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Author: Stephanie Schmitt-Grohé, Martín Uribe

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Optimal Fiscal and Monetary Policy in a Medium-Scale Macroeconomic Model

Stephanie Schmitt-Grohé, *Duke University, CEPR, and NBER*
Martín Uribe, *Duke University and NBER*

1 Introduction

This paper addresses a classic question in macroeconomics, namely: How should a benevolent government conduct stabilization policy? A central characteristic of all existing studies is that optimal policy is derived in highly stylized environments. Typically, optimal policy is characterized for economies with a single or a very small number of deviations from the frictionless neoclassical paradigm. A case in point is the large number of recent studies concerned with optimal monetary policy within the context of the two-equation, one-friction, neo-Keynesian model without capital accumulation.[1] Another example of studies in which the optimal policy design problem is analyzed within theoretical frameworks featuring a small number of rigidities include models with flexible prices and distorting income taxes (Lucas and Stokey 1983, Schmitt-Grohé and Uribe 2004a). An advantage of this stylized approach to optimal stabilization policy is that it facilitates understanding the ways in which policy should respond to mitigate the distortionary effects of a particular friction in isolation.

An important drawback of studying optimal stabilization policy one distortion at a time is that highly simplified models are unlikely to provide a satisfactory account of cyclical movements for more than just a few macroeconomic variables of interest. For this reason, the usefulness of this strategy for producing policy advice for the real world is necessarily limited.

The approach to optimal policy that we propose in this paper departs from the literature extant in that it is based on a rich, medium-scale, theoretical framework capable of explaining observed business-cycle fluctuations for a wide range of nominal and real variables. Following the lead of Kimball (1995), the model emphasizes the importance of combining nominal as well as real rigidities in explaining the propagation of macroeconomic shocks. Specifically, the model features four nominal frictions: sticky prices, sticky wages, a demand for money by households, and a cash-in-advance constraint on the wage bill of firms, and it features five sources of real rigidities: investment adjustment costs, variable capacity utilization, habit formation, imperfect competition in product and factor markets, and distortionary taxation. Aggregate fluctuations are assumed to be driven by supply shocks, which take the form of stochastic variations in total factor productivity, and demand shocks stemming from exogenous innovations to the level of government purchases and the level of government transfers. Altig et al. (2004) and Christiano, Eichenbaum, and Evans (2005) argue that the model economy for which we seek to design optimal policy can indeed explain the observed responses of inflation, real wages, nominal interest rates, money growth, output, investment, consumption, labor productivity, and real profits to productivity and monetary shocks in the postwar United States. In this respect, the present paper aspires to be a step ahead in the research program of generating policy evaluation that is of relevance for actual policymaking.

The government is assumed to be benevolent in the Ramsey sense; that is, it seeks to bring about the competitive equilibrium that maximizes the lifetime utility of the representative agent and has access to a commitment technology that allows it to honor its promises. The policy instruments available to the government are assumed to be taxes on income, possibly, differentiated across different sources of income, and the short-term nominal interest rate. Public debt is assumed to be nominal and non-state-contingent.

A key finding of the paper is that price stability appears to be a central goal of optimal monetary policy. The optimal rate of inflation under an income tax regime is 0.5 percent per year with a volatility of 1.1 percent. In this sense, price stickiness emerges as the single most important distortion shaping optimal policy. This result is surprising given that the model features a number of other frictions that, in isolation, would call for a volatile rate of inflation with a mean different from zero.

Consider first the forces calling for an optimal inflation rate that is different from zero. As is well known, the presence of a demand for money by households provides an incentive to drive inflation down to a level consistent with the Friedman rule. In this paper, we identify two additional reasons why the Ramsey planner may want to deviate from price stability. First, under an income tax regime, i.e., when all sources of income are taxed at the same rate, the Ramsey planner has an inflationary bias originating from the fact that it is less distorting to tax labor income than it is to tax capital income. With a cash-in-advance constraint on the wage bill of firms, inflation acts as a tax on labor income. Second, the Ramsey planner has an incentive to tax away transfers because they represent pure rents accruing to households. Without direct instruments to tax transfers, the government imposes an indirect levy on this source of household income via the inflation tax.

