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Econ 0107 – Macroeconomics I – Franck Portier

Problem set 3: Ricardian Equivalence
Chapter 10 in Ljungqvist & Sargent 4th edition
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1 Problem 1

Consider an economy that lasts for 2 periods $t = 1, 2$. The economy is populated by a mass 1 of households, all equal, with preferences

$$U(c_1, c_2) = \log(c_1) + \beta \log(c_2),$$

where $\beta < 1$ is the discount factor, (c_1, c_2) is consumption in the two periods. Households are endowed with income (y_1, y_2) and can save/borrow an amount s between time 1 and 2 at the interest rate r. They face taxes on capital income τ_2 in the second period but they do not pay any tax in the first period. Thus, the households' budget constraints in the two periods are

$$c_1 + s = y_1,$$
$$c_2 = s(1 + r(1 - \tau_2)) + y_2.$$

The government has expenditures (g_1, g_2) in the two periods, financed with capital income taxes τ_2 in the second period and debt b in the first period. At the end of the two periods, the government has to pay back its debt, gross of interests, only through taxes.

1. Write the first and second period budget constraint for the government and the intertemporal budget constraint for the government (i.e. the budget constraint at time $t = 1$ for both periods, where the future income and expenditures are discounted at rate r).

2. Solve the problem of the household and derive the first-order conditions for consumption (c_1, c_2) in both periods. Use these conditions to derive the Euler equation. Does the Euler Equation depend on taxes τ_2?

3. State the meaning of Ricardian Neutrality in this economy.

4. Does Ricardian Neutrality hold in this economy? Explain your answer, possibly proving your result.

2 Problem 2

Consider an economy that lasts for 2 periods $t = 1, 2$. The economy is populated by a mass 1 of households, all equal, with preferences

$$U(c_1, \ell_1, c_2, \ell_2) = \log(c_1) + \phi \log(1 - \ell_1) + \beta \log(c_2) + \beta\phi \log(1 - \ell_2)$$

where $\beta < 1$ is the discount factor, (c_1, c_2) is consumption, and (ℓ_1, ℓ_2) is labor supply. Households can save/borrow an amount a between time 1 and 2 at the interest rate r. The remuneration of their labor services at time $t = 1, 2$ is (w_1, w_2), but they face a labor income tax in both periods (τ_1, τ_2). Thus, the households' budget constraints in the two periods are

$$c_1 + a = w_1 \ell_1 (1 - \tau_1),$$
$$c_2 = a(1 + r) + w_2 \ell_2 (1 - \tau_2).$$

Production in period t takes place through a constant returns to scale technology that only uses labor as an input, i.e.

$$y_t = A \ell_t.$$

The government has expenditures (g_1, g_2) in the two periods, financed with labor income taxes (τ_1, τ_2) and debt b in the first period. At the end of the two periods, the government has to pay back its debt, gross of interests, only through taxes. Its budget constraints in the two periods is therefore

$$g_1 = w_1 \ell_1 \tau_1$$
$$g_2 + (1 + r) b = w_2 \ell_2 \tau_2.$$

1. Write the intertemporal budget constraint for households and government (i.e. the budget constraint at time $t = 1$ for both periods, where the future income and expenditures are discounted at rate r).
2. Solve the problem of the household and derive the first-order conditions (FOC) for labor (ℓ_1, ℓ_2) and consumption (c_1, c_2) in both periods. Use these conditions to derive the Euler equation. Does the Euler Equation depend on taxes? Does the FOC for labor depend on taxes?
3. Define formally a competitive equilibrium for this economy.
4. State the meaning of Ricardian Neutrality in this economy. Does Ricardian Neutrality holds in this economy? Explain your answer, possibly proving your result.

3 Problem 3

Consider an economy that lasts for two periods $t = 1, 2$. The economy is populated by two types of individuals, S and L who are both born in period $t = 1$. The (short-lived) individuals of type S live only for the first period. The (long-lived) individuals of type L live for both periods. There is a fraction ϕ of types S and a fraction $(1 - \phi)$ of types L. Type S has preferences

$$u(c_1) = \log c_1$$

and has an endowment of income y. Type L has preferences

$$u(c_1, c_2) = \log c_1 + \log c_2$$

and endowments of income y in each of the two periods. The interest rate is fixed at r.

The government implements a social security system as follows. In period 1, it taxes all (young) households (S and L) at rate τ, stores the revenues in a bank and then, in period two, it pays back the capitalized tax revenues equal to $(1+r)\tau y$ to all the old households alive in that period in a lump-sum fashion.

1. Write down the intertemporal government budget constraint.
2. Assume that $\phi = 0$. Solve the household problem and determine consumption allocations (c_1, c_2) for type L only as a function of (r, y, τ). Define Ricardian Equivalence. Does Ricardian Equivalence hold in this case?
3. Now assume that $\phi > 0$. Solve the household problem for both types of individuals. Compute aggregate consumption in both periods. Does it depend on τ? What is the implication of this result for Ricardian Equivalence in the case $\phi > 0$? Explain your result.

4 Text reading: 'Replicating Ricardian Equivalence Tests with Simulated Series", Emanuela Cardia, The American Economic Review, Vol. 87, No. 1 (Mar., 1997), pp. 65-79

1. Read the above paper of Emanuela Cardia (don't check the math) and write a one page summary.
2. What are the main features of the model?
3. What are the four configurations of the model Cardia is looking at?
4. How is the test of Ricardian equivalence on simulated data conducted?
5. Describe the results obtained.

Replicating Ricardian Equivalence Tests with Simulated Series

By EMANUELA CARDIA *

This paper replicates standard consumption function tests of Ricardian equivalence using series generated from a model which nests Ricardian equivalence within a non-Ricardian alternative (due to finite horizons and/or distortionary taxation). I show that the estimates of the effects of taxation on consumption are not robust and that standard tests may have weaknesses which can lead to conflicting results, whether Ricardian equivalence holds or not. The simulations also show that no clear conclusions about Ricardian equivalence can be drawn from observing a low correlation between the current account and government budget deficits. (*JEL* E62)

Consumption function tests designed to capture the effects of government debt and taxation on private consumption occupy a large segment of the empirical literature on Ricardian equivalence[1] and have yielded conflicting results. For example, Ricardian equivalence could not be rejected by Roger C. Kormendi (1983) and Kormendi and Philip Meguire (1986, 1990, 1995), but it could be rejected by Martin Feldstein (1982), Franco Modigliani and Arlie Sterling (1986, 1990), Feldstein and Douglas W. Elmendorf (1990), and Fred C. Graham (1995).[2] Using simulated series I show that these tests produce estimates of the effects of taxation and government debt on consumption that are not robust. These results suggest that standard tests might not be capable of providing conclusive evidence about Ricardian equivalence, whether Ricardian equivalence is true or not.

