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Abstract

We find and compare two simple fiscal rules. The first is a theoretical rule that approximates well Ramsey-optimal fiscal policy in a DSGE model calibrated to the U.S. economy over the period 1955:1 to 2007:3; The second is an empirical rule that approximates well actual U.S. fiscal policy over the same period. Our main findings are: First, Ramsey-optimal fiscal policy displays limited volatility even in the presence of sticky prices, while public debt absorbs most of the shocks. Second, actual U.S. fiscal policy is excessively counter-cyclical. Ramsey-optimal fiscal policy is negatively correlated with output over the business cycle, as expansions generate reduction in the level of public debt and the tax rate and vice versa. On the other hand, actual fiscal policy is positively correlated with output as the tax rate is raised during expansions and reduced during recessions. Third, actual fiscal policy is inconsistent with long-run debt sustainability over the period considered.

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1 Introduction

This paper studies how a benevolent fiscal authority should use fiscal policy to stabilize the economy and then uses it as a benchmark to evaluate actual fiscal policy in the United States. We analyze the optimal response of taxes and budget surpluses to temporary shocks to technology and government spending in an economy characterized by a number of frictions including incomplete capital markets, distortionary income taxes and sticky prices. In such environment public debt displays unit-root behavior in response to temporary shocks, which in turn requires an adjustment of the tax rate to guarantee the long-run sustainability of public finances. Unlike in frictionless environments, the tax rate cannot and should not be held constant in response to a temporary shock. And because taxes are distortionary, it matters for welfare when and how they are changed. Optimal fiscal stabilization is therefore a necessary and well-defined policy in our setup.

Our paper builds on two distinct literatures. The former is mainly theoretical and it studies optimal monetary and fiscal policy in dynamic stochastic general equilibrium (DSGE) models. Earlier contributions by Lucas and Stokey (1983) and Chari et al. (1991) focus on frictionless environments and find that state-contingent returns on government debt or state-contingent taxes on capital absorb most of the shocks to the government budget constraint. When the government issues nominal non-state-contingent debt, the price level is very volatile to make the real returns on debt state-contingent. The tax rate on labor income is remarkably stable over the business cycle and it displays the persistence properties of the original shocks. Later contributions focus on environments with frictions. Aiyagari et al. (2002) consider an economy where the government can issue only real non-state-contingent debt and find that optimality of fiscal policy imposes unit-root behavior on the tax rate and public debt. In an economy with price stickiness and nominal non-state-contingent public debt, Schmitt-Grohe and Uribe (2004a, 2006) find that public debt and the labor income tax rate display random walk behavior in response to temporary shocks. Inflation, on the other hand, is remarkably stable even if the degree of price stickiness is small.

The second literature we build on is more empirical and it focuses on estimating the dynamic effects of fiscal policy on macroeconomic variables. Blanchard and Perotti (2002) use a structural VAR whose identification relies on estimates of output elasticities of fiscal variables. This allows them to identify fiscal shocks that can then be used to trace their effects on the economy. They find that a government spending shock temporarily raises both output and consumption. This stylized fact is hard to reproduce in standard DSGE models, which typically predict a fall in private consumption. As a solution to this puzzle, Galí et al. (2007) propose a model with rule-of-thumb consumer, a key hypothesis, along with a Non-Walrasian labor market. These ingredients generate a positive response of private consumption and wages to a positive government spending shock. Their model assumes a linear fiscal rule where a lump-sum tax responds to the stock of debt and government spending. The coefficients of their fiscal rule are calibrated to replicate some moments of U.S. data analyzed with both a 4- and a 8-variable VAR. They assign positive coefficients to both debt and government spending. Bilbiie et al. (2006) suggest that the response to government spending shocks has changed considerably in the United States in the last twenty years and relate such change to increased asset-market participation. They consider a model where a fraction of agents are rule-of-thumb consumers and where fiscal policy follows a rule in which the government deficit depends on its own lag, the stock of debt and government spending. Then they find a number of parameter values, among which the degree of market participation, which minimize the distance between the empirical impulse responses and the impulse responses generated by the model. Their key finding is that the percentage of rule-of-thumb consumers has fallen significantly since the early 1980s.

Our work focuses on fiscal policy in an environment with frictions. We characterize optimal fiscal policy in a setting where the government issues nominal non-state-contingent debt, prices are sticky, steady-state output is sub-optimally low because of monopolistic competition and monetary policy follows an interest-rate rule. Hence, our modeling choices are close to the extant literature. The non-state-contingency of public debt gives unit-root behavior to public bonds and tax rate in our model, consistent with earlier findings.

The novelty of our paper is that we evaluate actual fiscal policy using optimal fiscal policy as a benchmark. Our approach summarizes fiscal policy via a simple, linear tax rule that describes how the labor income tax rate responds to a few variables, estimates an optimal and an actual fiscal rule in order to compare them. To be precise, first we summarize optimal fiscal policy by choosing the parameter values of the linear tax rule that minimize the distance between the impulse responses generated by the model with the linear tax rule and those generated by optimal fiscal policy. Then we summarize actual fiscal policy by choosing the parameter values of the linear tax rule that minimize the distance between the empirical impulse responses and those generated by the rule. At this point we have an optimal and an actual linear tax rule that we can compare. Since both tax rules have the same linear form, we can meaningfully compare the sign and size of the coefficients.

We find that, under optimal fiscal policy, the optimal labor income tax rate increases in response to a positive government spending shock and decreases in response to a positive technological shock. The bulk of the adjustment of the labor income tax rate occurs in the first few quarters after the shock, with its profile being practically flat after that. Nevertheless, the optimal labor income tax rate has limited volatility over the business cycle. The optimal labor income tax rate increases with public debt. Intuitively, a higher debt level raises steady-state interest payments, thereby raising the financing needs of the government in the long run. To collect larger revenues the government must therefore raise the tax rate. The implications of optimal tax policy for the budget balance are that the government should run surpluses when faced with positive technological shocks and deficits when faced with positive shocks to government spending. Budget balances under optimal fiscal policy are *not* simply pro-cyclical with respect to output. In fact, it is optimal to run budget deficits in response to a positive government spending shock even if the short-run effect on output is positive.

As for actual tax policy in the United States, we find that the tax rate responds positively both to a positive government spending shock (as predicted by optimal fiscal policy) and to a positive technological shock. The latter prediction is at odds with the prediction of optimal fiscal policy. A plausible interpretation of this finding is that U.S. tax policy has raised the labor income tax rate during expansions and lowered it during recessions. However, such policy is sub-optimal when output movements are due to technological shocks. A temporary technological improvement raises the real wage and discourages the supply of labor. The optimal labor income tax falls to prevent a sharp reduction in hours worked and, as a result, the expansionary effect on output is stronger. In a sense, U.S. tax policy has been excessively counter-cyclical. The empirical impulse responses support this interpretation of how U.S. tax policy has operated. Budget surpluses are small and barely significant following a technological shock and the output response is lower than what is predicted under optimal fiscal policy. U.S. tax rates have responded negatively to public debt, unlike what is predicted by optimal fiscal policy. Hence, larger public debt ratios have been accompanied by lower tax rates. This finding casts some doubts over the long-run sustainability of U.S. fiscal policy.

The remainder of the paper is organized as follows. Section 2 presents the model and Section 3 shows our calibration to the U.S. economy. In Sections 4 and 5 we characterize optimal fiscal policy and the dynamics under such policy. We discuss and estimate our simple, linear fiscal rule in Section 6. Our methodology is presented in Section 7 while we estimate our empirical rule in Section 8. Section 9 discusses the robustness of our findings and Section 10 concludes.

2 The Model

2.1 Households

We model a closed economy inhabited by a representative agent whose preferences are defined over per capita consumption and per capita hours worked. The model below draws extensively from Lambertini (2007), which studies optimal fiscal policy in a two-country monetary union setting. The representative agent maximizes the utility function

$$E_t \sum_{s=t}^{\infty} \beta^{s-t} U\left(c_s, n_s\right) \tag{1}$$

where $0 < \beta < 1$ is the discount factor, E_t denotes the mathematical expectations operator conditional on information available at the beginning of period t, c_t is consumption and n_t is hours worked in period t. Per capita consumption is defined over a continuum of differentiated goods distributed over the interval $[0, 1]$, which are produced domestically. More precisely

$$c_t = \left[\int_0^1 c_t(i)^{\frac{\theta-1}{\theta}} di\right]^{\frac{\theta}{\theta-1}}, \tag{2}$$

where $c_t(i)$ is consumption of good i at time t and $\theta > 1$ is the constant elasticity of substitution among the individual goods. $P_t(i)$ is the price of good i in period t. The price index P_t corresponding to the consumption index c_t is

$$P_t = \left[\int_0^1 P_t(i)^{1-\theta} di\right]^{\frac{1}{1-\theta}}, \tag{3}$$

which is the minimum cost of a unit of the aggregate consumption good defined by (2), given individual good prices $P_t(i)$.

We assume that each differentiated good uses a specialized labor input in its production and that the representative individual supplies all of the types of labor. In this case, all households have exactly the same wage incomes without the need to assume the existence of competitive financial markets where wage risks are efficiently traded. Let $n_t(i)$ be labor supply of type i in period t. Total hours worked in period t by the representative individual are

$$n_t \equiv \int_0^1 n_t(i)di.$$

All households start with the same financial assets and own an equal share of all the firms in the economy. The budget constraint in real terms for the representative agent in period t is

$$\frac{b_t^p}{1+i_t} + c_t = \frac{b_{t-1}^p}{\pi_t} + (1-\tau_t)\int_0^1 w_t(i)n_t(i)di + \int_0^1 \Pi_t(i)di, \tag{4}$$

where

$$b_t^p \equiv \frac{B_t^p}{P_t}, \quad w_t(i) \equiv \frac{W_t(i)}{P_t}, \quad \Pi_t(i) \equiv \frac{\Phi_t(i)}{P_t}.$$

$W_t(i)$ is the nominal wage of labor of type i in period t and $w_t(i)$ is the corresponding real wage. $\Phi_t(i)$ are the nominal profits of the firm producing good i in period t and $\Pi_t(i)$ are the corresponding real profits. We assume that each household owns the same share of all the firms in the economy. B_t^p is the purchase by each household of a riskless, one-period, nominal non-state-contingent bond. In real terms, such purchase is b_t^p. The bond is issued in period t, it can be purchased at the price of $1/(1+i_t)$ and it pays one unit of consumption in period $t+1$. τ_t is a labor income tax levied by the government at time t. Each household is subject to the transversality condition

$$\lim_{T\to\infty} E_t q_{t,T}\left[\frac{B_{t+1+T}^p}{P_t}\right] = 0 \tag{5}$$

on bond holding, where $q_{t,T}$ is the stochastic discount factor defined as

$$q_{t,T} = \Pi_{s=t}^T (1+i_s)^{-1}.$$

The household maximizes utility (1) subject to the budget constraint (4) and the transversality condition (5). Household's consumption must be optimally allocated across all differentiated goods. Expenditure on good i is negatively related to the relative price of good i and it satisfies the following first-order condition

$$c_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\theta} c_t. \tag{6}$$

The lagrangean multiplier on the household's budget constraint at time t is λ_t, which is equal to the marginal utility with respect to consumption

$$U_c(c_t, n_t) = \lambda_t. \tag{7}$$

As noted before, we assume incomplete financial markets as the only asset available is a riskless, non-contingent nominal bond. This implies that households are unable to fully eliminate uncertainty from their consumption and incomes. The optimal choice of bond holding gives the standard Euler equation

$$\frac{\lambda_t}{1+i_t} = \beta E_t \frac{\lambda_{t+1}}{\pi_{t+1}}, \tag{8}$$

where $\pi_{t+1} \equiv p_{t+1}/p_t$ is the (gross) inflation rate between $t+1$ and t. At last, households choose the optimal quantity for each labor type to supply, given the wages they face and the labor income tax rate. For each labor type i, the optimal supply satisfies the condition

$$-U_n(c_t, n_t(i)) = \lambda_t w_t(i)(1-\tau_t), \tag{9}$$

where $U_n(c_t, n_t(i))$ is the marginal disutility of supplying labor of type i. Everything else being equal, an increase in the labor income tax at time t reduces labor supply.