Optimal policy calls for low inflation volatility in spite of the following two distortions that by themselves call for high inflation volatility. First, the facts that nominal government debt is non-state-contingent and that regular taxes are distortionary make it attractive for the Ramsey planner to use unexpected variations in inflation as a lump-sum tax on private holdings of nominal government liabilities. This is indeed the reason why, in flexible price environments, the optimal inflation volatility is very high (see, for example, Calvo and Guidotti 1990, 1993; and Chari et al. 1991). Second, the fact that nominal wages are sticky provides an incentive for the government to set the price level so as to engineer the efficient real wage. This practice, when studied in isolation, also makes high inflation volatility optimal.

When the fiscal authority is allowed to tax capital and labor income at different rates, optimal fiscal policy is characterized by a large and volatile subsidy on capital. It is well known from the work of Judd (2002) that, in the presence of imperfect competition in product markets, optimal taxation calls for a subsidy on capital of a magnitude approximately equal to the markup of prices over marginal cost. However, our results suggest that the optimal capital subsidy is much larger than the one identified in the work of Judd. The reason for this discrepancy is that capital depreciation in combination with a depreciation allowance, which is ignored in the work of Judd, exacerbates the need to subsidize capital. This is because the markup distorts the gross rate of return on capital, whereas the subsidy applies to the return on capital net of depreciation.

In our model, the optimal capital subsidy is extremely volatile. Its standard deviation is 150 percent. The high volatility of capital income taxes emerges for the familiar reason that capital is a fixed factor of production in the short run, so the fiscal authority uses unexpected changes in the capital income tax rate as a shock absorber for innovations in its budget (see, for example, Judd 1992). We identify two frictions capable of driving this high volatility down significantly. One is time to tax. When tax rates are determined four quarters in advance, the optimal volatility of the capital income tax rate falls to about 50 percent. This is because the tax elasticity of the demand for capital increases with the number of periods between the announcement of the tax rate and its application. The second friction that is important in understanding the volatility of capital taxes is investment adjustment costs. Intuitively, the higher the impediments to adjusting the level of investment, the lower the elasticity of capital with respect to temporary changes in tax rates. In the absence of investment adjustment costs, the optimal volatility of the capital income tax rate falls to 65 percent. Furthermore, in an environment with four periods of time to tax and no capital adjustment cost, the optimal capital income tax has a volatility of 25 percent.

Ramsey outcomes are mute on the issue of what policy regimes can implement them. The information on policy one can extract from the solution to the Ramsey problem is limited to the equilibrium behavior of policy variables such as tax rates, the nominal interest rate, etc., as a function of the state of the economy. Even if the policymaker could observe the state of the economy, using the equilibrium process of the policy variables to define a policy regime would not guarantee the Ramsey outcome as the competitive equilibrium. The problem is that such a policy regime could give rise to multiple equilibria. We address the issue of implementation of optimal policy by limiting attention to simple monetary and fiscal rules. These rules are defined over a small set of readily available macro indicators and are designed to ensure local uniqueness of the rational expectations equilibrium. We find parameterizations of such policy rules capable of inducing equilibrium dynamics fairly close to those associated with the Ramsey equilibrium.

Finally, a methodological contribution of this paper is the development of a set of numerical tools that allow the computation of Ramsey policy in a general class of stochastic dynamic general equilibrium models. Matlab code to implement these computations is available at the authors' websites.

The remainder of the paper is organized in six sections. Section 2 presents the theoretical model and its calibration. Section 3 characterizes the Ramsey steady state. Section 4 studies the Ramsey dynamics in an economy where the fiscal authority is constrained to taxing all sources of income at the same rate. Section 5 identifies simple interest-rate and tax rules capable of mimicking well the Ramsey equilibrium dynamics. Section 6 studies the Ramsey problem in an economy in which capital and labor can be taxed at different rates. This section also analyzes the consequences of time to tax. Section 7 concludes.

2 The Model

The essential elements of the model economy that serves as the basis for our study of stabilization policy are taken from a recent paper by Christiano, Eichenbaum, and Evans (2005). This model and variations thereof have been estimated by a number of authors in the past couple of years. The structure of the model is the standard neoclassical growth model augmented with a number of real and nominal frictions. The nominal frictions are sticky prices, sticky wages, a money demand by households, and a money demand by firms. The real frictions consist of monopolistic competition in product and factor markets, habit formation, investment adjustment costs, variable capacity utilization, and distortionary taxation. We keep the description of the model brief and refer the reader to the expanded version of this paper (Schmitt-Grohé and Uribe 2005b) for a more detailed exposition.