The Blanchard-Yaari finite horizon model[3] is used to nest the Ricardian equivalence hypothesis within the non-Ricardian alternative. Deviations from Ricardian equivalence are due to the finiteness of households' horizons and to distortionary labor income taxation. Strictly convex adjustment costs in investment are assumed and different sources of fluctuations are considered: changes in the labor tax rate, in fiscal spending, and in productivity. This allows the relative importance of debt non-neutralities to be examined and a more "realistic" environment for the tests to be created.

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[1] See Robert J. Barro (1974, 1989). He argues that the way in which government spending is financed has no important effects on the economy.

[2] Mixed results are obtained in James R. Barth et al. (1986) and in Alfred A. Haug (1990). James M. Poterba and Lawrence H. Summers (1987) and Paul Evans (1988) examine the effects of a change in taxation that took place in the United States in 1981. While Poterba and Summers reject Ricardian equivalence, Evans cannot reject it. Evans (1988, 1990), Evans and Iftekhar Hasan (1994), and Leonardo Leiderman and Assaf Razin (1988) test whether the finiteness of horizons leads to the rejection of Ricardian neutrality. None can reject the null hypothesis. Evans (1993) extends his study to include 19 countries and rejects Ricardian equivalence. Other studies have looked at the effects of budget deficits on interest rates (for example, see Charles I. Plosser, 1982; Evans, 1987a, 1987b) and on current accounts (see Evans, 1990) and found them to be nonsignificant. See Douglas B. Bernheim (1987) and John J. Seater (1993) for complete literature surveys.

[3] Olivier J. Blanchard's (1985a) model builds upon that of Menahem E. Yaari (1965).

The model is simulated and the generated series for consumption, wealth, government spending, government debt, and tax revenues are used to estimate consumption equations similar to the ones estimated in the empirical literature to test Ricardian equivalence. The estimates obtained from the simulated series are remarkably close to the ones obtained using actual data; however, estimates of the coefficients on the tax and the government debt variables are not robust and, moreover, are often misleading. For example, although distortionary taxation has important effects on consumption, it is difficult to reject Ricardian equivalence. With finite horizons, changes in lump-sum taxation do not have important effects on consumption, but Ricardian equivalence is easier to reject. In addition, the simulations reveal that the lack of a systematic relation between current account and budget deficits is consistent with both Ricardian equivalence and the non-Ricardian alternative and does not by itself provide evidence in favor of the Ricardian equivalence hypothesis (for example, see Barro, 1989; Seater, 1993).

The remainder of the paper is organized as follows. In Section I, the model is presented. In Section II, the parameter values used in the simulations are presented. The results are discussed in Section III and, in the last section, conclusions are drawn.

I. The Economy

I consider a small open economy that produces one homogeneous, tradeable good within a setting of perfectly integrated international financial capital markets. The domestic real interest rate is pegged to the world real interest rate, which is exogenous. There is no aggregate uncertainty in the rest of the world and there are no common shocks to technology. All shocks are domestic shocks. These assumptions imply a constant real interest rate. It is also assumed that domestic households cannot buy foreign assets that have a payoff contingent on the realization of domestic shocks. With complete asset markets and no aggregate uncertainty in the rest of the world, domestic households can use asset markets to insure away any country-specific risk.

A. *Investment*

The representative firm maximizes the expected present value of profits:

$$(1)\quad V_t = E_t\left\{ \sum_{j=0}^{\infty} (1+r)^{-j} \times \left[Y_{t+j} - s_{t+j}N_{t+j} - \psi\frac{(K_{t+j} - K_{t+j-1})^2}{2K_{t+j}} - I_{t+j}\right]\right\}$$

subject to:

$$(2)\quad I_t = K_t - K_{t-1} + \delta K_t,$$

with K_{t-1} given. Here, r is the real interest rate, Y_t is output, I_t is gross investment, ψ is the cost-of-adjustment parameter, K_t is the capital stock, δ is a constant rate of depreciation, N_t is the labor input, and s_t is the real wage rate. E_t is the expectations operator conditional on information available at time t. Equation (2) implies that an investment in period t becomes a capacity increase in period t (this assumption is made to simplify the algebra). A Cobb-Douglas production function is assumed:

$$Y_t = \exp(a_t)K_t^{\phi}N_t^{(1-\phi)},$$

where a_t is a technology parameter. The first-order conditions are:

$$(3)\quad Y_{N,t} = s_t,$$

$$(4)\quad K_t - K_{t-1} = \frac{K_t}{\psi}(q_t - 1),$$

$$(5)\quad E_t q_{t+1} = (1+r)\left[q_t - \left(Y_{K,t} + \frac{\psi}{2}\left(\frac{K_t - K_{t-1}}{K_t}\right)^2 - \delta\right)\right],$$

where q_t is the Lagrangian multiplier associated with the constraint (2) (also known as "Tobin's q"), and $Y_{N,t}$ and $Y_{K,t}$ are the partial derivatives of output with respect to labor and capital, respectively.

B. *Households*

Individuals face a constant probability, γ, of surviving from one period to the next.[4] This probability is the same for all households and is independent of age. In this setting, the probability that an individual survives at least j periods is γ^j; that he survives exactly j periods is $\gamma^j(1-\gamma)$. His expected lifetime at birth is $(1-\gamma)\sum_{j=0}^{\infty} j\gamma^j = \gamma/(1-\gamma)$. The infinite horizon case is the limiting case as γ goes to 1. I normalize the size of the population to one by assuming that $(1-\gamma)$ individuals are born in each period. Let $c_{i,t+j}$ be expenditure on the consumption good in period $t+j$ of an individual whose age is i at time t. This individual maximizes his expected lifetime utility:

$$(6) \quad U_{i,t} = \sum_{j=0}^{\infty} \gamma^j \beta^j E_t[\ln(c_{i,t+j}) + \vartheta \ln(L_{i,t+j})]$$

subject to the constraints:

$$(7) \quad w_{i,t+1} = \frac{1+r}{\gamma}[w_{i,t} + s_t N_{i,t}(1-\tau_t) - c_{i,t} - T_t],$$

and

$$(8) \quad L_{it} + N_{it} = 1,$$

where β is the subjective discount factor, $L_{i,t}$ and $N_{i,t}$ are the fraction of time, at time t, that an individual of age i allocates to leisure and work activities, respectively. The total time endowment is normalized to 1. $w_{i,t}$ is financial wealth in period t of an individual of age i; ϑ is the weight given to leisure in the utility function. T_t denotes lump-sum taxation and τ_t is the labor income tax rate, both of which are age independent. s_t is the real wage which households take as given and is age independent. $\gamma\beta$ is the effective discount factor: the shorter the life horizon, the more impatient households are. $(1+r)/\gamma$ is the effective interest rate that households receive (pay) on their loans (debts). Evans (1993) interprets the presence of γ as the result of an actuarially fair bet. At the end of each period a household bets its entire wealth. If the household is still alive in the next period, it receives $1/\gamma$ times its wealth. If the household dies, it loses its entire wealth. This is transferred to a competitive life insurance company which guarantees to pay all outstanding debts.