2.2 Firms

For simplicity, we assume that firms produce using labor only. More precisely, firm i produces good i using the production function

$$y_t(i) = a_t n_t(i), \tag{10}$$

where a_t is an exogenous stochastic technological factor common to all firms. Hence, we abstract from firm-specific technological shocks to assume instead that shocks are common to all firms in the economy.

The demand for good i is given by

$$y_t(i)^d = \left[\frac{P_t(i)}{P_t}\right]^{-\theta} (c_t + g_t) \tag{11}$$

where c_t, g_t are total private and public consumption. We assume that government consumption is distributed across all type of goods produced in the economy and that its allocation on each type of good follows the same rule as (6). Hence, the demand function (11) follows directly from (6).

We consider price stickiness along the lines of the Calvo model. Every period, a fraction $\phi \in [0,1)$ of randomly chosen firms does not change price and meets demand at the posted price; the remaining fraction $1-\phi$ of firms sets the price optimally. In every period, firm i wishes to maximize the expected present value of its nominal profits subject to the constraint production meets demand:

$$E_t \sum_{s=t}^{\infty} \left\{ \phi^{s-t} q_{t,s} P_s \left[\frac{P_t(i)}{P_s} y_s(i) - w_s n_s(i)\right] + mc_s \left[a_s n_s(i) - \left(\frac{P_t(i)}{P_s}\right)^{-\theta} y_s\right]\right\}. \tag{12}$$

In the expression above, mc_t is the Lagrangean multiplier associated with the constraint that production meets demand. Every period firm i chooses how much labor to hire, given the wage. The associated first-order condition is:

$$mc_t(i) = \frac{w_t(i)}{a_t}, \tag{13}$$

which shows the (real) marginal cost of producing good i is equal to the real wage faced by firm i per unit of output produced. If firm i is allowed to change its price at time t, it also chooses $P_t(i)$ according to the condition:

$$\theta E_t \sum_{s=t}^{\infty} \phi^{s-t} q_{t,s} y_s mc_s \left(\frac{P_t(i)}{P_s}\right)^{-\theta-1} = (\theta-1) E_t \sum_{s=t}^{\infty} \phi^{s-t} q_{t,s} y_s \left(\frac{P_t(i)}{P_s}\right)^{-\theta}, \tag{14}$$

where $y_t = c_t + g_t$ is total aggregate demand at time t, which the firm takes as given. The optimal price at time t is such that expected future marginal revenues (the right-hand side of (14) equal expected future marginal costs (the left-hand side of (14).[1]

We abstract from production subsidies that bring long-run output levels are at their competitive levels. As a result, the deterministic steady state around which we approximate our economy is suboptimal and it is therefore inappropriate to use first-order approximations to the equilibrium conditions for second-order-accurate welfare evaluation. To retain the non-linearity of (14) and use second-order linear approximations to the equilibrium conditions, we follow Schmitt-Grohe and Uribe (2004c) and rewrite (14) as

$$v_t \frac{\theta}{\theta-1} = vv_t, \tag{15}$$

where the variables v_t and vv_t are defined as follows:

$$v_t \equiv E_t \sum_{s=t}^{\infty} \phi^{s-t} q_{t,s} y_s \frac{w_s}{a_s} \left(\frac{P_t(i)}{P_s}\right)^{-\theta-1} = \tilde{p}_t^{-\theta-1} y_t\, mc_t + \phi\beta E_t \frac{\lambda_{t+1}}{\lambda_t} \pi_{t+1}^{\theta} \left(\frac{\tilde{p}_t}{\tilde{p}_{t+1}}\right)^{-\theta-1} v_{t+1}, \tag{16}$$

$$vv_t \equiv E_t \sum_{s=t}^{\infty} \phi^{s-t} q_{t,s} y_s \left(\frac{P_t(i)}{P_s}\right)^{-\theta} = \tilde{p}_t^{-\theta} y_t + \phi\beta E_t \frac{\lambda_{t+1}}{\lambda_t} \pi_{t+1}^{\theta-1} \left(\frac{\tilde{p}_t}{\tilde{p}_{t+1}}\right)^{-\theta} vv_{t+1}. \tag{17}$$

Let $\tilde{P}_t$ be the price chosen by the firms that can update their prices at time t and $\tilde{p}_t \equiv \tilde{P}_t / P_t$. The dynamics of prices follows

$$1 = \phi \pi_t^{\theta-1} + (1-\phi) \tilde{p}_t^{1-\theta}. \tag{18}$$

[1] We focus on a symmetric equilibrium where all firms that change their prices in a given period choose exactly the same price.

2.3 Monetary and Fiscal Policies

In this cashless economy monetary policy amounts to controlling the nominal interest rate. We assume that the central bank is (instrument) independent from the fiscal authority in the sense that it has full control over the its monetary policy instrument. We consider the case where the monetary policy instrument is the nominal interest rate. Let $R_t \equiv 1 + i_t$ be the gross nominal interest rate. We assume that the central bank follows the interest rate rule:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\phi_r} \left[\left(\frac{\pi_t}{\pi}\right)^{\phi_\pi} \left(\frac{y_t}{y}\right)^{\phi_y}\right]^{1-\phi_r} \left(\frac{y_t}{y_{t-1}}\right)^{\phi_{yy}}, \tag{19}$$

where variables without a time subscript indicate their the steady-state values. This is a generalized Taylor rule whereby the nominal interest rate is adjusted in response to inflation and the output gap, defined as the difference between actual and steady-state output. The parameter ϕ_r captures interest rate smoothing. We estimate our benchmark interest rate rule using data from 1955:1 to 2007:4 and obtain $\phi_y = 0.11, \phi_\pi = 1.07, \phi_{yy} = 0.06, \phi_r = 0.92$ and this parameter combination ensures a locally unique equilibrium.

In period t, the fiscal authority spends g_t on the goods produced in the economy, it levies the labor income tax τ_t and it issues public debt B_t^g. Concerning government spending, we assume it is exogenous and stochastic. In fact, in section XX we will calibrate steady-state government spending to match the data and then consider the optimal tax response to an unexpected spending shock. In our model government spending does not enter the utility function of the representative agent. While we believe that most government consumption is not truly wasteful, our analysis would not be affected at all if government spending entered additively the utility function.

Given g_t, the fiscal authority (or government henceforth) decides how much of it should be financed via tax revenues and how much via issuing new debt. The budget constraint for the government in real terms is

$$\frac{b_t^g}{1+i_t} = \frac{b_{t-1}^g}{\pi_t} + g_t - \tau_t \int_0^1 w_t(i) n_t(i), \tag{20}$$

where $b_t^g \equiv B_{1,t}^g / P_t$. The budget deficit as percentage of GDP is

$$d_t \equiv \frac{B_t^g - B_{t-1}^g}{y_t} = i_t \frac{B_{t-1}^g}{y_t} + (1+i_t)\left(P_t \frac{g_t}{y_t} - \tau_t \frac{W_t}{a_t}\right) \tag{21}$$

2.4 Aggregation and Equilibrium

Let $x_t \equiv \int_{0,1} (P_t(i)/P_t)^{-\theta} di$. After some simplifications, x_t can be written as

$$x_t \equiv \int_0^1 \left(\frac{P_t(i)}{P_t}\right)^{-\theta} di = (1-\phi)\tilde{p}_t^{-\theta} + \phi \pi_t^{\theta} x_{t-1}. \tag{22}$$

In equilibrium, the supply of good i must equal its demand:

$$a_t n_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\theta} y_t. \tag{23}$$

Aggregating over all the firms in the economy, we obtain the condition for equilibrium in the goods market:

$$a_t n_t = x_t y_t, \tag{24}$$

where $y_t = c_t + g_t$. Equilibrium in the goods market implies clearing in the asset market:

$$b_t^g = b_t^p. \tag{25}$$

Given a sequence of tax rates τ_s and initial conditions, a competitive equilibrium is a set of sequences $c_s, n_s, b_s^p, w_s, \pi_s, v_s, vv_s, mc_s, x_s, i_s, \tilde{p}_s, \lambda_s, b_s^g, a_s, g_s$ that satisfy (4), (7) -(9), (13), (15)-(20), (24)-(25), given the stochastic processes for technological and government consumption shocks and initial conditions.

3 Calibration

We calibrate our model to the post-1955 U.S. economy. The time unit is a quarter and we assume that the period utility function is:

$$U(c, n) = \log(c) + d\log(1 - n).$$

We set the parameter d equal to 2 to match a steady-state working time of one third. The discount factor β is 0.99, which is consistent with a steady-state real rate of return of 4.1 percent a year. We assign a value of 1/3 to the parameter ϕ that captures the fraction of firms that can change their prices in any given quarter. This value implies an average life span of prices of 4.5 months and it is in line with the findings of Bils and Klenow (2004) but shorter than the life span suggested by Sbordone (2002) and Clarida et al. (1999). The steady-state gross inflation rate is one. The price-elasticity of demand θ is set equal to 11 that implies a steady-state mark-up of 10 percent, as consistent with the work of Basu and Fernald (1997).

In our benchmark specification we set the parameters of the interest rate rule as follows: $\phi_y = 0.08, \phi_\pi = 1.8$ and $\phi_R = 0.84$. These parameter values are in line with those of Smets and Wouters (2007), except that we do not include a short-run feedback from the change in output gap. Our benchmark rule explains almost 90 percent of the fluctuations in the federal fund rate since 1955. In section 9 we discuss the implications for our findings of alternative values for the parameters of the interest-rate rule.