2.1 The Private Sector

The economy is assumed to be populated by a large representative family with a continuum of members. Consumption and hours worked are identical across family members. The household's preferences are defined over per capita consumption, c_t, and per capita labor effort, h_t, and are described by the utility function:

$$E_0 \sum_{t=0}^{\infty} \beta^t \frac{[(c_t - bc_{t-1})^{1-\phi_4}(1-h_t)^{\phi_4}]^{1-\phi_3} - 1}{1-\phi_3}$$

where E_t denotes the mathematical expectations operator conditional on information available at time t, $\beta \in (0,1)$ represents a subjective discount factor, and $\phi_3 > 0$ and $\phi_4 \in (0,1)$ are parameters. Preferences display internal habit formation, measured by the parameter $b \in [0,1)$. The consumption good is assumed to be a composite made of a continuum of differentiated goods c_{it} indexed by $i \in [0,1]$ via the aggregator:

$$c_t = \left[\int_0^1 c_{it}^{1-1/\eta}\, di\right]^{1/(1-1/\eta)} \tag{6.1}$$

where the parameter $\eta > 1$ denotes the intratemporal elasticity of substitution across different varieties of consumption goods.

For any given level of consumption of the composite good, purchases of each individual variety of goods $i \in [0,1]$ in period t must solve the dual problem of minimizing total expenditure, $\int_0^1 P_{it} c_{it}\, di$, subject to the aggregation constraint given in equation (6.1), where P_{it} denotes the nominal price of a good of variety i at time t. The demand for goods of variety i is then given by:

$$c_{it} = \left(\frac{P_{it}}{P_t}\right)^{-\eta} c_t$$

where P_t is a nominal price index defined as:

$$P_t \equiv \left[\int_0^1 P_{it}^{1-\eta}\, di\right]^{1/(1-\eta)}$$

This price index has the property that the minimum cost of a bundle of intermediate goods yielding c_t units of the composite good is given by $P_t c_t$.

Labor decisions are made by a central authority within the household, a union, which supplies labor monopolistically to a continuum of labor markets of measure 1 indexed by $j \in [0,1]$. In each labor market j, the union faces a demand for labor given by $(W_t^j/W_t)^{-\tilde{\eta}} h_t^d$. Here, W_t^j denotes the nominal wage charged by the union in labor market j at time t, W_t is an index of nominal wages prevailing in the economy, and h_t^d is a measure of aggregate labor demand by firms. In each particular labor market, the union takes W_t and h_t^d as exogenous. The case in which the union takes aggregate labor variables as endogenous can be interpreted as an environment with highly centralized labor unions. Higher-level labor organizations play an important role in some European and Latin American countries, but they are less prominent in the United States. Given the wage charged in each labor market $j \in [0,1]$, the union is assumed to supply enough labor, h_t^j, to satisfy demand. That is:

$$h_t^j = \left(\frac{w_t^j}{w_t}\right)^{-\tilde{\eta}} h_t^d \tag{6.2}$$

where $w_t^j \equiv W_t^j/P_t$ and $w_t \equiv W_t/P_t$. In addition, the total number of hours allocated to the different labor markets must satisfy the resource constraint $h_t = \int_0^1 h_t^j\, dj$. Combining this restriction with equation (6.2), we obtain:

$$h_t = h_t^d \int_0^1 \left(\frac{w_t^j}{w_t}\right)^{-\tilde{\eta}} dj$$

Our setup of imperfectly competitive labor markets departs from most existing expositions of models with nominal wage inertia. For in these models, it is assumed that each household supplies a differentiated type of labor input. This assumption introduces equilibrium heterogeneity across households in the number of hours worked. To avoid this heterogeneity from spilling over into consumption heterogeneity, it is typically assumed that preferences are separable in consumption and hours and that financial markets exist that allow agents to fully insure against employment risk. Our formulation has the advantage of avoiding the need to assume both separability of preferences in leisure and consumption and the existence of such insurance markets. As we will explain later in more detail, our specification gives rise to a wage-inflation Phillips curve with a larger coefficient on the wage-markup gap than the model with employment heterogeneity across households.

The household is assumed to own physical capital, k_t, which accumulates according to the following law of motion:

$$k_{t+1} = (1-\delta)k_t + i_t\left[1 - \frac{\kappa}{2}\left(\frac{i_t}{i_{t-1}} - 1\right)^2\right]$$

where i_t denotes gross investment, and δ is a parameter denoting the rate of depreciation of physical capital. The process of capital accumulation is subject to investment adjustment costs. The assumed functional form for the adjustment-cost function implies that up to first-order adjustment costs are nil in the vicinity of the deterministic steady state. The parameter κ is positive.