The first-order conditions of the consumer's problem are:

$$(9) \quad \frac{1}{c_{i,t}} = \beta(1+r)E_t\left(\frac{1}{c_{i,t+1}}\right),$$

$$(10) \quad N_{i,t} = 1 - \vartheta \frac{c_{i,t}}{s_t(1-\tau_t)},$$

which is the household's labor supply function. Applying a first-order Taylor expansion, condition (9) may be written to the first order as:

$$(9') \quad E_t c_{i,t+1} = \beta(1+r)c_{i,t}.$$

Using (9′) consumption can be derived as a function of human and financial wealth:

$$(11) \quad c_{i,t} = (1-\beta\gamma)(w_{i,t} + h_{i,t}),$$

where $h_{i,t}$ is human wealth at time t of an individual whose age is i at that time:

$$(12) \quad h_{i,t} = \sum_{j=0}^{\infty} (1+r)^{-j}\gamma^j \times E_t[s_{t+j}N_{i,t+j}(1-\tau_{t+j}) - T_{t+j}].$$

[4] A stochastic discrete-time version of Blanchard's model that is similar to the one employed here is developed in Jacob A. Frenkel and Razin (1992) and Evans (1993). In Evans (1993), the probability of dying is interpreted as being a measure of how much living households feel disconnected from future generations.

C. *Aggregation*

Aggregate human wealth is the sum of the human wealth of cohorts of different ages:

$$(13)\quad h_t = (1-\gamma)\sum_{i=0}^{\infty}\gamma^i h_{i,t} = (1-\gamma) \times \Big\{ s_t N_{o,t}(1-\tau_t) - T_t + \frac{\gamma}{1+r} \times E_t[s_{t+1}N_{o,t+1}(1-\tau_{t+1}) - T_{t+1}] + \cdots \Big\} + (1-\gamma)\gamma\Big\{ s_t N_{1,t}(1-\tau_t) - T_t + \frac{\gamma}{1+r} \times E_t[s_{t+1}N_{1,t+1}(1-\tau_{t+1}) - T_{t+1}] + \cdots \Big\} + \cdots .$$

Equation (10) can be used to replace the age-dependent component of labor income with consumption. By using the first-order condition for consumption (9′), repeatedly, the following is derived:

$$h_t = s_t(1-\tau_t) - T_t + \frac{\gamma}{1+r}E_t[s_{t+1}(1-\tau_{t+1}) - T_{t+1}] + \cdots - \frac{\vartheta}{1-\beta\gamma}c_t,$$

where c_t is aggregate consumption. Using (10) and rearranging:

$$(14)\quad E_t h_{t+1} = \frac{(1+r)}{\gamma}[h_t - s_t N_t(1-\tau_t) + T_t] - \frac{\vartheta}{1-\beta\gamma}(E_t c_{t+1} - \beta(1+r)c_t).$$

It can easily be shown that financial wealth evolves independently of γ:

$$(15)\quad w_{t+1} = (1+r)[w_t + s_t N_t(1-\tau_t) - c_t - T_t].$$

Aggregate consumption as a function of aggregate wealth [see equation (11)] is simply:

$$(16)\quad c_t = (1-\beta\gamma)(w_t + h_t).$$

Applying (16), $E_t c_{t+1} - ((1+r)/\gamma)c_t$ may be expressed as:

$$(17)\quad E_t c_{t+1} - \frac{1+r}{\gamma}c_t = (1-\gamma\beta)\left(E_t w_{t+1} - \frac{1+r}{\gamma}w_t + E_t h_{t+1} - \frac{1+r}{\gamma}h_t\right).$$

Using equations (14) and (15) and rearranging the terms, the following is obtained:

$$(18)\quad E_t c_{t+1} = \beta(1+r)c_t - \frac{(1-\gamma\beta)(1-\gamma)}{(1+\vartheta)\gamma}E_t w_{t+1}.$$

With $\vartheta = 0$ this equation is the discrete-time equivalent of the one derived in Blanchard (1985a), where labor supply is fixed.

D. *Government*

The government has to satisfy the following constraint:

$$(19)\quad b_{t+1} = (1+r)[b_t - s_t N_t \tau_t - T_t + G_t],$$

where G_t denotes government purchases at time t, b_t is the government's debt at time t, and:

$$(20)\quad T_t = \frac{\eta}{(1+r)}b_t + \bar{T}.$$

To rule out the possibility that the government takes part in Ponzi games, I assume that $\eta \geq r$ (e.g., see Blanchard, 1985a). In this case, as the government debt increases, taxation increases and $b_{t+1} - b_t$ decreases. $\bar{T}$ is a constant level of lump-sum taxation.

E. *The Macromodel*

Households hold wealth (w) in the form of government bonds (b), shares in domestic firms (V), and net foreign assets owned by domestic households (f):

$$(21)\quad w_t = b_t + f_t + V_t \equiv b_t + f_t + q_t K_{t-1}.$$

It can easily be shown that the last equality holds for linearly homogeneous production and cost functions (these are the same conditions for marginal and average q to coincide in a continuous time model, as in Fumio Hayashi, 1982). The current account equation is:

$$(22)\quad f_{t+1} = (1+r)\left[f_t + Y_t - c_t - G_t - \psi\frac{(K_t - K_{t-1})^2}{2K_t} - I_t\right].$$