Government consumption is calibrated to be 17 percent of GDP at the steady state, which is equal to the empirical U.S. average since 1983. Government consumption and technology are assumed to follow the stochastic processes

$$\ln g_t = (1 - \rho_g)\ln g + \rho_g \ln g_{t-1} + \epsilon_t^g, \tag{26}$$

Parameter	Value	Description
β	0.99	Subjective discount factor
d	2	Calibrated to match $N = 0.3$
θ	11	Calibrated to match 1.1 gross value-added markup
ϕ	1/3	Degree of price stickiness
ϕ_y	0.11	Coefficient on output
ϕ_π	1.07	Coefficient on inflation
ϕ_R	0.92	Coefficient on lagged interest rate
ϕ_{yy}	0.06	Coefficient on lagged growth rate
g/Y	0.17	Government consumption to GDP ratio
b^g/Y	0.6	Government debt to GDP ratio
ρ_g	0.94	Serial correlation of $\ln g_t$
σ_g	0.0106	Standard deviation of innovation to $\ln g_t$
ρ_a	0.84	Serial correlation of $\ln a_t$
σ_a	0.0078	Standard deviation of innovation to $\ln a_t$

Table 1: Structural parameters

$$\ln a_t = (1 - \rho_a) \ln a + \rho_a \ln a_{t-1} + \epsilon_t^a, \tag{27}$$

where g, a are the steady-state values of technology and government consumption, respectively. We estimate the parameters $\rho_g, \sigma_g, \rho_a, \sigma_a$ from the VAR whose impulse response functions we match in section 8.[2] We impose a debt-to-GDP ratio for the government of 60 percent per year, which is close to the average federal debt-to-GDP ratio over the period 1947-2007. Together with government consumption, this implies a steady-state labor income tax rate of 19.4 percentage points. Table 1 summarizes the values assigned to the parameters of our model.

4 Ramsey Fiscal Policy

We characterize the fully optimal fiscal policy when the fiscal authority effectively has access to a commitment technology. This is the sequence of tax rates $\{\tau_s\}$ the fiscal authority commits in advance to and such that the utility of the representative consumer (1) is maximized. In plain words, the fully optimal fiscal policy is the sequence of tax rates that implements the competitive equilibrium associated with the highest social welfare.

In a more formal way, our fully optimal fiscal policy is a set of sequences $c_s, n_s, b_s^p, w_s, \pi_s, v_s$, $vv_s, mc_s, x_s, i_s, \tilde{p}_s, \lambda_s, b_s^g, a_s, g_s$ and τ_s for $s \geq t$ that maximize (1) subject to the competitive-equilibrium conditions (4), (7) -(9), (13), (15)-(20), (24)-(25), the values of the lagrangean

[2] The VAR is described in detail in section 7. More precisely, we run a VAR with six variablesfrom which we obtain the standard deviation of government expenditure and labor productivity, σ_g and σ_a. We estimate the autocorrelation coefficient ρ_g by regressing the impulse response of government spending to a government spending shock on its first lag. We estimate ρ_a in an analogous manner.

multipliers associated with those conditions for $s < t$, the stochastic processes for technological and government consumption and initial conditions.

Our definition of fully optimal fiscal policy is equivalent to the Ramsey equilibrium concept except that our first-order conditions for period t are not different from the others. This the concept called "optimal from the timeless perspective" of Woodford (2003). Our results are therefore directly comparable with those that focus on stationary allocation rules.[3]

5 Dynamics under Ramsey Fiscal Policy

We approximate the dynamics under Ramsey fiscal policy by taking a second-order approximation to the equilibrium conditions. As stated earlier, long-run output is below its perfectly competitive level in our setting because we abstract from the existence of production subsidies. This makes the use of first-order approximation to the equilibrium conditions inappropriate.[4]

The left-hand side of Table 2 reports the standard deviation, serial correlation and correlation with output of some macroeconomic variables of interest in our model. These moments have been computed using a Monte Carlo simulation of our benchmark economy with structural parameters as specified in Table 1. We performed 2000 simulations of 200 quarters and we present the average moments of our 2000 simulations.

An interesting result of our simulation is that inflation and the gross nominal interest rate display little volatility under Ramsey fiscal policy. It is known that optimal monetary policy makes inflation extremely stable over the business cycle even in an environment with little price stickiness.[5] Notice, however, that monetary policy is not optimal in our model but follows an interest-rate rule with smoothing.

Changes in the level of public debt absorb most of the impact of unanticipated shocks, even though the tax rate also displays some volatility. The standard deviation of the tax rate under Ramsey we find here is much higher than the one in Chari et al. (1994). However, they characterize optimal monetary and fiscal policy and monetary policy is the shock absorber since prices are flexible in their setup and inflation variability is costless. Ramsey fiscal policy predicts that the income tax rate should be pro-cyclical over the business cycle, in the sense that the tax rate on average increases when output goes up and vice versa, with correlation coefficient of 0.48. Later we will show that the optimal tax rate rises in the short run in response to government spending and technology being above average. The standard deviation of the tax rate under Ramsey in our setup is higher than that in Schmitt-Grohe and Uribe (2006). They find that the tax rate should be negatively correlated with output while we find the opposite. These differences are explained by two factors. First, monetary policy is not optimal in our model but follows a Taylor-type rule that implies a different response of the nominal interest rate to shocks. Since Ramsey fiscal policy is sensitive to

[3] For example, Schmitt-Grohe and Uribe (2006).

[4] We compute second-order accurate solutions to the equilibrium conditions using the methodology of Schmitt-Grohe and Uribe (2004b).

[5] See Schmitt-Grohe and Uribe (2004a).

nominal interest rates, which are inversely related to the price of nominal bonds, the optimal tax rate in the two models is also different. Second, we have a simpler setup that does not feature investment, habit persistence as well as a number of frictions that are likely to make the optimal tax rate less volatile.

The right-hand side of Table 2 reports the empirical second moments for the United States over the period 1955 to 2007. The second moments of the data are larger than those under Ramsey fiscal policy, although comparable. We report the second moments of two tax rates. The first, τ, is an average tax rate obtained dividing revenues from personal current taxes by the wages and salary disbursed in the economy, which are both available at a quarterly frequency. τ_{CBO} is the effective personal income tax rate calculated by the Congressional Budget Office. This rate is available at annual frequency from 1979 to 2005. τ_{nber} is the U.S. federal average *marginal* income tax rate on wages in the NBER TAXSIM model. This is a rate available at annual frequency from 1960 to 2007. Here we assume that the tax rate remained constant throughout the four quarters in each calendar year. All three tax rates display higher standard deviation than the rate under Ramsey. τ and τ_{cbo} are average tax rates that display low but positive correlation with output. Part of this positive correlation may be due to the progressivity of the U.S. tax system whereby an increase in income may bump taxpayers to a higher tax bracket and result in a higher income tax rate *without* a fiscal policy change. Being the average *marginal* tax rate, τ_{nber} does not suffer from this problem. The U.S. marginal tax rate displays very little and negative correlation with output.

To gain further understanding of the dynamics under Ramsey fiscal policy, we present the theoretical impulse responses to the two shocks (government spending and technology) of our model. Figure 1 shows the impulse response of a number of macroeconomic variables to a one percentage point increase in government purchases. It is optimal to finance an increase in government spending in part by raising the labor income tax and in part by running budget deficits. Budget deficits permit a smoother path of taxation that spreads over time the distortions stemming from it. An increase in government purchases raises aggregate demand and the demand for labor, which in turn raises the real wage and labor supply, despite the increase in taxes. As a result, output also increases in the short run. Inflation goes up, as typical in response to an aggregate demand shock, which in turn raises the nominal interest rate. Taxes and public debt display unit-root behavior in our model in the sense that public debt (nominal and real) and therefore the tax rate move to a new permanently higher level in response to a temporary shock. But a higher steady-state tax rate leads to lower hours worked, output and private consumption in the long run.

Figure 2 reports the impulse response of the same macroeconomic variables analyzed in Figure 1 in response to a technological shock. A positive supply shock raises the marginal productivity of labor and thereby the real wage in the short run. As a result, private consumption, leisure and output increase in the short run. Inflation falls temporarily, thereby lowering the nominal interest rate. The optimal fiscal response consists in raising the tax rate in the short run and then reduce it to its long-run level. As a result budget surpluses arise that reduce the debt level in the long run.