Owners of physical capital can control the intensity at which this factor is utilized. Formally, we let u_t measure capacity utilization in period t. We assume that using the stock of capital with intensity u_t entails a cost of $[\gamma_1(u_t - 1) + \gamma_2/2(u_t - 1)^2]k_t$ units of the composite final good. The parameters γ_1 and γ_2 take on positive values. Both the specification of capital adjustment costs and capacity utilization costs are somewhat peculiar. More standard formulations assume that adjustment costs depend on the level of investment rather than on its growth rate, as is assumed here. Also, costs of capacity utilization typically take the form of a higher rate of depreciation of physical capital. The modeling choice here is guided by the need to fit the response of investment and capacity utilization to a monetary shock in the U.S. economy. For further discussion of this point, see Christiano, Eichenbaum, and Evans (2005, Section 6.1) and Altig et al. (2004).

Households rent the capital stock to firms at the real rental rate r_t^k per unit of capital. Thus, total income stemming from the rental of capital is given by $r_t^k u_t k_t$. The investment good is assumed to be a composite good made with the aggregator function in equation (6.1). Thus, the demand for each intermediate good $i \in [0,1]$ for investment purposes, i_{it}, is given by $i_{it} = i_t(P_{it}/P_t)^{-\eta}$.

As in earlier related work (Schmitt-Grohé and Uribe 2004b, Altig et al. 2004), we motivate a demand for money by households by assuming that purchases of consumption are subject to a proportional transaction cost that is increasing in consumption-based money velocity. Formally, the purchase of each unit of consumption entails a cost given by $\phi_1 v_t + \phi_2/v_t - 2\sqrt{\phi_1\phi_2}$. Here:

$$v_t \equiv \frac{c_t}{m_t^h}$$

is the ratio of consumption to real money balances held by the household, which we denote by m_t^h. The functional form assumed for the transaction cost technology ensures that the Friedman rule, i.e., a zero nominal interest rate, need not be associated with an infinite demand for money. It also implies that both the transaction cost and the distortion it introduces vanish when the nominal interest rate is zero. The transaction cost function also guarantees that in equilibrium, money velocity is always greater than or equal to a satiation level given by $\sqrt{\phi_2/\phi_1}$. Our specification of the transaction technology ensures that the demand for money is decreasing in the nominal interest rate.

Households are assumed to have access to a complete set of nominal state-contingent assets. Specifically, each period $t \geq 0$, consumers can purchase any desired state-contingent nominal payment X_{t+1}^h in period $t+1$ at the dollar cost $E_t r_{t,t+1} X_{t+1}^h$. The variable $r_{t,t+1}$ denotes a stochastic nominal discount factor between periods t and $t+1$. Households must pay taxes on labor income, capital income, and profits. We denote by τ_t^h, τ_t^k, and τ_t^ϕ, respectively, the labor income tax rate, the capital income tax rate, and the profit tax rate in period t. A tax allowance is assumed to apply to costs due to depreciation. Households receive real lump-sum transfers from the government in the amount n_t per period. The household's period-by-period budget constraint is given by:

$$E_t r_{t,t+1} x_{t+1}^h + c_t[1 + \phi_1 v_t + \phi_2/v_t - 2\sqrt{\phi_1\phi_2}] + i_t + m_t^h$$
$$= \frac{x_t^h + m_{t-1}^h}{\pi_t} + n_t + (1 - \tau_t^k)[r_t^k u_t - \gamma_1(u_t - 1) - \gamma_2/2(u_t - 1)^2]k_t$$
$$+ \tau_t^k q_t \delta k_t + (1 - \tau_t^h) h_t^d \int_0^1 w_t^j \left(\frac{w_t^j}{w_t}\right)^{-\tilde{\eta}} dj + (1 - \tau_t^\phi)\phi_t$$

The variable $x_t^h/\pi_t \equiv X_t^h/P_t$ denotes the real payoff in period t of nominal state-contingent assets purchased in period $t-1$. The variable ϕ_t denotes dividends received from the ownership of firms, q_t denotes the price of capital in terms of consumption, and $\pi_t \equiv P_t/P_{t-1}$ denotes the gross rate of consumer-price inflation.

We introduce wage stickiness in the model by assuming that each period the household (or union) cannot set the nominal wage optimally in a fraction $\tilde{\alpha} \in [0, 1)$ of randomly chosen labor markets. In these markets, the wage rate is indexed to the previous period's consumer-price inflation according to the rule $W_t^j = W_{t-1}^j \pi_{t-1}^{\tilde{\chi}}$, where $\tilde{\chi}$ is a parameter measuring the degree of wage indexation. When $\tilde{\chi}$ equals 0, there is no wage indexation. When $\tilde{\chi}$ equals 1, there is full wage indexation to past consumer price inflation. In general, $\tilde{\chi}$ can take any value between 0 and 1.