The investment equations (4) and (5), the consumption equation (18), the government budget constraint (19), and the current account equation (22) constitute the equations of the model that I calibrate and simulate. By forwarding equation (21) and taking its expected value, $E_t w_{t+1}$ can be eliminated from the consumption equation. N_t and s_t can be eliminated using equations (10) and (3), respectively. This leaves five dynamic equations and five endogenous variables $\{K_{t-1}, q_t, c_t, b_t, f_t\}$. All the equations of the model are linearized by taking a first-order Taylor's expansion around the deterministic steady state (see also King et al., 1988). The model is simulated using the forward-backward method for rational expectations models described in Blanchard and Charles M. Kahn (1980). There are three predetermined variables $\{K_{t-1}, b_t, f_t\}$, which are associated with an initial condition, and two variables that are free. These are the two forward-looking variables $\{c_t, q_t\}$. For a (regular) saddle-point equilibrium, three stable roots and two unstable ones are needed. For all the parameter values considered, this condition was upheld. I assume that the forcing variables, $\{\tau_t, G_t, a_t\}$, follow a first-order autoregressive process with normal independently and identically distributed disturbances. The linearized version of the model can be written in the following form (see Blanchard, 1985b pp. 217–18):

$$(23)\quad \mathbf{Z}_t = \mathbf{\Omega}\mathbf{Z}_{t-1} + \boldsymbol{\nu}_t,$$

$$(24)\quad \mathbf{x}_t = \mathbf{A}_{11}\mathbf{x}_{t-1} + \mathbf{A}_{12}\mathbf{p}_{t-1} + \mathbf{B}_1\mathbf{Z}_{t-1},$$

$$(25)\quad \mathbf{p}_t = \mathbf{F}_1\mathbf{x}_t + \mathbf{F}_2\mathbf{Z}_t,$$

where: $\mathbf{Z}_t = \{\hat{\tau}_t, \hat{G}_t, \hat{a}_t\}'$, $\mathbf{x}_t = \{\hat{K}_{t-1}, \hat{b}_t, \hat{f}_t\}'$, $\mathbf{p}_t = \{\hat{c}_t, \hat{q}_t\}'$, the circumflex accent,^, on a variable denotes deviations from its steady state, and $\hat{G}_t$ denotes proportional deviations of fiscal spending from its steady state.

II. Model Parameterization and Simulation

The parameter values used for the numerical simulations are described in Table 1. As in Edward C. Prescott (1986), I use an annual depreciation rate of 10 percent, a labor share, $1 - \phi$, equal to 0.64, and an annual real interest rate of 4 percent. The cost-of-adjustment parameter was set equal to 0.5 to reproduce the observed volatility in the investment series. η describes how quickly a higher government debt will bring higher taxes (see equation (20)) and is set equal to 0.08. The sensitivity of the results to this parameter value is discussed in the next section.

Four different cases are considered.[5] *In case 1,* Ricardian equivalence holds. Labor supply is fixed so that taxation of labor income does not affect resource allocation and acts as a lump-sum tax. An infinite horizon is approximated by setting γ close to one and $(1 - \beta)/\beta$ close to the real interest rate (see Table 1).

[5] The results do not depend on the particular parameter values that were chosen.

TABLE 1—PARAMETER VALUES

Model parameter values	
Capital share, ϕ	0.36
Investment adjustment cost, ψ	0.50
Real interest rate, r	0.04
No Ponzi game condition, η	0.08
Steady-state value of the labor tax rate, τ	0.23
Depreciation rate, δ	0.10

	Case-specific parameters			
	Case 1	Case 2	Case 3	Case 4
Probability of survival, γ	0.999992	0.999992	0.986	0.986
Weight on leisure in the utility function, ϑ	0	2.10920	0	2.10821
Subjective discount factor, β	0.96154012	0.9615390	0.9652	0.9628

Stochastic processes

$$\mathbf{Z}_{t+1} = \boldsymbol{\Omega}\mathbf{Z}_t + \boldsymbol{\nu}_{t+1} \text{ where } E\boldsymbol{\nu}\boldsymbol{\nu}' = \boldsymbol{\Sigma} \text{ and } \mathbf{Z}_t = \{\hat{\tau}_t, \hat{G}_t, \hat{a}_t\}'$$

$$\boldsymbol{\Omega} = \begin{bmatrix} 0.95 & 0 & 0 \\ 0 & 0.95 & 0 \\ 0 & 0 & 0.95 \end{bmatrix} \qquad \boldsymbol{\Sigma} = \begin{bmatrix} 0.00695^2 & 0 & 0 \\ 0 & 0.01159^2 & 0 \\ 0 & 0 & 0.00763^2 \end{bmatrix}$$

In case 2, Ricardian equivalence fails because of distortionary taxation. Here the horizon of agents is infinite and labor supply is endogenous. The subjective discount factor has been set so that the weight on leisure in the utility function, ϑ, is as in Prescott (1986) close to 2 (see Table 1). *In case 3,* Ricardian equivalence fails because of finite horizons. Labor supply is fixed and $\gamma = 0.986$ (this implies a life expectancy at birth of roughly 70 years). *In case 4,* Ricardian equivalence fails for two reasons: horizons are finite and taxation is distortionary. With $\gamma = 0.986$ and $\beta = 0.9628$, the weight on leisure in the utility function is again close to 2.

Table 2 describes the implied steady-state values of the different variables. The initial value of fiscal spending is 20 percent of national income. The constant component of taxes ($\bar{T}$) is set so that government debt is 35 percent of output. The results are not sensitive to these assumptions. For the tax rate on labor income, the series on the effective marginal tax rate on labor income derived in Douglas H. Joines (1981) and extended by Ellen R. McGrattan (1994) was used. Using this series, the average effective labor income tax rate between 1956 and 1987 is calculated to be approximately 0.23 (in the steady state I set $\tau = 0.23$) and the standard deviation of shocks to the labor tax rate 0.00695. The standard deviation of shocks affecting the logarithmic transformation of fiscal spending is estimated to be 0.01159.[6] Following Prescott (1986), the standard deviation for the productivity shocks is set equal to 0.00763. Changes in taxes, fiscal spending, and productivity are assumed to be highly persistent.

Using these parameter values and the theoretical model described in the previous section, one can examine whether distortionary taxation and finite horizons have important effects on consumption. It could very well be that these effects are small and that Ricardian equivalence holds as a close approximation.

[6] I estimated a first-order autoregressive process [AR(1)] for the logarithmic transformation of government spending deflated by the consumer price index, using data between 1956 and 1987 from the International Financial Statistics (IFS) CD-ROM files (September 1993).

TABLE 2—STEADY-STATE VALUES

	Case 1	Case 2	Case 3	Case 4
Output, Y	1.712	0.514	1.712	0.514
Consumption, c/Y	0.544	0.545	0.542	0.545
Capital, K/Y	2.6	2.6	2.6	2.6
Wealth, w/Y	3.048	3.084	3.011	3.091
Net foreign assets, f/Y	0.098	0.134	0.061	0.141
Government bonds, b/Y	0.35	0.35	0.35	0.35
Hours worked, N	1.0	0.3	1.0	0.3
Tax revenues, $(T + \tau Y_N N)/Y$	0.213	0.213	0.213	0.213
Fiscal spending, G/Y	0.20	0.20	0.20	0.20

TABLE 3—FRACTION OF THE VARIANCE OF CONSUMPTION DUE TO INNOVATIONS IN THE LABOR TAX RATE

	Case 1	Case 2	Case 3	Case 4
One-step-ahead variance	0	0.2176	0.0082	0.2406
Unconditional variance	0	0.2175	0.0274	0.2000

To examine this issue, the fraction of the forecast error variance of consumption that is explained by innovations in the labor tax rate, technological changes, and government consumption may be calculated. In Table 3 I report the fraction of both the one-step-ahead and the unconditional variance of consumption that is due to innovations to the labor tax rate. With distortionary taxation (case 2), 21.75 percent of the unconditional variance of consumption is due to innovations in the labor tax rate.[7] The one-step-ahead contribution is of similar magnitude. With finite horizons (case 3), changes in the labor tax rate explain 2.74 percent of the unconditional variance of consumption. The one-step-ahead contribution to the forecast error variance of consumption is close to zero.[8] While distortionary taxation has important effects on consumption, finite horizons have fairly small effects. In the following section, I analyze whether these differences can be captured by applying standard consumption function tests on Ricardian equivalence to the simulated series.