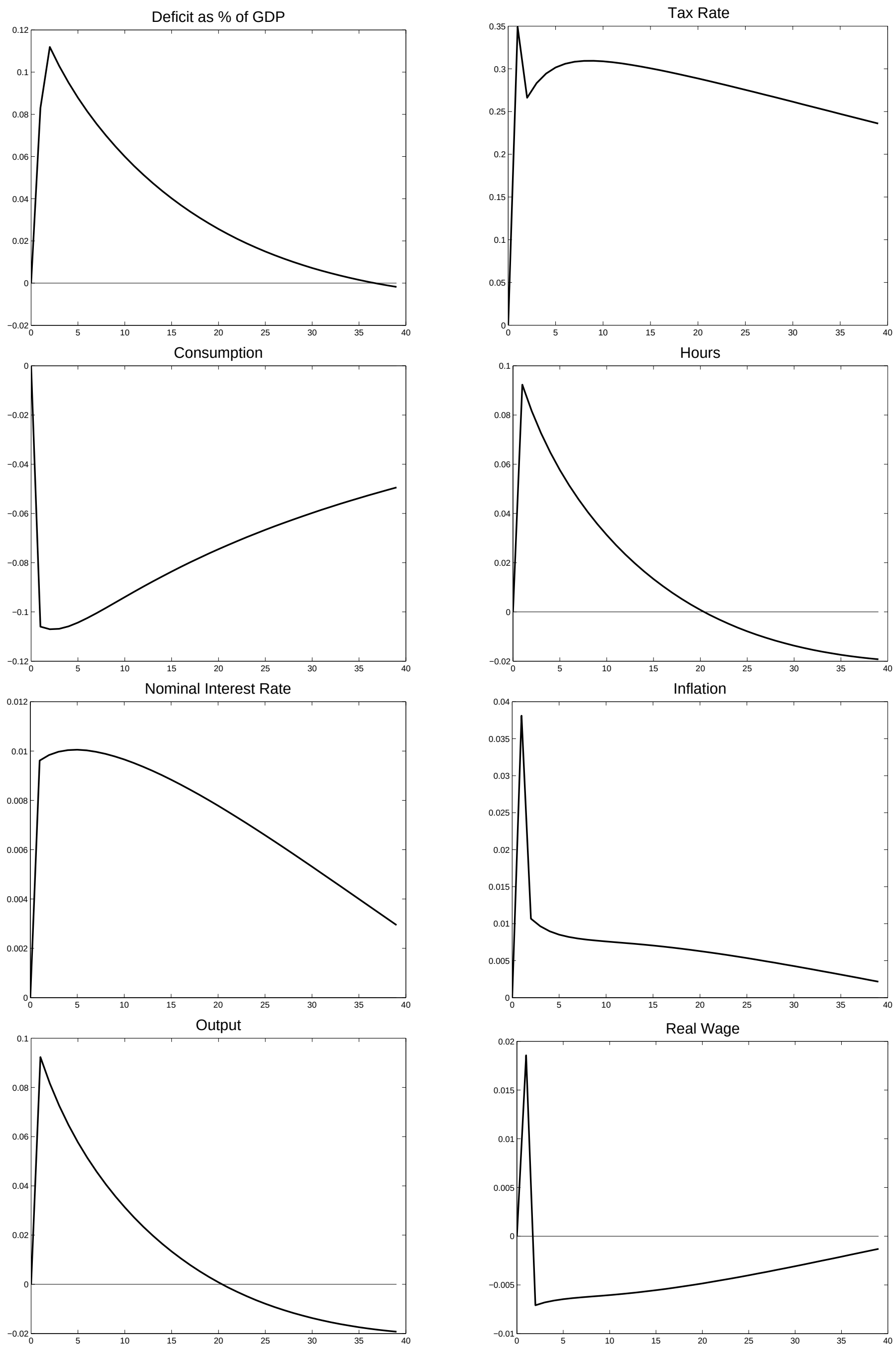

Figure 1: Impulse Responses to a Government Spending Shock

All variables are expressed in percentage point deviations from their steady-state values. The length of the impulse responses is 40 quarters.

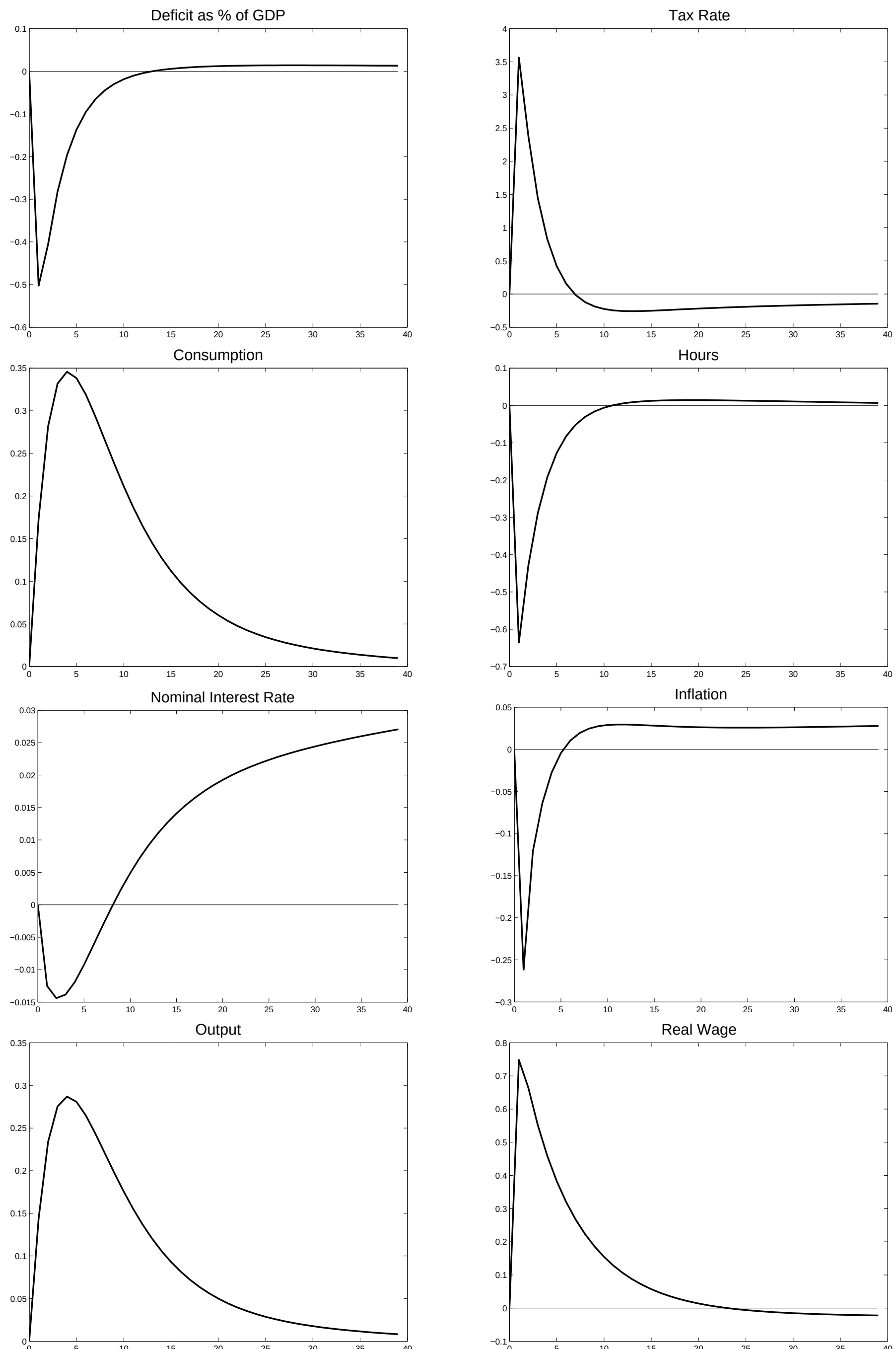

Figure 2: Impulse Responses to a Productivity Shock

All variables are expressed in percentage point deviations from their steady-state values. The length of the impulse responses is 40 quarters.

Variable	Ramsey Fiscal Policy			Data		
	Standard Deviation	Serial Correlation	Correlation w Output	Standard Deviation	Serial Correlation	Correlation w Output
b^g	19.00	0.99	-0.38	12.69	0.99	-0.06
$1+i$	0.20	0.99	-0.23	0.44	0.92	0.16
π	0.38	0.65	-0.23	0.47	0.76	0.30
w	1.45	0.84	0.83	2.95	0.97	0.24
n	0.87	0.66	-0.46	1.24	0.96	0.32
y	0.87	0.97	1.00	2.84	0.95	1.00
c	1.00	0.97	0.85	2.05	0.98	0.84
def/y	0.78	0.75	-0.50	1.68	0.92	-0.47
τ	5.09	0.28	0.44	7.59	0.86	0.15
τ_{cbo}				7.15	0.94	0.23
τ_{nber}				7.47	0.96	-0.08

Table 2: Second Moments: Ramsey and Actual U.S. Fiscal Policy

Notes: (1) All second moments are relative to the percent deviations from steady-state values. (2) The serial correlation is relative to the first lag. (3) τ is an average personal income tax rate obtained by dividing personal tax revenues by total wage and salary disbursements; τ_{cbo} is the effective federal individual income tax rate published by the CBO for all income quintiles for the period 1979 to 2005; τ_{nber} is the U.S. federal average marginal income tax rate on wages in the NBER TAXSIM model. This is an annual tax rate, which we convert to quarterly by a simple linear interpolation method. (4) The sources of the data are described in section 7.

To summarize, it is optimal to run budget deficits and raise the income tax rate in response to an unanticipated increase in government spending shock while it is optimal to run budget surpluses and raise the income tax rate in response to a positive technological shock. Hence, under Ramsey fiscal policy, budget surpluses are pro-cyclical with respect to technological shocks but counter-cyclical with respect to government spending shocks. On the other hand, labor income tax rates are pro-cyclical with respect to government spending shocks but display a non-monotonic response to technological shocks, being pro-cyclical in the short run but counter-cyclical in the long run. In terms of output

The non-monotonic response of the labor income tax response to a technological shock is intriguing

are counter-cyclical with respect to technological shocks and pro-cyclical with respect to government spending shocks. The counter-cyclicality of the tax rate with respect to technological shocks helps to soften the (negative) response of labor supply and makes the effect of the technological shock more expansionary on output.[6]

[6]Models with habit persistence predict that the Ramsey tax rate increases on impact in order to prevent

The nature of the correlation of optimal fiscal policy with output depends on the shock. In general, budget surpluses are pro-cyclical and tax rates are counter-cyclical with respect to output in the medium and long run. In the short run, however, output raises in response to a government spending shock. Hence, budget surpluses are pro-cyclical and the tax rate counter-cyclical with respect to output in response to a technological shock but budget surpluses are counter-cyclical and the tax rate pro-cyclical with respect to output in response to a government spending shock in the short run. Our simulations suggest that the optimal tax rate is generally counter-cyclical over the business cycle.

6 Linear Fiscal Rules

Our goal is to compare actual fiscal policy with optimal fiscal policy. To do that we implement a two-stage approach. First, we consider a class of simple, log-linear fiscal rules and find the values of its parameters that approximate well Ramsey fiscal policy. We refer to it as the *theoretical rule*. Second, we find the parameter values of the log-linear fiscal rule that approximates well actual fiscal policy. We are going to refer to the latter as the *empirical rule*.

We consider the following family of log-linear fiscal rules:

$$\log\left(\frac{\tau_t}{\tau}\right) = \alpha_b \log\left(\frac{b_t^g}{b^g}\right) + \alpha_g \log\left(\frac{g_t}{g}\right) + \alpha_a \log\left(\frac{a_t}{a}\right). \tag{28}$$

According to (28), the income tax rate is a log-linear function of real public debt and the exogenous shocks that drive the business cycle in the model, namely government spending and technology. We believe it is important to have real public debt in the fiscal rule because the steady-state level of the tax rate depends from the debt. Because the nature of the exogenous shock (demand vs supply) is important in determining the optimal fiscal response, we introduced the shocks directly into the fiscal rule. Other fiscal rules are possible. Schmitt-Grohe and Uribe (2006) specify a tax-rate rule where the tax rate depends linearly on its own lag and log deviations of government liabilities and output from their respective steady-state values. Galí et al. (2007) posit a tax rule where taxes are lump sum and depend on the deviations of government spending and public debt from their steady-state values. Bilbliie et al. (2006) assume that the deviation of the structural deficit from zero depends on its lag, the deviation of government spending and the level of public debt. We prefer not to include macroeconomic variables such as output in the tax rule because such variables are linear combinations of public debt, which is a state variable of our model. This would make it difficult to uniquely estimate the parameters of the tax rule in the light of the fact that the correlation of the optimal tax rate with output depends on the type of shock. We also believe that the fiscal rule (28) is as information-demanding as any other rule that includes output or the output gap among its determinants. In fact, government spending data is typically

consumption from jumping up and then it quickly falls below to its original level.

available at the same frequency as output and a measure of the output gap implicitly provides a measure of a productivity shock.