Each variety of final goods is produced by a single firm in a monopolistically competitive environment. Each firm $i \in [0, 1]$ produces output using as factor inputs capital services, k_{it}, and labor services, h_{it}. The production technology is given by:

$$z_t k_{it}^{\theta} h_{it}^{1-\theta} - \psi$$

where the parameter θ lies between 0 and 1. The variable z_t denotes an aggregate, exogenous, and stochastic productivity shock whose law of motion is given by:

$$\ln z_t = \rho_z \ln z_{t-1} + \epsilon_t^z$$

where $\rho_z \in (-1, 1)$, and ϵ_t^z is an i.i.d. innovation with mean zero, standard deviation σ_{ϵ^z}, and bounded support. The parameter $\psi > 0$ introduces fixed costs of operating a firm in each period. It implies that the production function exhibits increasing returns to scale. We model fixed costs to ensure a realistic profit-to-output ratio in steady state.

Aggregate demand for good i, which we denote by y_{it}, is given by:

$$y_{it} = (P_{it}/P_t)^{-\eta} y_t$$

where:

$$y_t \equiv c_t[1 + \phi_1 v_t + \phi_2/v_t - 2\sqrt{\phi_1\phi_2}] + i_t + g_t$$
$$+ [\gamma_1(u_t - 1) + \gamma_2/2(u_t - 1)^2]k_t$$

denotes aggregate absorption. The variable g_t denotes government consumption of the composite good in period t.

We rationalize a demand for money by firms by imposing that wage payments be subject to a cash-in-advance constraint of the form:

$$m_{it}^f \geq \nu w_t h_{it}$$

where m_{it}^f denotes the demand for real money balances by firm i in period t and $\nu \geq 0$ is a parameter indicating the fraction of the wage bill that must be backed with monetary assets. The presence of a working-capital requirement introduces a financial cost of labor that is increasing in the nominal interest rate. We note also that because all firms face the same factor prices and because they all have access to the same production technology that is linearly homogeneous up to a constant term, marginal costs are identical across firms.

Prices are assumed to be sticky à la Calvo (1983) and Yun (1996). Specifically, each period $t \geq 0$, a fraction $\alpha \in [0, 1)$ of randomly picked firms is not allowed to optimally set the nominal price of the good they produce. Instead, these firms index their prices to past inflation according to the rule $P_{it} = P_{it-1}\pi_{t-1}^{\chi}$. The interpretation of the parameter χ is the same as that of its wage counterpart $\tilde{\chi}$. The remaining $1 - \alpha$ firms choose prices optimally.

2.2 *The Government*

Each period, the government consumes g_t units of the composite good. We assume that the variable g_t is exogenous and that its logarithm follows a first-order autoregressive process of the form:

$$\ln(g_t/\bar{g}) = \rho_g \ln(g_{t-1}/\bar{g}) + \epsilon_t^g$$

where $\rho_g \in (-1, 1)$ and $\bar{g} > 0$ are parameters, and ϵ_t^g is an i.i.d. innovation with mean zero, standard deviation σ_{ϵ^g}, and bounded support. The parameter $\bar{g}$ represents the nonstochastic steady-state level of government absorption. We assume that the government minimizes the cost of producing g_t. As a result, public demand for each variety $i \in [0, 1]$ of differentiated goods g_{it} is given by $g_{it} = (P_{it}/P_t)^{-\eta} g_t$. A second source of government expenditures is transfer payments to households in the amount n_t, measured in units of the composite good. Like government consumption, transfers are assumed to be exogenous and to follow the law of motion:

$$\ln(n_t/\bar{n}) = \rho_n \ln(n_{t-1}/\bar{n}) + \varepsilon_t^n$$

where $\rho_n \in (-1, 1)$ and $\bar{n} > 0$ are parameters, and ε_t^n is an i.i.d. innovation with mean zero, standard deviation σ_{ε^n}, and bounded support. The parameter $\bar{n}$ represents the nonstochastic steady-state level of government transfers.