III. Results

The model described in Section I is simulated and some of the generated series are used to estimate consumption functions that are similar to those estimated by Feldstein (1982), Kormendi (1983), Kormendi and Meguire (1986, 1990, 1995), Modigliani and Sterling (1986), Barth et al. (1986), Feldstein and Elmendorf (1990), and Graham (1995).[9] The regressors used in the consumption equation are those usually included in these studies: current income, lagged income, wealth net of government debt, government consumption, tax revenue, and government debt.[10] Each simulation is for a sample of 45 periods, which is roughly the average sample size used in the empirical tests.[11] Shocks to productivity, fiscal spending,

[7] I also found that innovations in the labor tax rate explain 21.7 percent of the unconditional variance of output (the contribution to the one-step-ahead variance is of similar magnitude). In McGrattan (1994), 28 percent of the forecast variance of consumption and 27 percent of the forecast variance of output are explained by innovations in the labor tax rate. She uses simulated series and a Cholesky decomposition.

[8] With smaller values of η, the contribution of taxation increases. With $\eta = 0.07$, for example, taxation explains 4.622 percent of the unconditional variance of consumption and 1 percent of the one-step-ahead forecast variance of consumption.

[9] Simulations in this paper reproduce the standard stylized facts reported in King et al. (1988), Mary G. Finn (1990), Enrique G. Mendoza (1991), Cardia (1991), David K. Backus et al. (1992), and Marianne Baxter and Mario J. Crucini (1993). Jeremy Greenwood and Gregory W. Huffman (1991) and McGrattan (1994) use a real-business-cycle model to assess the impact of distortionary taxation on the economy.

[10] I choose the same dynamic structure (all current variables except for the lagged value of income) and a subset of the regressors used in this literature. Other regressors often included are government transfers and interest payments on the government debt. The first variable cannot be generated by the model. The second one would be colinear to government debt because the real interest rate is constant in the model.

[11] In some of their estimations, Kormendi (1983) and Kormendi and Meguire (1986, 1990, 1995) include the war years. This makes their sample 50 to 60 years long. My results do not change when I consider a longer sample.

and the labor tax rate make the economy deviate from the steady state.

Three different specifications of the consumption function are estimated depending on whether tax revenue and/or the government debt variables are included. The equations are estimated in two ways: using a Cochrane-Orcutt autoregressive transformation and using first differences as is standard in the literature.[12] The null hypothesis is that the coefficients on the tax revenue variable and/or government debt are not significantly different from zero. Under the null hypothesis, households discount future taxation and a redistribution of taxation over time does not affect consumption. The results are described in Tables 4–7. I report the mean values of the ordinary least squares (OLS) estimates from 1,000 replications and of the associated *t*-statistics, as well as the number of times in which the results are consistent with Ricardian equivalence (i.e., when the null hypothesis at the 5-percent significance level cannot be rejected). I also report the number of times in which Ricardian equivalence is rejected *and* the signs of the coefficients are consistent with the view that taxes decrease consumption or that government debt is net wealth to households. In this case, an increase in government debt to increase consumption is expected. Box-Pierce statistics using the first 12 residual autocorrelations were computed and the mean and median values of their marginal significance levels are reported in the last two lines of Tables 4–7.

Table 4 reports the results of the OLS estimations when Ricardian equivalence holds (case 1). The parameter estimates of the tax revenue and government debt parameters are not robust, although they are fairly small. The mean value estimate of the parameter on the tax revenue variable in equation (1) is 0.001 (see the first column of Table 4); its standard deviation over 1,000 replications is 0.013. The minimum value is −0.041 and the maximum value is 0.054 (not reported in the table). The mean value estimate of the parameter on the government debt variable in equation (2) is also close to zero (see the second column of Table 4). In about 21 percent of the experiments the results are consistent with the non-Ricardian alternative, and in about 62 percent of the experiments the results are consistent with the Ricardian equivalence hypothesis. In the remaining cases the coefficient estimates are significantly different from zero, but have a sign inconsistent with any of the considered hypotheses. When the data are differenced and the government debt variable is excluded, the null hypothesis cannot be rejected 94.4 percent of the time.

Table 5 describes the OLS estimates obtained when distortionary taxation and infinite horizons (case 2) are assumed. Again, the estimates of the coefficients on tax revenue and government debt are not robust. The results suggest that taxation has small effects on consumption. The mean value of the parameter on the tax revenue variable in the first equation estimated is −0.001. The standard deviation over 1,000 replications is 0.0325, the minimum value is −0.11, and the maximum value is 0.11 (not reported in the table). Ricardian equivalence cannot be rejected in 73.1 percent of the cases when equation (1) is estimated, in 33.8 percent of the cases when equation (2) is estimated, and in 42.2 percent of the cases when equation (3) is estimated. Excluding shocks to fiscal spending from the simulations does not change the results. When changes in the labor taxes only are included (i.e., both fiscal spending and productivity are kept constant), Ricardian equivalence is always rejected and the estimates are robust and consistent with the non-Ricardian view (the mean value of the tax revenue parameter estimate is −0.22).

Table 6 describes the results from the OLS regressions assuming finite horizons and nondistortionary taxation (case 3). In most cases, Ricardian equivalence is rejected. Similar results are obtained when households are required to be more connected to future generations and life expectancy is set to be twice as long (about 140 years). When the parameter η was decreased, the results were very similar.

[12] Both types of transformations are used in the empirical literature. Although the simulated series are stationary and there is no need to difference, I do this to impose on the simulated data the same transformation that empirical tests impose on the actual data (for example, see Kormendi, 1983; Kormendi and Meguire, 1986, 1990, 1995). Estimating the equations in levels yields results that are similar to the ones obtained with a Cochrane-Orcutt transformation.