We pick the values of the parameters $\alpha_b, \alpha_g, \alpha_a$ that minimize the distance between the theoretical impulse responses of our model under Ramsey fiscal policy and the corresponding impulse responses of the model where fiscal policy follows the theoretical rule (28). The length of the impulse responses is set to 20 quarters. We consider the set of variables $V = \{d_t, \tau_t, c_t, y_t, n_t, w_t, i_t, \pi_t\}$ and compute the impulse response functions from a second-order accurate approximation of the equilibrium conditions under Ramsey fiscal policy of the variables in V to the exogenous shocks of our model g_t, a_t. Let these impulse responses be $\Phi^R_{i,t}$, for $i = 1$ to 8 and $t = 1$ to 20. In a similar fashion we let $\Phi_{i,t}(\alpha)$ be the impulse responses from a second-order accurate approximation of the model in which fiscal policy follows the theoretical rule (28), where $\alpha = \{\alpha_b, \alpha_g, \alpha_a\}$. Notice that impulse responses in $\Phi_{i,t}(\alpha)$ depend on the choice of the three parameters in the set α. Then we define the distance D between the equilibrium with Ramsey fiscal policy and the equilibrium with the theoretical rule as

$$\min_{\alpha} D = \frac{\sum_{i,t} W_{i,t} \left(\Phi^R_{i,t} - \Phi_{i,t}(\alpha)\right)^2}{\sum_{i,t} W_{i,t} \left(\Phi^R_{i,t}\right)^2}, \tag{29}$$

where $W_{i,t}$ are the weights assigned to each impulse response and period. We assign uniform weights both across time and impulse responses for two reasons. First, we are interested in matching both the short and medium run. Second, we do not have reason to give more importance to one set of impulse responses over the others. As will be clear from the discussion that follows, the results are robust to the particular choice of weights assigned to each impulse response. The denominator in (29) is a constant re-scaling factor that normalizes the distance to be equal to 1 when $\Phi_{i,t}(\alpha) = 0$ and zero if the theoretical rule model replicates exactly the impulse responses of the model with Ramsey fiscal policy.

The theoretical rule that minimizes the distance D is given by

$$\log\left(\frac{\tau_t}{\tau}\right) = 0.151 \log\left(\frac{b^g_t}{b^g}\right) + 0.036 \log\left(\frac{g_t}{g}\right) + 1.408 \log\left(\frac{a_t}{a}\right). \tag{30}$$

Figure 3 shows the impulse response functions to a government spending shock of the variables in V under Ramsey fiscal policy and under the theoretical fiscal rule (30). Figure 4 shows the impulse response functions to a technological shock. The dynamics generated by the theoretical fiscal rule is remarkably close to that generated by the Ramsey fiscal policy. The distance D for the theoretical fiscal rule is 0.008.

7 Methodological Issues for Empirical VARs

After having derived the Ramsey equilibrium and constructed a theoretical fiscal that approximates it well, we bring the model to the data. We consider the family of fiscal rules specified in (28) and we choose the values for the parameters $\alpha_b, \alpha_g, \alpha_a$ so as to minimize the

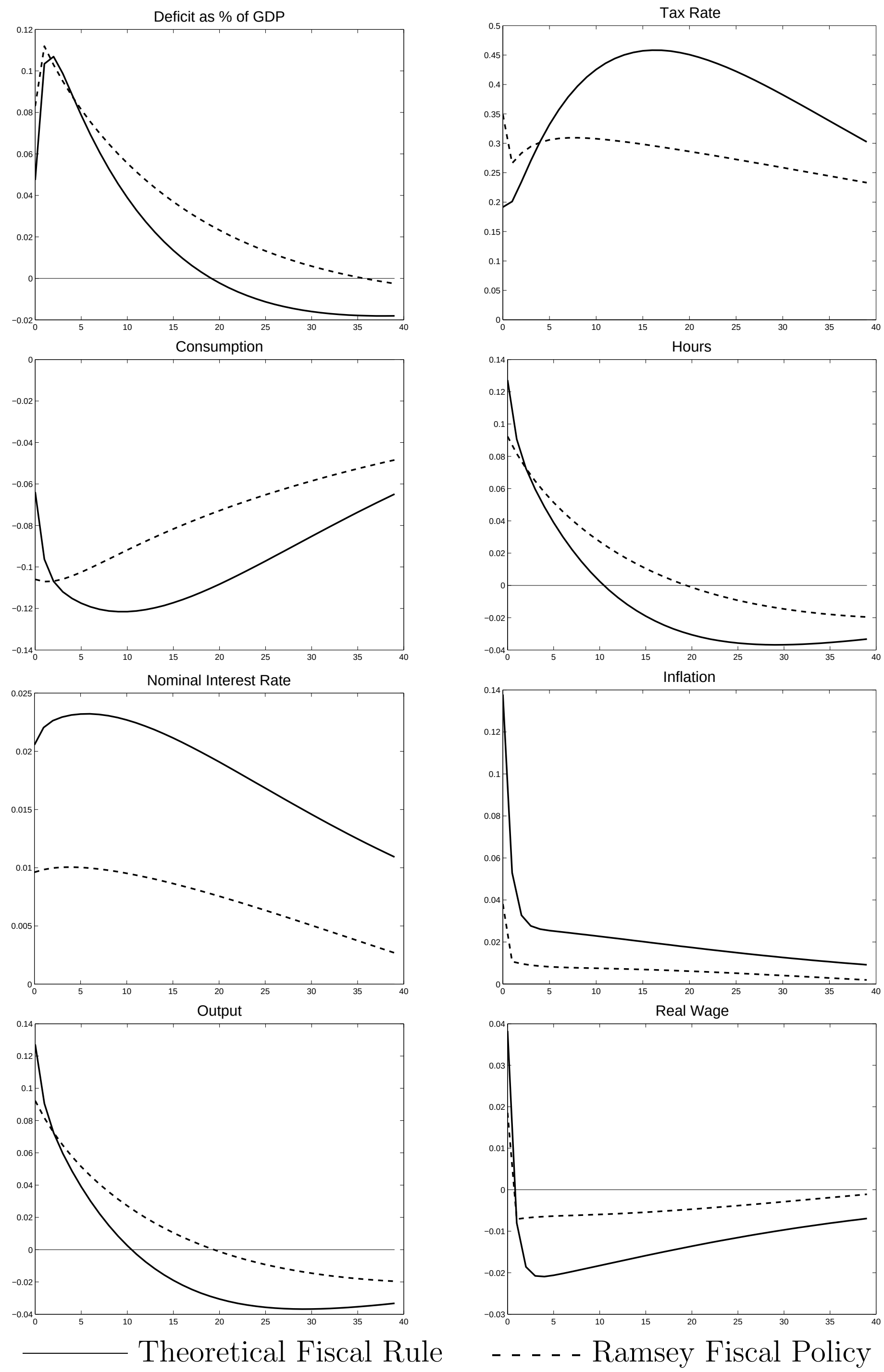

Figure 3: Impulse Responses to a Government Spending Shock

Note: All variables are expressed in percentage point deviations from their steady-state values.

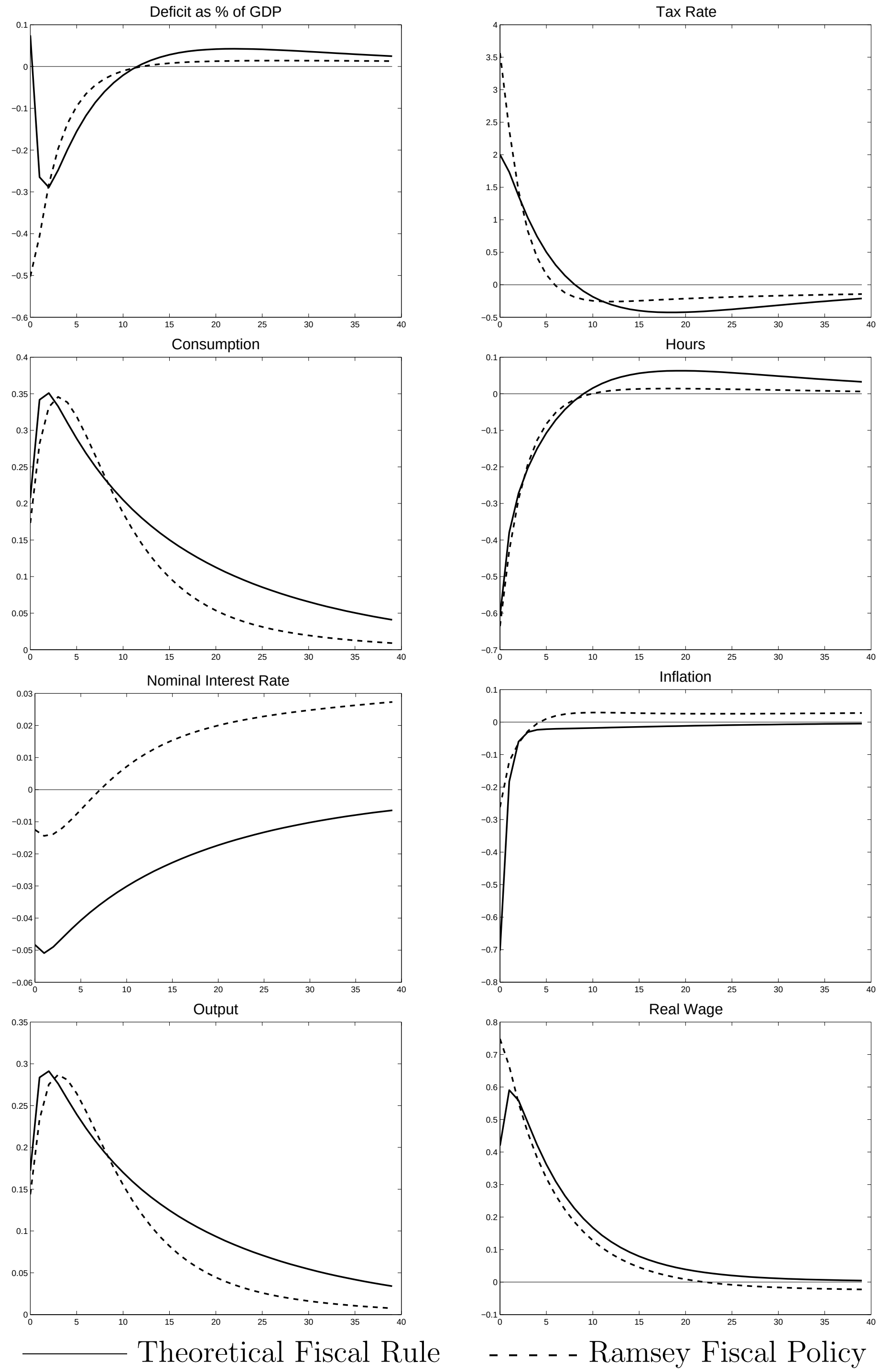

Figure 4: Impulse Responses to a Technological Shock

Note: All variables are expressed in percentage point deviations from their steady-state values.

distance between the empirical impulse responses and the impulse responses of the model with the theoretical fiscal rule. This estimated fiscal rule summarizes how U.S. income tax policy have been conducted in the last 25 years. We can then compare the theoretical and estimated fiscal rules and shed some light on how close actual fiscal policy has been to its optimal counterpart.