The government levies labor, capital, and profit income taxes. It grants allowances for the costs of depreciation and variations in capacity utilization. Total tax revenues are then given by $\tau_t \equiv \tau_t^k[r_t^k u_t - a(u_t) - q_t\delta]k_t + \tau_t^h h_t^d w_t + \tau_t^\phi \phi_t$. The government issues money given in real terms by $m_t \equiv m_t^h + \int_0^1 m_{it}^f\, di$. The fiscal authority covers deficits by issuing one-period, nominally risk-free bonds, B_t. The period-by-period budget constraint of the consolidated government is then given by $b_t - (R_{t-1}/\pi_t)b_{t-1} + m_t - m_{t-1}/\pi_t = g_t + n_t - \tau_t$. Letting $a_t \equiv R_t b_t + m_t$, we can write the government's budget constraint as:

$$\frac{a_t}{R_t} + m_t(1 - R_t^{-1}) + \tau_t = \frac{a_{t-1}}{\pi_t} + g_t + n_t$$

We assume that at time 0, the benevolent government has been operating for an infinite number of periods. In choosing optimal policy, the government is assumed to honor commitments made in the past. This form of policy commitment has been referred to as "optimal from the timeless perspective" (Woodford 2003).

A Ramsey equilibrium is defined as the competitive equilibrium that maximizes the lifetime utility of the representative agent. Technically, the difference between the usual Ramsey equilibrium concept and the one employed here is that here, the structure of the optimality conditions associated with the Ramsey equilibrium is time invariant. By contrast, under the standard Ramsey equilibrium definition, the equilibrium conditions in the initial periods are different from those applying to later periods.

Our results concerning the business-cycle properties of Ramsey-optimal policy are comparable to those obtained in the existing literature under the standard definition of Ramsey optimality (e.g., Chari, Christiano, and Kehoe 1995). The reason is that existing studies of business cycles under the standard Ramsey policy focus on the behavior of the economy in the stochastic steady state (i.e., they limit attention to the properties of equilibrium time series excluding the initial transition).

2.3 *Calibration*

We calibrate the model at a quarterly frequency. Most of the parameter values are taken from the empirical work of Christiano, Eichenbaum, and Evans (2005) and Altig et al. (2004). These papers estimate the structural parameters of the model presented in the previous section using postwar U.S. data. A notable exception to this rule is the calibration of the degree of indexation in product prices and wages. The reason is that, in those papers, the parameters governing the degree of indexation are not estimated. They simply assume full indexation of all prices to past product price inflation. Instead, we draw from the econometric work of Cogley and Sbordone (2004) and Levin et al. (2005), who find no evidence of indexation in product prices. We therefore set $\chi = 0$. At the same time, Levin et al. estimate a high degree of indexation in nominal wages. We therefore assume that $\tilde{\chi} = 1$.

Table 6.1 gathers the values of the deep structural parameters of the model implied by our calibration strategy. A more detailed description of this strategy is contained in the expanded version of this paper (Schmitt-Grohé and Uribe 2005b).

3 The Ramsey Steady State

Consider the long-run state of the Ramsey equilibrium in an economy without uncertainty. We refer to this state as the Ramsey steady state. Note that the Ramsey steady state is in general different from the allocation/policy that maximizes welfare in the steady state of a competitive equilibrium.

Table 6.2 displays the Ramsey steady-state values of inflation, the nominal interest rate, and labor and capital income tax rates under a number of environments of interests. The figures reported in the table correspond to the exact numerical solution to the steady state of the Ramsey problem.

3.1 *The Optimal Level of Inflation*

Consider first the case in which profits are taxed at the same rate as income from capital ($\tau_t^{\phi} = \tau_t^k$ for all t). In this case, the Ramsey planner chooses to conduct monetary policy to nearly stabilize the price level.