TABLE 4—OLS ESTIMATES OF CONSUMPTION EQUATION[a] (CASE 1, RICARDIAN EQUIVALENCE)

Equation c_t	(1) C-O	(2) C-O	(3) C-O	(4) FD	(5) FD	(6) FD
const	0.199	0.205	0.193	0.00	0.00	0.00
	(41.91)	(36.96)	(37.77)	(0.00)	(0.00)	(0.00)
Y_t	0.355	0.358	0.357	0.363	0.364	0.364
	(85.07)	(89.59)	(93.52)	(108.3)	(108.6)	(112.5)
Y_{t-1}	−0.040	−0.037	−0.037	−0.028	−0.027	−0.027
	(−9.53)	(−9.31)	(−9.44)	(−9.39)	(−9.26)	(−9.39)
w_t^b	0.035	0.034	0.035	0.028	0.028	0.028
	(43.38)	(31.99)	(33.70)	(8.49)	(7.17)	(7.32)
G_t	−0.442	−0.442	−0.442	−0.441	−0.440	−0.440
	(−30.88)	(−31.55)	(−31.87)	(−39.16)	(−40.25)	(−40.64)
TR_t	0.001	−0.001		0.00	−0.001	
	(0.16)	(−0.09)		(0.04)	(−0.09)	
b_t		0.001	0.001		0.001	0.001
		(0.66)	(0.67)		(0.38)	(0.37)
Consistent with Ricardian equiv.[b]	73.4%	35.0%	46.1%	94.4%	60.5%	63.8%
Consistent with non-Ricardian view[c]	10.9%	35.9%	32.6%	1.8%	24.2%	22.9%
Q	0.167	0.153	0.121	0.086	0.104	0.100
	0.073	0.053	0.030	0.037	0.039	0.036

[a] t-statistics in parentheses. All statistics are the averages over 1,000 replications. c = consumption, Y = output, w^b = financial wealth net of government bonds, G = government spending, TR = tax revenue, b = government bonds. The results described in columns 1–3 have been obtained by estimating the equations using a Cochrane-Orcutt autoregressive transformation. For the results in columns 4, 5, and 6, the estimations used data in first differences. The mean value of the estimated first-order serial correlation coefficient is 0.474 for the first equation, 0.452 for the second, and 0.485 for the third. Q is the Box-Pierce statistics computed from the first 12 residual autocorrelations. I report the mean and the median (second line) marginal significance levels.

[b] Percentage of cases Ricardian equivalence cannot be rejected at a 5-percent significance level.

[c] Percentage of cases I reject Ricardian equivalence at a 5-percent significance level because the coefficient on TR is negative (when significant) and/or the coefficient on b is positive (when significant).

Similar results were also obtained for $\eta = 0.1$ and 0.3. However, in about 60 percent of the cases, when $\eta = 0.5$, the Ricardian equivalence hypothesis could not be rejected. The intuition of this result is clear: as η is raised, increases in taxation are made increasingly temporary and it is therefore more likely that the benefits will fall on the same individuals who saw their taxes increase.

When Ricardian equivalence fails because of distortionary taxation and finite horizons (case 4, see Table 7), Ricardian equivalence cannot be rejected in 54.7 percent of the cases when equation (1) is estimated, in 13.5 percent of the cases when equation (2) is estimated, and in 38.2 percent of the cases when equation (3) is estimated.[13]

Overall, the estimates indicate that the coefficients on income, wealth, and government spending are very robust across the simulations and remarkably similar to the ones reported in the empirical literature.[14] By contrast, the estimates of the parameters on

[13] In several instances for case 4 (see Table 7), distortionary taxation eliminated the significant effects of finite horizons. With distorting taxes, an increase in the labor tax rate increases tax revenues by less than if all taxes are lump sums (as in case 3) because it decreases output. The effect of an increase in the labor tax rate on the tax revenue regressor is less important than with finite horizon, and the small but significant effects that finite horizons have may be more difficult to capture.

[14] For case 4 (see Table 7) the coefficient estimate of the parameter on the income variable has mean values 0.25 and 0.26 (depending on whether the equations are estimated using a Cochrane-Orcutt transformation or in first differences). The same coefficient is between 0.28 and 0.34 in Kormendi (1983), and between 0.22 and 0.36 in

TABLE 5—OLS ESTIMATES OF CONSUMPTION EQUATION[a] (CASE 2, DISTORTIONARY TAXATION)

Equation c_t	(1) C-O	(2) C-O	(3) C-O	(4) FD	(5) FD	(6) FD
const	0.117	0.120	0.113	0.00	0.00	0.00
	(49.60)	(48.02)	(51.01)	(0.01)	(0.04)	(0.04)
Y_t	0.199	0.200	0.200	0.202	0.204	0.203
	(38.10)	(41.02)	(41.19)	(53.18)	(54.62)	(54.95)
Y_{t-1}	−0.055	−0.051	−0.052	−0.039	−0.038	−0.038
	(−10.37)	(−10.19)	(−10.47)	(−10.27)	(−10.18)	(−10.40)
w_t^b	0.014	0.014	0.014	0.010	0.010	0.010
	(28.81)	(22.29)	(23.66)	(4.54)	(3.87)	(3.92)
G_t	−0.177	−0.175	−0.175	−0.176	−0.174	−0.174
	(−5.75)	(−5.90)	(−5.92)	(−7.10)	(−7.24)	(−7.32)
TR_t	−0.001	−0.013		−0.005	−0.008	
	(−0.09)	(−0.73)		(−0.36)	(−0.56)	
b_t		0.006	0.005		0.005	0.003
		(1.57)	(1.44)		(0.69)	(0.51)
Consistent with Ricardian equiv.	73.1%	33.8%	42.2%	95.1%	57.6%	64.0%
Consistent with non-Ricardian view	14.7%	49.9%	43.8%	3.8%	30.9%	23.9%
Q	0.194	0.191	0.157	0.160	0.172	0.163
	0.092	0.090	0.054	0.101	0.097	0.095

[a] See notes to Table 4. The mean value of the estimated first-order serial correlation coefficient is 0.439 for the first equation, 0.411 for the second, and 0.439 for the third.

the tax revenue and the government debt variables are unstable and tests for Ricardian equivalence are often misleading whether Ricardian equivalence holds or not.[15] In the previous section, I found that innovations to the labor tax rate, when horizons are finite, have fairly small effects on consumption. However, when standard consumption function tests are replicated using simulated series, they most often lead to the rejection of Ricardian equivalence. These results are consistent with the findings of Evans (1993). Using the Blanchard model, he tests the Ricardian hypothesis against the non-Ricardian alternative where the deviations from Ricardian equivalence are uniquely due to the finiteness of horizons. He strongly rejects the null hypothesis but finds that the effects on consumption of the departure from Ricardian equivalence are relatively small.