There are several ways to bring a theoretical model to the data. A first option is suggested by Sargent (1989) and it consists in adding error terms to the equations of the DSGE model. These errors can be interpreted as data measurement errors and the resulting hybrid model can be directly estimated. In order to fit the data, however, the error terms must be modeled as autocorrelated, which makes it difficult to interpret them as measurement errors. Furthermore, most of the persistence of the estimated model is due to the autocorrelation of the error terms rather than to a good fit of the model to the data.

An alternative method combines the use of VARs and DSGE models to obtain estimates of the deep structural parameters of the theoretical model. Galí et al. (2007) estimate different VARs (with 4 or 8 variables, including and excluding military spending, and using different sub-samples) and then calibrate a number of deep parameters of the theoretical model on the basis of selected statistics from the VARs, such as the impact effect or the half-life response of variables. Their calibrated model reproduces well the impact of government spending on macroeconomic variables.

A more comprehensive method is proposed by Woodford and Rotemberg (1998). They identify a monetary policy shock in a VAR on the basis of restrictions stemming from the theoretical model and then minimize the distance between empirical and theoretical impulse responses to the monetary shock. They focus on the short run responses of the model and match the first four quarters after the shock. As only monetary shocks are considered, Woodford and Rotemberg can identify separately a subset of the model's structural parameters of interest.

Bilbiie et al. (2006) apply this methodology to a model that includes fiscal policy and minimize the distance between theoretical and empirical (VAR) impulse responses to a government spending shock. They identify shocks to government spending on the assumption that the latter is not contemporaneously affected by the other variables in the VAR. Even though their measure of distance gives more weight to short-run observations, the model fits quite well the long period too.

We estimate a VAR using quarterly U.S. data. We include per capita real gross domestic product, per capital real government consumption, a measure of productivity consistent with our production function, namely output per man-hour in the non-farm business economy, non-farm business real hourly compensation, the average weekly hours of production workers (monthly converted into quarterly) and the deficit/GDP ratio.[7] To match the theoretical impulse responses with their empirical counterparts, we must identify the impulse response

[7]The data sources are: (1) BLS for average weekly hours of production workers and nonfarm business real hourly compensation; (2) BEA for real government cons per capita, gross domestic product per capita, the deficit ratio (annualized deficit divided by annualized gdp); (3) BIS for the output per man-hour in the nonfarm business economy.

functions of the VAR in a way consistent with the hypotheses underlying the theoretical model. Our model assumes that government spending and productivity are exogenous. This implies that government spending and technology are unaffected by contemporaneous shocks in other macroeconomic variables. Therefore, a consistent identification scheme assumes that government spending and productivity are not affected contemporaneously by the shocks in the other variables contained in the VAR.[8] This exogeneity assumption is implemented by placing government expenditure and productivity as the first variables in the VAR and using a Cholesky identification. The resulting VAR is:

$$\begin{bmatrix} \cdot & 0 & 0 \\ 0 & \cdot & 0 \\ \cdot & \cdot & \cdot \end{bmatrix} \cdot \begin{bmatrix} g \\ a \\ X \end{bmatrix} = A(L) \cdot \begin{bmatrix} g \\ a \\ X \end{bmatrix} + \begin{bmatrix} \varepsilon_g \\ \varepsilon_a \\ \varepsilon_X \end{bmatrix}$$

where X is the vector of macroeconomic variables and $A(L)$ is a matrix of free parameters. The contemporaneous matrix is not block triangular because of the presence of an extra zero that forces the contemporaneous effect of g and a to be zero.

We remain close to the existing literature and estimate a recursive VAR (using a Cholesky decomposition) that imposes the following identifying assumptions: (1) government spending is not contemporaneously affected by the other variables in the VAR (the two zeros in the first row of the contemporaneous matrix); (2) productivity is not contemporaneously affected by the other variables X in the VAR (the last zero in the second row). Hence, we do not impose the additional restriction that government spending does *not* contemporaneously affect productivity (the first zero in the second row), but we test it. It turns out that the condition is indeed verified and that a swap in estimation order between government spending and productivity would not significantly influence the impulse responses.

We considered alternative identification schemes (long-run restrictions and a mix of short- and long-run restrictions) but opted for a Cholesky decomposition for a number of reasons. First, as suggested earlier, our model assumes that government spending and technology are unaffected by contemporaneous shocks in the other macroeconomic variables. Second, there are no clear long-run restrictions for a government spending shock, whose permanent effect on the debt level depends on the response of the tax rate. Third, the scheme that identifies technological shocks as the only ones having a permanent effect on labor productivity in the long run is inconsistent with our model, which is expressed in deviations from a steady state, and with deterministic de-trending of the data, as we do given our relatively short estimation sample.

8 Empirical Estimate of the Linear Fiscal Rule

This section aims to find the parameter values of our simple fiscal rule that replicate well the empirical impulse response functions derived from the VAR analysis described above.[9]

[8] Blanchard and Perotti (2001), Fatás and Mihov (2001) and Galí et al. (2007) have also used such identification scheme.

[9] All variables are de-trended using a Hodrick-Prescott filter.

We use our matching technique by minimizing the distance between the impulse responses generated by the model under the tax rule (28) and the corresponding ones of the VAR. We consider a total of ten impulse responses, namely the responses of output, hours worked, real wage and deficit as percent of GDP to a government spending shock and to a productivity shock.[10] The first 20 periods of each impulse response are matched. As we discussed earlier, we assign equal weights to all periods and impulse responses.

The resulting empirical fiscal rule is

$$\log\left(\frac{\tau_t}{\tau}\right) = -0.047\log\left(\frac{b_t^g}{b^g}\right) + 0.306\log\left(\frac{g_t}{g}\right) - 0.556\log\left(\frac{a_t}{a}\right). \tag{31}$$

According to our findings, the U.S. tax rate has been increased in response to a positive technological shock and to a positive government spending shock. On the other hand, the tax rate has responded negatively to upwards movements of the government debt. Figures 5 and 6 show the empirical impulse responses and those derived by our model when rule (31) is implemented. The matching is good for most of the impulse responses. Overall, the impulse responses generated under (31) explain almost 74% of the dynamics implied by the VAR analysis. Therefore our empirical rule can be considered a good approximation of U.S. income tax policy in the last 20 years.

First, a positive shock (1%) to government spending generates a rise in output, with an impact effect of around 0.2% and an implied impact multiplier of about 1 and a maximum multiplier of 1.06 after two periods. This multiplier is comparable to Blanchard and Perotti (2002), who find an impact multiplier of around one. As in their papers, the effect is quite persistent, with a half-life of about nine quarters. Turning to the same impulse response under the tax rule derived above, it lies almost entirely within the plus and minus one-standard deviation bands. According to the model, output increases on impact by around 0.12% and displays a high degree of persistence although it returns to the initial level at a slightly faster pace with respect to the impulse response from the VAR.

Second, as in Galí et al. (2007), after a small, negative impact response, the real wage rises persistently and significantly in response to an increase in government spending, with a half-life of approximately 14 quarters. In this respect the fiscal rule is not able to fully capture the dynamics of real wages. As a matter of fact the impulse response of our empirical rule is practically flat. The dynamic response of hours worked is positive and significant on impact, a response to higher real wage. The model-based impulse response captures well the initial positive response of hours but it predicts a monotonic return to the steady state.

Third, a government spending shock increases the deficit ratio in the short run. The implied fiscal multiplier of a 1% increase in government spending is 0.86 at impact and 1.02 at its peak after two periods.The fiscal rule does a good job in mimicking the deficit

[10] Our model, like other standard models, does not match well the dynamic response of private consumption to a government spending shock, as pointed out by Galí et al. (2007). For this reason, we do not include private consumption in our set of matched impulse responses, as it would worsen the match of all our macroeconomic variables while still doing a poor job with private consumption.