Table 6.1
Structural Parameters

Parameter	Value	Description
β	0.9902	Subjective discount factor (quarterly)
θ	0.25	Share of capital in value added
ψ	0.0594	Fixed cost
δ	0.0173	Depreciation rate (quarterly)
ν	0.5114	Fraction of wage bill subject to a CIA constraint
η	6	Price-elasticity of demand for a specific good variety
$\tilde{\eta}$	21	Wage-elasticity of demand for a specific labor variety
α	0.6	Fraction of firms not setting prices optimally each quarter
$\tilde{\alpha}$	0.64	Fraction of labor markets not setting wages optimally each quarter
b	0.65	Degree of habit persistence
ϕ_1	0.0267	Transaction cost parameter
ϕ_2	0.1284	Transaction cost parameter
ϕ_3	1	Preference parameter
ϕ_4	0.75	Preference parameter
κ	2.48	Parameter governing investment adjustment costs
γ_1	0.0339	Parameter of capacity-utilization cost function
γ_2	0.0685	Parameter of capacity-utilization cost function
χ	0	Degree of price indexation
$\tilde{\chi}$	1	Degree of wage indexation
$\bar{g}$	0.0505	Steady-state value of government consumption (quarterly)
$\bar{n}$	0.0232	Steady-state value of government transfers (quarterly)
ρ_z	0.8556	Serial correlation of the log of the technology shock
σ_{ϵ^z}	0.0064	Standard deviation of the innovation to log of technology
ρ_g	0.87	Serial correlation of the log of government spending
σ_{ϵ^g}	0.016	Standard deviation of the innovation to log of government consumption
ρ_n	0.78	Serial correlation of the log of government transfers
σ_{ϵ^n}	0.022	Standard deviation of the innovation to log of government transfers
b/y	1.68	Debt-to-GDP ratio (quarterly)

Table 6.2
Ramsey Steady States

Environment				Steady-State Outcome				Profit
τ_t^{ϕ}	χ	$\bar{n}$	γ_2	π	R	τ^h	τ^k	Share
τ_t^k				0.2	4.2	35.4	−6.3	0.6
τ_t^k	1			4.6	8.8	34.7	−6.6	0.6
τ_t^k	1	0		−3.8	0	24.1	−5.3	2.3
τ_t^k		0		−0.2	3.8	23.3	−5.2	2.3
1				0.3	4.3	38.2	−44.3	0.8
1			6,850	0.3	4.3	37.8	−84.9	1.4
τ_t^k, τ_t^h				0.5	4.5	30.0	30.0	0.3

Note: The inflation rate, π, and the nominal interest rate, R, are expressed as a percentage per year. The labor income tax rate, τ^h, and the capital income tax rate, τ^k, are expressed as a percentage. Unless indicated otherwise, parameters take their baseline values, given in table 6.1.

The optimal inflation rate is 18 basis points per year (line 1 of table 6.2). It is worth noting that, although small, the steady-state inflation rate is positive. This finding is somewhat surprising because a well-known result in the context of simpler versions of the new Keynesian model is that the Ramsey steady-state level of inflation is negative and lies between the one called for by the Friedman rule and the one corresponding to full price stabilization. In calibrated example economies, the optimal deflation rate is, however, small (see, for instance, Schmitt-Grohé and Uribe 2004b, Khan et al. 2003). In these simpler models, the optimal inflation rate is determined by the tradeoff between minimizing the opportunity cost of holding money (which requires setting the inflation rate equal to minus the real interest rate) and minimizing price dispersion arising from nominal rigidities (which requires setting inflation at 0). Clearly, our finding of a positive inflation rate suggests that in the medium-scale economy we study in this paper, there must be an additional tradeoff that the Ramsey planner faces in setting the rate of inflation. To make the presence of the third tradeoff nitid, we consider the case of indexation of product prices to lagged inflation, $\chi = 1$ (line 2 of table 6.2). In this case, the long-run distortions stemming from nominal rigidities are nil. (Recall that in our calibration, nominal wages are fully indexed, i.e., $\tilde{\chi} = 1$.) Therefore, in this case, there is no tradeoff between the sticky-price and money-demand frictions. In the absence of any additional tradeoffs, one should expect the Friedman rule to be optimal in this case. However, line 2 of table 6.2

shows that under long-run price flexibility, the optimal rate of inflation is 4.6 percent per year, a value even further removed from the Friedman rule than the one that is optimal under no indexation in product markets (line 1 of table 6.2).

The third tradeoff turns out to originate in the presence of government transfer payments to households, n_t. Line 3 of table 6.2 shows that under full indexation and in the absence of government transfers, the Friedman rule emerges as the optimal monetary policy. That is, the nominal interest rate is 0, and the inflation rate is negative and equal to the rate of discount in absolute value. The reason why lump-sum government transfers induce positive inflation is that from the viewpoint of the Ramsey planner, they represent pure rents accruing to households and as such can be taxed without creating a distortion. In the absence of a specific instrument to tax transfer income, the government chooses to tax this source of income indirectly when it is used for consumption. Specifically, in the model, consumption purchases require money. As a result, a positive opportunity cost of holding money—i.e., a positive nominal interest rate—acts as a tax on consumption.[2]

Clearly, in the present model, if lump-sum transfers could be set optimally, they would be set at a negative value in a magnitude sufficient to finance government expenditures and output subsidies aimed at eliminating monopolistic distortions in product and factor markets. But in reality, government transfers are positive and large. In the United States, they averaged 7 percent of gross domestic product (GDP) in the postwar era. Justifying this amount of government transfers as an optimal outcome lies beyond the scope of this paper. One obvious theoretical element that would introduce a rationale for positive government transfers would be the introduction of some form of heterogeneity across households.