In the previous section, distortionary taxation was found to have important effects on consumption (with 21.75 percent of the variance of consumption due to innovations in the labor tax rate). Nevertheless, using simulated series consumption function tests indicates that it is difficult to distinguish between a situation in which there are distorting taxes and a situation in which there is Ricardian equivalence. Why do we observe this apparently conflicting result? The most serious problem is the endogeneity of income. With distortionary taxation, an increase in the labor tax rate decreases consumption, work effort,

Kormendi and Meguire (1986, 1990). With the simulated series, the mean values of the coefficient on wealth are 0.021 and 0.015. In Kormendi (1983), this coefficient varies between 0.02 and 0.046. In Modigliani and Sterling (1986, 1990), it is between 0.01 and 0.032, and in Kormendi and Meguire (1986, 1990) between 0.006 and 0.037. The mean value of the coefficient on fiscal spending is −0.192 in the simulations and between −0.17 and −0.28 in Kormendi (1983), −0.11 and −0.26 in Kormendi and Meguire (1986, 1990), and −0.04 and −0.22 in Modigliani and Sterling (1986).

[15] In some cases the Box-Pierce Q statistics indicate serially correlated errors. A richer dynamic specification (including the lagged value of consumption and/or of government spending, for example) provides a solution to the problem of serially correlated errors without changing the results and the conclusions of the paper.

TABLE 6—OLS ESTIMATES OF CONSUMPTION EQUATION[a] (CASE 3, FINITE HORIZON)

Equation c_t	(1) C-O	(2) C-O	(3) C-O	(4) FD	(5) FD	(6) FD
const	0.112	0.162	0.128	0.00	0.00	0.00
	(25.35)	(27.24)	(13.57)	(0.04)	(0.00)	(0.07)
Y_t	0.385	0.386	0.375	0.394	0.393	0.384
	(76.57)	(93.16)	(51.18)	(98.75)	(110.9)	(48.17)
Y_{t-1}	−0.038	−0.038	−0.036	−0.029	−0.027	−0.028
	(−7.59)	(−9.29)	(−4.90)	(−8.38)	(−9.30)	(−4.13)
w_t^b	0.038	0.043	0.044	0.029	0.036	0.031
	(26.94)	(30.65)	(16.70)	(7.20)	(8.33)	(3.35)
G_t	−0.405	−0.409	−0.407	−0.409	−0.406	−0.409
	(−23.43)	(−29.51)	(−15.71)	(−31.77)	(−37.31)	(−16.08)
TR_t	−0.063	−0.076		−0.069	−0.077	
	(−7.21)	(−10.66)		(−10.68)	(−13.23)	
b_t		0.013	0.006		0.013	−0.004
		(8.15)	(2.40)		(3.92)	(−0.35)
Consistent with Ricardian equiv.	4.2%	0.0%	43.0%	0.0%	0.0%	83.8%
Consistent with non-Ricardian view	95.8%	99.6%	52.1%	100%	100%	4.6%
Q	0.089	0.158	0.374	0.054	0.111	0.626
	0.005	0.054	0.315	0.004	0.047	0.68

[a] See notes to Table 4. The mean value of the estimated first-order serial correlation coefficient is 0.653 for the first equation, 0.453 for the second, and 0.546 for the third.

and output.[16] The estimate of the coefficient on the tax revenue variable only captures part of the effects of the change in taxation on consumption (for a given output level). This will bias the estimates of the coefficient on the tax variable towards zero, since an increase in distortionary taxation decreases output, and output and consumption are positively correlated. When I use productivity (which is exogenous in the model) as a proxy for output, the results improve dramatically. In this case, the estimate of the coefficient on taxation includes the indirect effects of changes in income. For case 2, with equation (1), Ricardian equivalence cannot be rejected in only 0.2 percent of the cases. With equation (2), Ricardian equivalence is always rejected (these results are not reported in the tables).[17] Similar results are obtained when I estimate equations (4) and (5), and for case 4 (when deviations from Ricardian equivalence are due to both distortionary taxation and finite horizons). When the bond variable is included without the tax variable (specifications 3 and 6), the results are again not very robust. This may be due to the fact that the bond variable also captures the negative effects of taxation (which is now an omitted variable) on consumption. These results suggest that the availability of an exogenous proxy for income could significantly improve the results.[18]

The model used in this paper allows one to look at another element often considered to favor the Ricardian equivalence hypothesis (for example, see Barro, 1989); namely, the low correlation between the ratio of the current account deficit and the budget deficit to output in

[16] A similar result is found in Greenwood and Huffman (1991). In the previous section, I found that innovations in the labor tax rate explain 21.7 percent of the variance of output.

[17] For equation (2), the median significance level of the Box-Pierce Q statistics is 0.358.

[18] Many authors have pointed out that the endogeneity problems related to the inclusion of these regressors may be serious (for example, see Bernheim, 1987). Although some authors use instrumental variables, good instruments are not readily available.

TABLE 7—OLS ESTIMATES OF CONSUMPTION EQUATION[a] (CASE 4, DISTORTIONARY TAXATION AND FINITE HORIZON)

Equation c_t	(1) C-O	(2) C-O	(3) C-O	(4) FD	(5) FD	(6) FD
const	0.094	0.103	0.093	−0.00	−0.00	−0.00
	(36.98)	(36.56)	(34.91)	(−0.04)	(−0.03)	(−0.03)
Y_t	0.248	0.251	0.250	0.256	0.257	0.257
	(40.32)	(44.25)	(41.32)	(56.41)	(58.49)	(52.80)
Y_{t-1}	−0.063	−0.060	−0.062	−0.046	−0.044	−0.045
	(−9.93)	(−10.13)	(−9.88)	(−10.15)	(−10.21)	(−9.57)
w_t^b	0.022	0.021	0.021	0.015	0.015	0.014
	(25.89)	(21.08)	(20.72)	(4.85)	(4.50)	(3.93)
G_t	−0.190	−0.192	−0.194	−0.193	−0.189	−0.193
	(−5.59)	(−6.06)	(−5.67)	(−7.18)	(−7.36)	(−6.77)
TR_t	−0.036	−0.053		−0.042	−0.049	
	(−1.87)	(−2.85)		(−2.79)	(−3.15)	
b_t		0.011	0.007		0.010	0.00
		(2.86)	(1.80)		(1.26)	(0.04)
Consistent with Ricardian equiv.	54.7%	13.5%	38.2%	24.3%	12.4%	68.4%
Consistent with non-Ricardian view	43.8%	78.4%	49.6%	75.7%	80.5%	16.6%
Q	0.184	0.180	0.171	0.140	0.171	0.287
	0.088	0.076	0.069	0.084	0.103	0.219