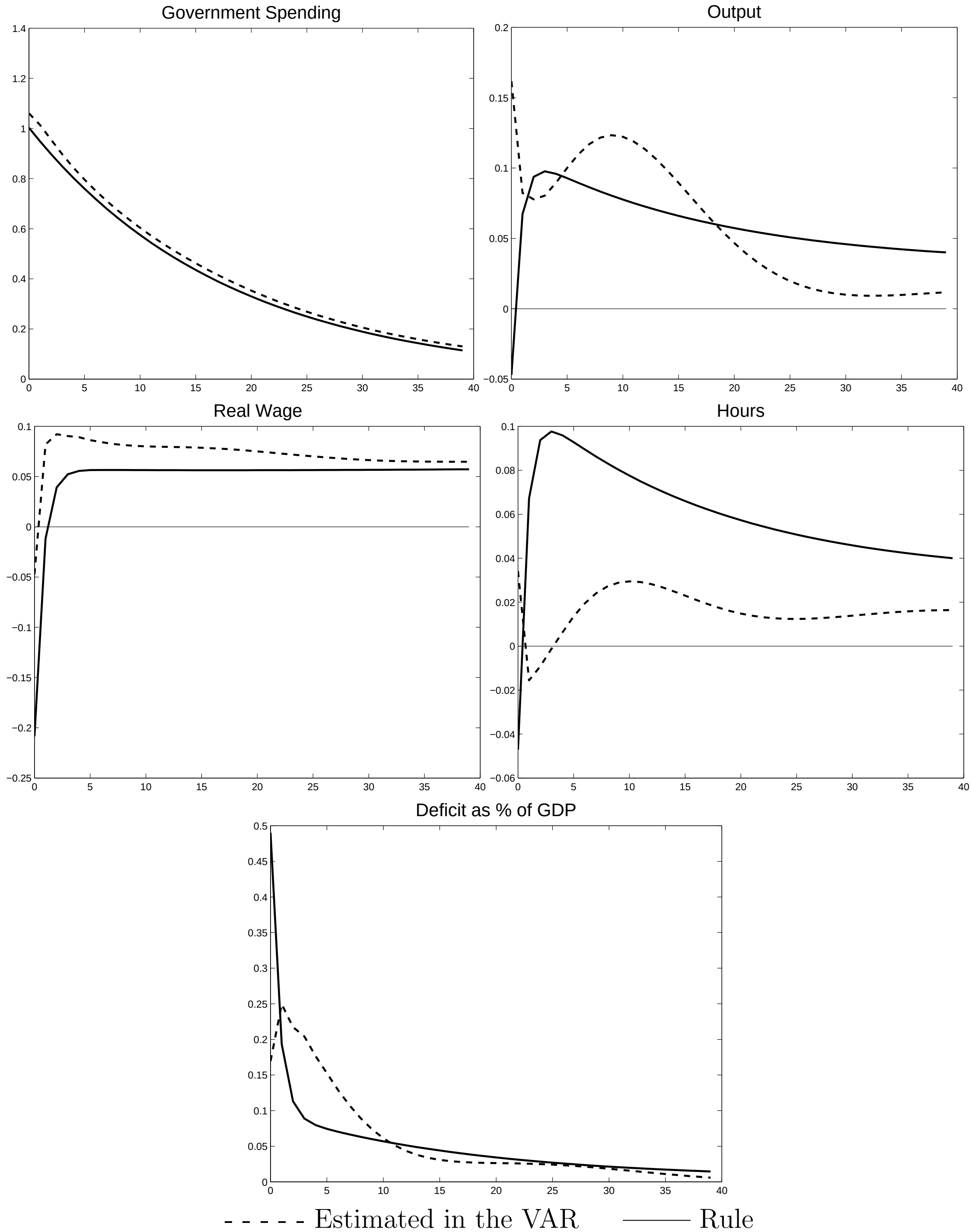

Figure 5: Impulse Responses to a Government Spending Shock

Note: Estimated in the VAR and theoretical impulse responses to a xx standard deviation innovation to government spending. The dotted lines are the confidence interval around the estimated impulse responses calculated as ±1 standard deviations of empirical distributions. Sample period for the estimated VAR: 1955:1 to 2007:4. The horizontal axis represents quarters after the shock.

dynamics, as the impulse response of the theoretical model lies completely within the +/- one-standard deviation bands.

The effects of a technology shock cannot be compared with the extant literature, as we are the first to match these impulse responses. A positive 1% shock to productivity increases output by about 0.5% on impact, with the effect remaining significant for 10 quarters. The corresponding impulse response under the empirical rule replicates well the dynamics under the VAR both on impact and in the longer horizon although with a larger magnitude. The real wage increases in the first two quarters by 0.6%, with a peak effect of 0.7%. Hours worked decline on impact and remain significantly below equilibrium throughout the length of the impulse response. Our empirical fiscal rule captures well the negative short-run response of hours worked to a technological shock, although it predicts a monotone response and is therefore unable to capture the peak effect after 10 quarters displayed by the impulse response of the VAR. The empirical rule also does a good job in capturing the response of the real wage, except in overstating such effect in the first two periods. Finally, a positive productivity shock has second round effects (via macroeconomic variables) on the government budget, significantly reducing the deficit ratio. The impulse response under the rule slightly overstates the response of the deficit in the first two period, but it performs very well from period 3 onwards.

Comparing the empirical rule with the theoretical rule (30) derived from the Ramsey equilibrium, it is clear that actual fiscal policies have not been optimal in the United States in the time horizon of our sample. The empirical rule suggests that the labor income tax rate has fallen by 0.09 percentage points in response to a 1 percentage point increase in real public debt in the last twenty years. Optimal fiscal policy, on the other hand, predicts an increase of the labor income tax rate of 0.06 percentage points. This finding raises some questions as to the long-run sustainability of U.S. fiscal policy.

As for the response to government spending, α_g, the empirical and theoretical rules have the same sign but the magnitude of the response in the empirical rule is almost three times greater than that in the theoretical one. This implies that actual U.S. income tax rates have overreacted to government spending changes.

The most problematic estimate to interpret is the one of α_a, which measures the response of the tax rate to productivity changes. Under optimal fiscal policy, the labor income tax rate should fall by 0.17 percentage points in response to a 1 percentage point increase in technology. The estimated fiscal rule implies that income tax rate have increased 0.53 percentage points in response to the shock. This suggests that labor income tax rates have been excessively pro-cyclical with respect to technological shocks and therefore with respect to output. This result is clearly in line with the finding in table 2 that U.S. labor income tax rates have been positively correlated with output over the business cycle while optimal ones should be negatively correlated. It appears that U.S. labor income tax rates have been raised during periods with output above trend and cut in periods with output below trend. As suggested earlier, this policy is suboptimal because it further reduces the supply of labor following a technological shock, thereby limiting its expansionary effect on the economy.

Figure 7 shows the responses of the labor income tax rate under the theoretical and the

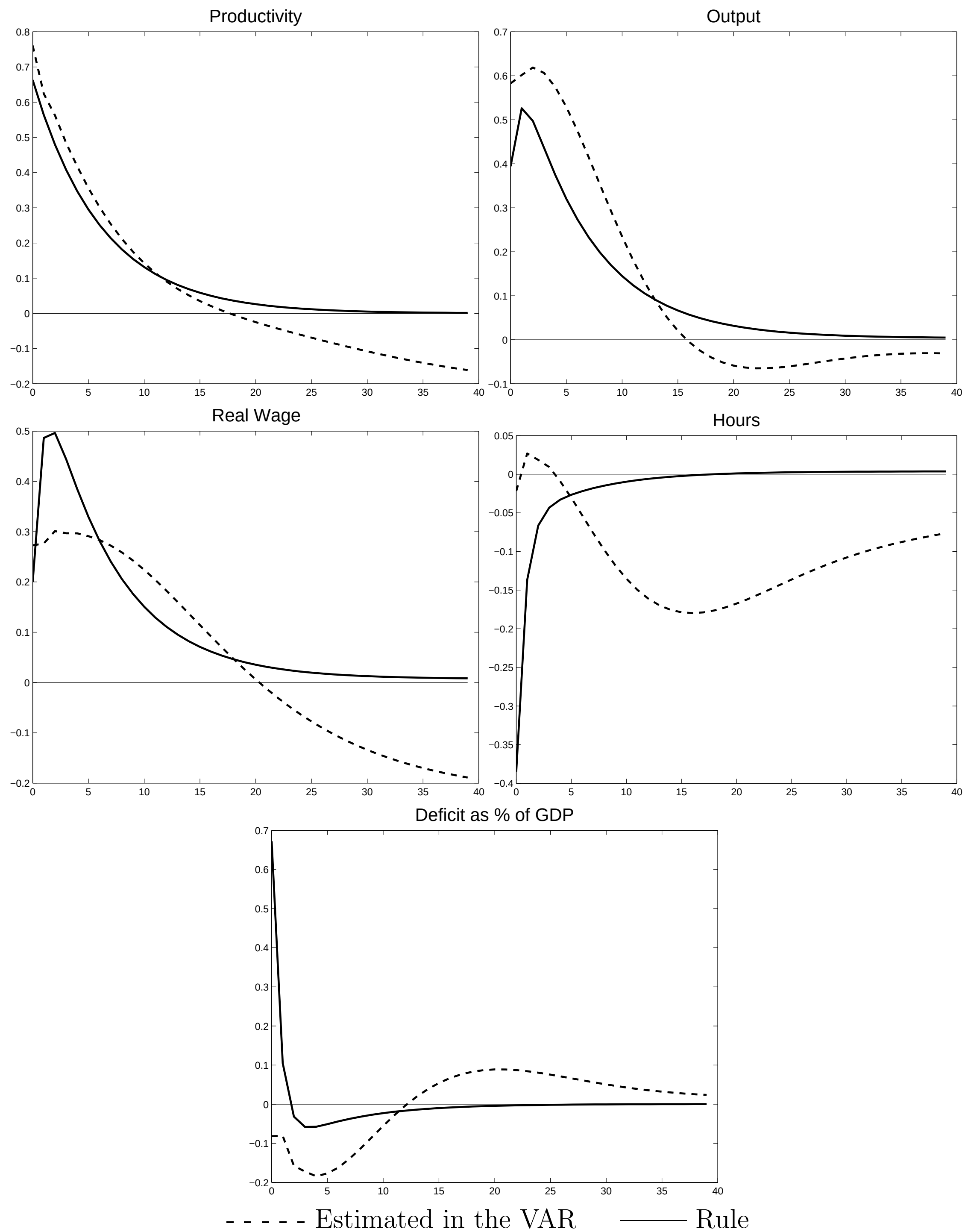

Figure 6: Impulse Responses to a Productivity Shock

Note: Estimated in the VAR and theoretical impulse responses to a xx standard deviation innovation to government spending. The dotted lines are the confidence interval around the estimated impulse responses calculated as ± 1 standard deviations of empirical distributions. Sample period for the estimated VAR: 1955:1 to 2007:4. The horizontal axis represents quarters after the shock.

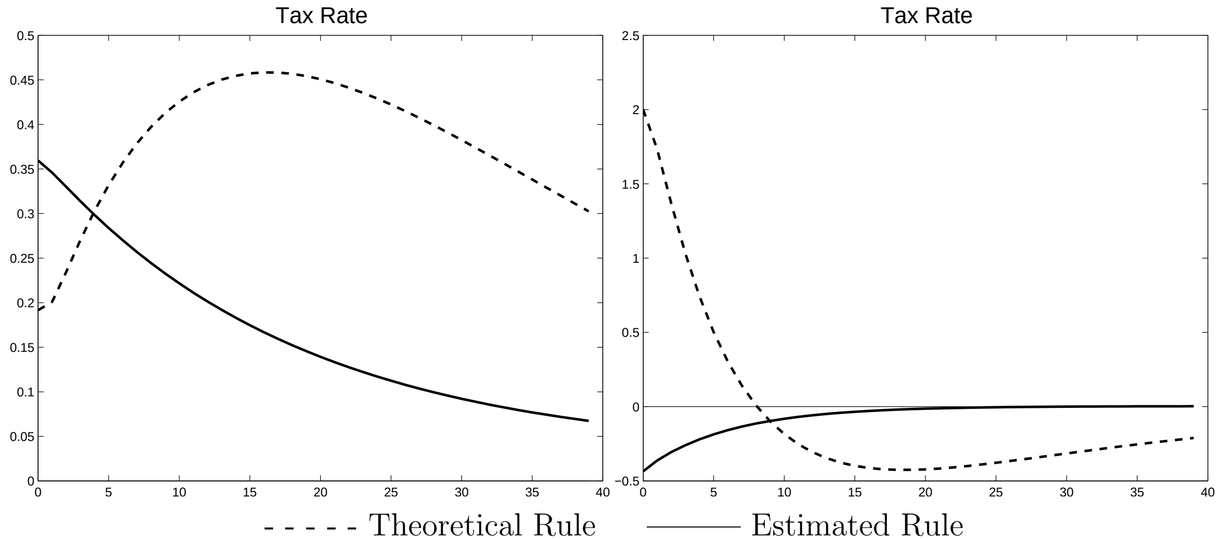

Figure 7: Impulse Responses to a Government Spending Shock (left) and a Productivity Shock (right)

empirical fiscal rule. The dynamics of the tax rate under the two fiscal rules are clearly different. Following a government spending shock, the estimated rule suggests that the tax rate is raised in the short run, but lowered in the long run, the latter stemming from the negative response of the tax rate to a change in government debt. Following a technological shock, the tax rate is raised instantaneously and then it keeps on increasing. Once again, the medium-run dynamics is dictated by the negative response of the tax rate to public debt, which also makes the dynamic system unstable.

