}{(1+d)} < 1 \qquad (12)$$

which is a tax-smoothing result in a general equilibrium setup. That is, the optimal, flat tax rate is within the region $0 < 1 - a < q < 1$. Note that the tax rate is higher than $1 - a$ (which is the productivity of public production services) because the government also provides public consumption services. Also, note that since the tax rate is constant over time, and the government balances its budget in each time period, the level of endogenous government expenditures inherits the properties of the state of the economy (here, the state is the beginning-of-period capital stock, k_t). This is shown by (10c) and (10d) above.[12]

We therefore derived a closed-form solution for the optimal tax rate in a Barro-type model of long-term growth and optimal fiscal policy. Note that Barro [1990], Barro and Sala-i-Martin [1992], Benhabib and Velasco [1996] and Devereux and Wen [1998] have also derived closed-form solutions in similar setups. However, Barro [1990] and Barro and Sala-i-Martin [1992] use a highly stylised model to derive the first-best tax rate. Benhabib and Velasco [1996] study more types of equilibria than here. However, they use a small open economy model in which the return to capital is determined by the exogenous world return. Devereux and Wen [1998] use the *AK* model in which the return to capital, *A*, is a parameter. In contrast, in our model all returns are endogenously determined, and we also have both consumption and production government services. Thus, our setup is more general.

To summarize, the government's Markov strategy (12), in combination with the private agent's optimal rules, (10a) and (10b), and the government budget constraints, (10c) and (10d), give a Markov-perfect general equilibrium. In this equilibrium, it is optimal to keep the tax rate constant over time.

3. EMPIRICAL RESULTS

3.1 The econometric model

To test whether the general equilibrium model is data consistent, we use (12) into (10a)-(10d) and re-express the latter as stochastic shares of output.[13] Thus,

$$\frac{c_t}{y_t} = g_1[1-(g_3+g_4)] + m_{1t} \tag{13a}$$

$$\frac{k_{t+1}}{y_t} = g_2[1-(g_3+g_4)] + m_{2t} \tag{13b}$$

$$\frac{h_t}{y_t} = g_3 + m_{3t} \tag{13c}$$

$$\frac{g_t}{y_t} = g_4 + m_{4t} \tag{13d}$$

where $g_1 = (1-ab)$, $g_2 = ab$, $g_3 = bq$, $g_4 = (1-b)q$ and $g_3 + g_4 = q$ are constants, and m_{it} for $i = 1,2,3,4$ are stochastic error terms.[14] The single cross-equation

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[12] Also note that consumption and capital decrease with the optimal tax rate (compare this with the inverse U-curve when the tax rate is exogenous in (10a)-(10b) above).

[13] To obtain the shares we simply divide both sides of (10a)-(10d) by y_t in (9).

[14] To introduce a multiplicative stochastic shock (for instance, in the production function) in the theoretical model above is straightforward and does not change any of our results if we assume that

overidentifying restriction implied by the tax-smoothing model in general equilibrium is thus $g_1 = 1 - g_2$.

3.2 Estimation and testing

We next estimate and test the general equilibrium model (13a)-(13d), using annual data from 1961-1995 for all OECD economies where a full data set is available.[15] We use the Full Information Maximum Likelihood (FIML) estimator to obtain estimates of the model's parameters. Relative to single equation estimators, the advantages of FIML in this context are that (i) it is generally more efficient than alternatives such as GMM (ii) cross-equation restrictions can be easily implemented and tested and (iii) it allows direct estimation of an auto-regressive process for the errors to remove the serial correlation inherent in annual macroeconomic time-series relationships[16].

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agents make their decisions after the current shock is realized (see, e.g. Sargent [1987, pp. 51-55] and Stokey and Lucas [1989, p. 275]). However, when the shock enters additively (for instance, when the budget constraint in (2) is subject to an additive stochastic shock) the results change because the model is not linear-quadratic and hence certainty equivalence does not hold. For a similar problem in a linear-quadratic setup, see Lockwood *et al*. [1996, p. 904]). Nevertheless, we can show that, even when the shock enters additively, our main results do not change if we take an approximation around the deterministic version of the model. However, since this would unnecessarily complicate the theoretical model, we follow the usual practice and introduce shocks in the econometric model in an *ad hoc* fashion.