[a] See notes to Table 4. The mean value of the estimated first-order serial correlation coefficient is 0.475 for the first equation, 0.418 for the second, and 0.458 for the third.

the G-7 countries (see Table 8, last column). The simulated series can be used to calculate the correlation between the ratios of the budget deficit and current account deficit to output. The results are reported in Table 8. The correlation implied by each of the four models (when all shocks are included) is also calculated and reported. In only one case (finite horizons with only shocks to the labor tax rate) can I find a strong positive relation between budget deficit ratio and current account deficit ratio that is robust across simulations. Whenever distortionary taxation is added or the influence of other shocks is included, this relation is lost. Distortionary taxation inhibits this relation because it affects consumption, output, and investment. A lower labor tax rate increases consumption, the number of hours worked, and output. The increase in output increases national savings, while the increase in consumption decreases national savings. Investment increases because, as the number of hours worked increases, accumulation takes place to restore the initial capital-labor ratio. The net effect on the current account is uncertain. It seems, therefore, that no clear conclusions about Ricardian equivalence can be derived from observing a low correlation between budget deficit ratios and current account deficit ratios.

IV. Conclusions

This paper replicates standard consumption tests on Ricardian equivalence using simulated series. When the generated series are used to estimate a consumption function, the estimates of the coefficients on income, wealth, and government spending are robust and remarkably close to the ones produced in the empirical literature. The estimates of the coefficients on the tax revenue and government debt variables are not robust, which is also the case in the empirical literature. This suggests that the conflicting empirical evidence on Ricardian equivalence may be due to a weakness in the statistical tests performed. Moreover, the tests are not able to discriminate between a good and a poor approximation to Ricardian equivalence. Distortionary taxation is found to have important effects on consumption and yet the OLS estimates often did not lead to a rejection of Ricardian equivalence. With

TABLE 8—BUDGET DEFICIT/CURRENT ACCOUNT DEFICIT CORRELATIONS (RATIOS TO OUTPUT)

	Correlation[a] implied by the model (all shocks included)	All shocks[b]	Shocks to technology & labor tax rate[b]	Shocks to labor tax rate[b]	Data[c] 1956–1989
					U.S. 0.6745[e]
Case 1 (Ricardian equivalence)	0.173	0.103 (−0.55, 0.70)	0.039 (−0.56, 0.61)	0[d]	Canada −0.3225
					France 0.0956
Case 2 (Distortionary taxation)	−0.080	0.153 (−0.60, 0.80)	0.111 (−0.62, 0.75)	−0.106 (−0.60, 0.42)	Germany 0.0227
					Italy 0.4513
Case 3 (Finite horizon)	0.290	0.164 (−0.47, 0.68)	0.097 (−0.49, 0.64)	0.729 (0.26, 0.94)	Japan −0.2736
					U.K.
Case 4 (Distortionary taxation and finite horizon)	0.052	0.178 (−0.56, 0.77)	0.102 (−0.64, 0.73)	−0.112 (−0.64, 0.45)	−0.0902

[a] Correlation between the budget deficit and the current account deficit calculated using equations (23), (24), and (25).

[b] Mean values over 1,000 replications. In parenthesis I report the 25th smallest and the 25th largest of the 1,000 correlation coefficients.

[c] Using yearly values from the IFS CD-ROM (September 1993).

[d] I do not include the effects of very small changes in consumption. Output does not change and consumption is almost constant (small variations are due to the fact that infinite horizon is approximated). The mean value of the standard deviation of the current account deficit ratio to output is 5.8×10^{-7}. The mean value of the standard deviation of the budget deficit ratio to output is 0.009.

[e] The correlation is 0.3615 between 1956 and 1982.

finite horizons, the effects of changes in taxation are fairly small, but the null hypothesis is easily rejected. The results of the OLS estimates improve dramatically when exogenous regressors are used.

The simulations also show that the lack of a strong relation between the current account deficit ratio and the government budget deficit ratio that has been found for the G-7 countries is consistent with both Ricardian equivalence and the non-Ricardian alternative. In the literature, the low correlation has been considered to favor the Ricardian equivalence hypothesis.

APPENDIX

The linearized version of the theoretical model (see equations (23), (24), and (25)) can be written as: $\mathbf{\Psi}_o \mathbf{y}_t = \mathbf{\Psi}_1 \mathbf{y}_{t-1} + \varepsilon_t$ in which $\mathbf{y}_t = \{\mathbf{Z}_t', \mathbf{x}_t', \mathbf{p}_t'\}'$,

$$\text{where } \mathbf{\Psi}_o = \begin{vmatrix} \mathbf{I} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{I} & \mathbf{0} \\ -\mathbf{F}_2 & -\mathbf{F}_1 & \mathbf{I} \end{vmatrix},$$

$$\mathbf{\Psi}_1 = \begin{vmatrix} \mathbf{\Omega} & \mathbf{0} & \mathbf{0} \\ \mathbf{B}_1 & \mathbf{A}_{11} & \mathbf{A}_{12} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} \end{vmatrix} \text{ and } \varepsilon_t = \begin{vmatrix} \boldsymbol{\nu}_t \\ \mathbf{0} \\ \mathbf{0} \end{vmatrix}.$$

Thus, $(\mathbf{\Psi}_o - \mathbf{\Psi}_1 L)\mathbf{y}_t = \boldsymbol{\varepsilon}_t$ where L is the lag operator. It follows that (assuming all inverses exist)

$$(\mathbf{I} - \mathbf{\Psi}_o^{-1}\mathbf{\Psi}_1 L)\mathbf{y}_t = \mathbf{\Psi}_o^{-1}\varepsilon_t \Rightarrow$$

$$\mathbf{y}_t = (\mathbf{I} - \mathbf{\Psi}_o^{-1}\mathbf{\Psi}_1 L)^{-1}\mathbf{\Psi}_o^{-1}\varepsilon_t \text{ and, therefore,}$$

$$\mathbf{y}_t = \sum_{i=o}^{\infty} (\mathbf{\Psi}_o^{-1}\mathbf{\Psi}_1)^i \mathbf{\Psi}_o^{-1}\varepsilon_{t-i}.$$

The s-period-ahead and the unconditional forecast error variance of consumption can be computed using the parameters of the model and of the generating process. In all the four cases considered in the paper, productivity shocks have very important effects on consumption; they explain at least 77 percent of the unconditional forecast error variance of consumption. An appendix available on request from the author describes the linearized version of the model and the mapping between $\mathbf{A}_{11}$, $\mathbf{A}_{12}$, $\mathbf{F}_1$, $\mathbf{F}_2$, and $\mathbf{B}_1$ on the one hand and the economic parameters on the other.

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