9 Robustness

We have estimated our empirical VAR using two lags, as suggested by the selection criteria and in contrast with some of the existing literature that uses four lags.[11] To check if our results are robust to the number of lags included in the VAR, we re-estimate our VAR using four lags and performed again the matching of the empirical rule. The rules of the coefficient are reported in the following table:

	α_b	α_g	α_a	Distance
2 lags	-0.09	0.31	0.53	0.37
4 lags	-0.10	0.09	0.44	0.37

Table 3: Estimated Fiscal Rule with 2 and 4 Lags in the VAR

The rule matching the 4-lags VAR is similar to that matching the 2-lags VAR, though α_g is smaller. In any case, the qualitative features of the rule are preserved. The fit remains similar and good, supporting our choice of the more parsimonious specification.

[11](Galí et al. (2007), Bilbiie et al. (2006), Perotti (2004) and Blanchard and Perotti (2002).

Our class of simple, linear fiscal rules relates taxes to debt and to the shocks in the most parsimonious way. An alternative specification includes the lagged value of the tax rate as follows:

$$\log\left(\frac{\tau_t}{\tau}\right) = \alpha_b \log\left(\frac{b_t^g}{b^g}\right) + \alpha_g \log\left(\frac{g_t}{g}\right) + \alpha_a \log\left(\frac{a_t}{a}\right) + \alpha_\tau \log\left(\frac{\tau_{t-1}}{\tau}\right).$$

We re-estimate our theoretical and empirical fiscal rule using the specification above. The following parameter values we obtain are summarized in table 4 where, for ease of exposition, we report again the parameter values for the specification with the lagged tax rate

	α_b	α_g	α_a	α_τ	Distance
Theoretical without τ_{t-1}	0.06	0.11	-0.17	–	0.01
Theoretical with τ_{t-1}	0.01	0.04	-0.15	0.57	0.00
Empirical without τ_{t-1}	-0.08	0.31	0.53	–	0.37
Empirical with τ_{t-1}	-0.03	0.11	0.33	0.58	0.36

Table 4: Theoretical and Estimated Fiscal Rule with and without the lagged tax rate

The inclusion of the lagged tax rate takes into account part of the persistence of the system, thereby reducing the size of the other coefficients of the rule. This result is valid for both the theoretical and the empirical rule. Once again, the qualitative features of the rule remain unaltered and the fit remains good.

The introduction of habit persistence and capital are likely to affect only the first few periods of the response of the labor income tax and budget surpluses. Schmitt-Grohe and Uribe (2006) show that the labor income tax rate falls for a couple of quarters and then increases in response to a government spending shock while it increases for a couple of quarters and then it falls in response to a technological shock. We believe the qualitative findings of our paper will survive the introduction of these features.

We have assumed that monetary policy follows an interest rate rule that features a muted response to output. Under Ramsey fiscal policy, raising the parameter ϕ_y to 0.5 and lowering the parameter ϕ_i to 0, as originally suggested by Taylor (1993), is still going to: a) raise the income tax rate and generate deficits in response to a government spending shock; b) reduce the income tax rate generate surpluses in response to a technological shock. However, the short-run dynamic responses of the tax rate and surpluses depend critically on the values of the parameters of the interest-rate rule. This suggests that monetary-fiscal interactions are important.[12] At the same time, our empirical VARs would deliver inconsistent results and suggest the presence of a structural break in 1983:1 if we extend the sample to include data prior to that date. Hence, we leave the analysis of the period pre-1983 and alternative interest-rate rule to future works.

[12] As suggested already in the literature. See for example Dixit and Lambertini (2003).

10 Conclusions

We have studied the optimal response of taxes to temporary shocks to technology and government spending in an economy characterized by a number of frictions and used the result as a benchmark to evaluate actual fiscal policy in the United States. Both optimal and actual fiscal policies are summarized by a simple and linear tax rule whose coefficients are derived by minimizing the distance between impulse responses generated under the rule and alternatively by optimal fiscal policy and by empirical VARs.

Regarding optimal fiscal policies, we have three main findings. First, the optimal labor income tax rate has to increase in response to a positive government spending shock and decrease in response to a positive technological shock. However, the optimal labor income tax rate has limited volatility over the business cycle. Second, the optimal labor income tax rate has to respond positively to an increase in the public debt. Third, it is optimal running budget deficits in response to a positive government spending shock, determining an short-run positive effect on output. Therefore it is not always optimal to implement pro-cyclical budget balances with respect to output.

As for actual tax policy in the United States, our findings can be summarized as follows. First, the tax rate responds positively both to a positive government spending shock (as predicted by optimal fiscal policy) and, contrarily to the optimal rule, to a positive technological shock. We believe therefore that the U.S. tax policy has been conducted in a sub-optimal manner by having been “excessively” counter-cyclical. Second, budget surpluses are small and barely significant following a technological shock, while at the same time the output response is lower than predicted under optimal fiscal policy. Third, U.S. tax rates have responded negatively to public debt, unlike what is predicted by optimal fiscal policy: Increasing public debt ratios have not triggered higher tax rates. Therefore, it is questionable whether U.S. fiscal policy can be sustained in the long-run.

The analysis carried out in this paper lends itself to a number of extensions. The model has been kept rather simple in order to develop the matching methodology in the cleanest and easiest way. However, a number of features can be added in order to capture several patterns shown in the data. Without been exhaustive, we can mention the introduction of rule-of-thumb consumers, as in Galí (2007) or Bilbiie et al (2006), in order to capture the positive response of private consumption to a positive government spending shock shown in the data.

The empirical analysis can also be extended to other regions. In fact, it would be interesting to replicate the study for the European Union or the Euro Area. However, good quarterly fiscal data are lacking at the moment. As an intermediate step, it is our intention to start with country studies selecting those European countries where data availability allows good empirical work.

References

Aiyagari, S. Rao; Marcet, Albert; Sargent, Thomas J. and Juha Seppala. 2002. "Optimal Taxation without State-Contingent Debt," *Journal of Political Economy,* 110(6), December, 1220-54.

Basu, Susantu and John Fernald. 1997. "Returns to Scale in U.S. Production: Estimates and Implications," *Journal of Political Economy,* 105, 249-83. April.

Bilbiie, Florin O., Meier, Andre and Gernot J. Muller. 2006. "What Accounts for the Changes in U.S. Fiscal Policy Transmission?" ECB working paper No. 582.

Bils, Mark and Peter Klenow. 2004. "Some Evidence on the Importance of Sticky Prices." *Journal of Political Economy,* 112.

Blanchard, Olivier and Roberto Perotti. 2002. "An Empirical Characterization of the Dynamic Effects of Changes in Government Spending and Taxes on Output," *The Quarterly Journal of Economics,* Vol. 117, No. 4, 1329-1368.

Chari, V. V.; Christiano, Lawrence J. and Patrick J. Kehoe. 1991. "Optimal Fiscal and Monetary Policy: Some Recent Results," *Journal of Money, Credit and Banking,* 23, August, 519-39.

Clarida, Richard, Galí, Jordi and Mark Gertler. 1999. "The Science of Monetary Policy: A New Keynesian Perspective," *Journal of Economic Literature,* 37, 1661-1707.

Clarida, Richard, Galí, Jordi and Mark Gertler. 2000. "Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory," *Quarterly Journal of Economics,* 115(1), 147-80.

Dixit, Avinash and Luisa Lambertini. 2003a. "Interactions of Commitment and Discretion in Monetary and Fiscal Policies." *American Economic Review*, 93(5), December, 1522–42.

Fatas, Antonio and Mihov, Ilian. 2001. "Government Size and Automatic Stabilizers: International and Intranational Evidence," *Journal of International Economics,* 55(1), 3-28.

Galí, Jordi; Lopez-Salido J. David and Javier Valles. 2007. "Understanding the Effects of Government Spending on Consumption," *Journal of the European Economic Association,* 5(1), March, 227-70.

Lambertini, Luisa. 2007. "Optimal Fiscal Policy in a Monetary Union," working paper.

Lucas, Robert and Nancy Stokey. 1983. "Optimal Fiscal and Monetary Policy in an Economy without Capital." *Journal of Monetary Economics,* 12(1): 55-93.

Perotti, Roberto. 2004. "Estimating the Effects of Fiscal Policy in OECD Countries". *mimeo,* IGIER, Bocconi Univerity, Milan.

Rotemberg, Julio and Michael Woodford. 1999. "Interest Rate Rules in an Estimated Sticky Price Model." *Monetary Policy Rules,* Taylor, J. ed. The University of Chicago Press, 57-119.

Sargent, Thomas. 1989. "Two Models of Measurements and the Investment Accelerator," *Journal of Political Economy,* 97(2): 251-87.

Sbordone, Argia. 2002. "Prices and Unit Labor Costs: A New Test of Price Stickiness," *Journal of Monetary Economics,* 49(2), 265-292.

Schmitt-Grohe, Stephanie and Martin Uribe. 2004a. "Optimal Monetary and Fiscal Policy Under Sticky Prices." *Journal of Economic Theory,* 114 (2), 198-230.

Schmitt-Grohe, Stephanie and Martin Uribe. 2004b. "Solving Dynamic General Equilibrium Models Using a Second-Order Approximation to the Policy Function." *Journal of Economic Dynamics and Control,* 28, January, 755-775. September.

Schmitt-Grohe, Stephanie and Martin Uribe. 2004c. "Optimal Simple and Implementable Monetary and Fiscal Rules, "NBER Working Papers 10253.

Schmitt-Grohe, Stephanie and Martin Uribe. 2006. "Optimal Fiscal and Monetary Policy in a Medium-Scale Macroeconomic Model," in Gertler, Mark and Kenneth Rogoff, eds., *NBER Macroeconomics Annual 2005,* MIT Press: Cambridge, MA, 383-425.

Taylor, John B. 1993. "Discretion Versus Policy Rules in Practice," *Carnegie-Rochester Conference Series on Public Policy,* 39, pp. 195-214.

Taylor, John B. 1999. "A Historical Analysis of Monetary Policy Rules," in Taylor, John B. ed. *Monetary policy rules,* NBER Conference Report series: Chicago and London: University of Chicago Press, 341-44.

Woodford, Michael. 2003. *Interest & Prices.* Princeton University Press.