[15] Data on private final consumption, *C*, public general consumption, *G*, and gross fixed capital formation, *I*, are from individual country Annual National Accounts. The government investment data, *H* is from the OECD Business Sector database. The end-of-period capital stock, *K* is calculated for each country using a perpetual inventory and a constant 7% rate of depreciation. Note that the results reported in Table 1 do not change when alternative deprecation rates ranging from 5 to 10% are employed. Finally note that the following countries were not included due to limited data availability: Luxembourg (data from 1970), Mexico (data from 1980), Republic of Korea (data from 1970) and Turkey (data from 1973).

[16] Clearly, treating serial correlation, as a problem of specification is not relevant here since our aim is to directly test the implications of the theory. Accordingly, to ensure that all serial correlation is eliminated, we employ an *AR(2)* process for all equations in all countries. Further note that the conclusions we draw above are not altered if we employ an *AR(1)* specification.

Table 1: Parameter Estimates & Wald Tests of Overidentifying Restriction

Countries	*Estimation Period*	*Parameter Estimates & t-ratios* γ_1	γ_2	$\theta(= g_3+g_4)$	*Wald Test* $\gamma_1=(1-\gamma_2)$
Germany	1961-93	0.88 (0.84)	3.08 (9.96)	0.21 (35.17)	5.48
France	1963-95	0.75 (19.38)	2.84 (22.24)	0.19 (16.55)	298.64
Italy	1961-95	0.90 (3.47)	2.89 (12.67)	0.37 (8.96)	82.10
Netherlands	1961-95	0.74 (16.01)	2.82 (11.54)	0.15 (7.90)	84.95
Belgium	1961-95	0.78 (14.10)	2.61 (13.57)	0.16 (5.60)	104.9
United Kingdom	1963-95	0.78 (1.69)	2.54 (5.91)	0.21 (1.82)	9.69
Ireland	1961-95	0.75 (13.99)	2.45 (5.90)	0.17 (5.85)	24.70
Denmark	1961-95	0.76 (13.96)	2.91 (10.46)	0.27 (7.61)	69.10
Spain	1964-95	0.70 (11.20)	2.55 (3.00)	0.28 (3.10)	6.47
Greece	1961-95	0.74 (3.18)	2.80 (10.06)	0.13 (4.30)	26.17
Portugal	1961-93	0.56 (0.36)	2.19 (0.36)	-0.12 (-0.04)	0.82
United States	1961-95	0.77 (5.32)	2.19 (4.33)	0.14 (0.74)	9.23
Canada	1961-95	0.77 (23.89)	5.63 (0.80)	0.22 (7.45)	0.44
Japan	1961-95	0.67 (17.05)	3.74 (3.47)	0.43 (8.51)	9.49
Australia	1961-95	0.72 (18.10)	2.80 (12.58)	0.17 (4.28)	93.15
Norway	1962-95	1.00 (0.09)	5.85 (0.09)	0.48 (0.08)	0.01
New Zealand	1962-95	0.77 (35.41)	2.82 (8.15)	0.16 (21.96)	53.70
Sweden	1961-95	0.75 (17.19)	3.28 (6.81)	0.29 (7.32)	34.47
Finland	1961-95	-1.57 (-0.001)	3.76 (3.44)	0.12 (2.12)	0.98
Iceland	1961-95	0.82 (4.10)	2.76 (3.73)	0.25 (1.43)	7.61
Switzerland	1961-95	0.70 (2.74)	3.59 (6.64)	0.14 (4.52)	34.36
Austria	1961-94	0.70 (22.80)	3.24 (9.92)	0.19 (7.66)	70.81

Note: the critical value of the Wald test (which is distributed χ^2) for one degree of freedom at the 5% significance level is 3.84.

Columns 3-5 of Table 1 above provide information pertaining to both the value and significance of the estimated model parameters. Column 5 reports the Wald test of whether the single cross-equation restriction is valid. The results in Table 1 reveal that in no country are both implications of the tax-smoothing model supported by the data (i.e. that $q(=g_3+g_4)=1-a+\frac{ad(1-b)}{(1+d)}$ is significant and between zero and unity; and that the cross-equation restriction imposed by the model, $g_1=1-g_2$ holds[17]). Although at first glance, the latter restriction appears to hold in Portugal, Canada, Norway and Finland (see column 6), a closer examination of the results reveal that this

[17] Application of recursive FIML estimation by using a variable start date with a fixed end date; a variable end date with a fixed start date; and a moving fixed window of 20 observations (for the countries with enough observations) does not alter our findings in Table 1. To preserve space, these results are not presented here but can be made available on request.

is because either γ_1 and γ_2 or γ_1 or γ_2 are not significant (see columns 3 and 4). Accordingly, in these countries, we can conclude that the models are not sufficiently well determined statistically to enable us to discriminate between the null given by the cross-equation restriction and the alternative.[18]

Although the tax-smoothing result has been one of the most popular models of optimal fiscal policy, perhaps due to its clarity and algebraic convenience, our findings suggest that its empirical relevance is limited. Perhaps this finding is not surprising given the very restrictive set of assumptions required to obtain this result in a general equilibrium set-up. For instance, the model assumes fully rational and long-sighted behaviour on the part of private agents and policymakers.

4. CONCLUSIONS

In this paper we have constructed a Barro-type general equilibrium model of growth and endogenous fiscal policy in which policymakers find it optimal to keep the tax rate constant over time. Data from 22 OECD countries uniformly rejects the empirical viability of this model. In contrast to the findings from the partial equilibrium studies cited above, our results suggest that the policy recipe to keep the tax rate flat over time (so as to smooth out its intertemporal distortive effects on growth) does not hold when private agents and policymakers react to each other. These results generalise Malley and Philippopoulos [1999a] who do not incorporate government production services and hence long-term growth.

Since the tax-smoothing result relies on some rather unrealistic assumptions about the functioning of the economy, in related work we search for alternative general

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[18] Note that experimentation with all possible combinations of *AR(2)* and *AR(1)* error structures for the

equilibrium models of growth and endogenous fiscal policy, which may be more consistent with the data (see Malley and Philippopoulos [1999b]). We show that setups which allow for deviations from the assumptions of far-sighted or fully rational policymakers are less at odds with the data. Another extension would be to assume, and formally test, that policymakers are rational but they have their own political agenda (see e.g. Persson and Tabellini [1999]).

4-equations of each country's system did not produce better determined models.

5. APPENDICES

Appendix A: Proof of equations (10a)-(10b)

We conjecture that the value function in (3) is $U(k_t; q_t) = u_0 + u_1 \log k_t + u_2 q_t + u_3 \log q_t$, where u_0, u_1, u_2 and u_3 are undetermined coefficients. Then, (3) is rewritten as:

$$u_0 + u_1 \log k_t + u_2 q_t + u_3 \log q_t = \max_{k_{t+1}} \left\{ \log c_t + d \log g_t + b\left[u_0 + u_1 \log k_{t+1} + u_2 q_{t+1} + u_3 \log q_{t+1} \right] \right\}$$

where from (2) and (9) in the text, $c_t = A^{\frac{1}{a}} (1 - q_t)(b q_t)^{\frac{1-a}{a}} k_t - k_{t+1}$.

Condition (4a) in the text becomes $\frac{1}{c_t} = \frac{b u_1}{k_{t+1}}$, and condition (4b) becomes $\frac{u_1}{k_t} = \frac{(1 - q_t) a A^{\frac{1}{a}} (b q)^{\frac{1-a}{a}}}{c_t}$. These two optimality conditions combined give (10b) in the text. In turn, (10a) follows from (2) and (10b). Next, we have to verify that the conjecture is correct. Substituting (10a) and (10b) back into the Bellman, and equating coefficients, we get $u_1 = \frac{1}{1-b} > 0$, while the values of u_2 and u_3 depend on the next period tax rate, q_{t+1}. If policy were exogenous, u_2 and u_3 would depend on the properties of the process for the tax rate (see e.g. Sargent [1987]). In a general equilibrium model like the one here, where policy is endogenously chosen, the values of u_2 and u_3 cannot be determined before we solve for the optimal (Markov) tax strategy. This is what we do in Appendix B below.

Appendix B: Proof of equation (12)

We conjecture that the value function in (11) is $V(k_t) = e_0 + e_1 \log k_t$, where e_0 and e_1 are undetermined coefficients. Then, we work as in Appendix A above. That is, we use this conjecture into (11), derive the first-order condition for q_t and the envelope condition for k_t, and substitute these two optimality conditions back into the Bellman (11). This gives (12) in the text. It is then easy to verify that the conjecture for the value function is correct. In doing so, we get values for e_0 and e_1. Note that the Markov strategy (12) also completes the solution for u_2 and u_3 in Appendix A above. This completes the general (Markov-perfect) equilibrium solution.

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