Whether set optimally or not, government transfers must be financed. Comparing lines 1 and 4 of table 6.2, it follows that the government must increase the labor income tax rate by 12 percentage points to finance transfer payments of 7 percent of GDP. Thus, the economy featuring transfers is significantly more distorted than the one without transfers. Because, in general, optimal stabilization policy will depend on the average level of distortion present in the economy, it is of importance for the purpose of this paper to explicitly include transfers into the model. It is noteworthy that under the calibration shown in table 6.1 (particularly under no indexation), allowing for transfers has almost no effect on the steady-state Ramsey policy except for the level of the labor income tax rate. Specifically, comparing lines 1 and 4 of table 6.2 shows that removing transfers has almost no bearing on the optimal rate of inflation and capital income taxation in the steady state.

We conclude that the tripodal tradeoff that determines the Ramsey long-run rate of inflation is resolved in favor of price stability. In this sense, the nominal price friction appears to dominate the money demand friction and the transfer-taxation motive in shaping optimal monetary policy in the long run.

3.2 *Optimal Tax Rates*

Consider first the economy where profit income is taxed at 100 percent ($\tau_t^{\phi} = 1$). In this case, shown in line 5 of table 6.2, the Ramsey plan calls for subsidizing capital at the rate of 44.3 percent in the deterministic steady state. It is well known from the work of Judd (2002) that in the presence of imperfect competition in product markets, the markup of prices over marginal costs introduces a distortion between the private and the social returns to capital that increases exponentially over the investment horizon. As a result, optimal policy calls for eliminating this distortion by setting negative capital income tax rates. To gain insight into the nature of the capital income subsidy, note that in steady state, the private return to investment is given by $(1-\tau^k)(uF_k/\mu - \delta - a(u))$, where μ denotes the steady-state markup, uF_k denotes the marginal product of capital, δ denotes the depreciation rate, and $a(u)$ denotes the cost of utilizing capital at the rate u. The social return to capital is given by $uF_k - \delta - a(u)$. Equating the private and social returns to investment requires setting τ^k so that:

$$(1-\tau^k)(uF_k/\mu - \delta - a(u)) = uF_k - \delta - a(u)$$

Because in the presence of market power in product markets, the markup is greater than unity ($\mu > 1$), it follows that τ^k must be negative. Using the fact that in the steady state $1 = \beta[(1-\tau^k)\cdot(uF_k/\mu - \delta - a(u)) + 1]$, we can write the above expression as:

$$1 - \tau^k = \mu\left[\frac{(\beta^{-1} - 1)}{\beta^{-1} - 1 - (\mu - 1)(\delta + a(u))}\right] \tag{6.3}$$

It is clear from this expression that if the depreciation rate is 0 ($\delta = 0$), and capacity utilization is fixed at unity (so that $a(u) = 0$), then the optimal capital income tax rate is equal to the net markup in absolute value. The case of 0 depreciation and constant capacity utilization is the one considered in Judd (2002).[3] We find that the introduction of depreciation in combination with a depreciation allowance, which is clearly the case of greatest empirical interest, magnifies significantly the size of the optimal capital subsidy. For instance, in our economy, the markup is 20 percent, the depreciation rate is 7 percent per year, and the discount factor is 4 percent per year. In the case of no depreciation and fixed capacity utilization, the formula in equation (6.3) implies a capital subsidy equal in size to our assumed markup of 20 percent. However, with a conservative depreciation rate of 7 percent per year and fixed capacity utilization—which we induce by increasing γ_2 by a factor of 10^5—the optimal subsidy on capital income skyrockets to 85 percent (see line 6 of table 6.2). The reason for this tremendous rise in the size of the subsidy is that the government taxes the rate of return on capital net of depreciation, whereas the markup distorts the rate of return on capital gross of depreciation.

Allowing for variable capacity utilization (by setting γ_2 at its baseline value of 0.0685), reduces the capital subsidy from 85 percent (line 6 of table 6.2) to 44 percent (line 5 of table 6.2). The reason why the subsidy is smaller in this case is that $a(u)$ is negative, which results in a lower effective depreciation rate.[4]

An additional factor determining the size of the optimal subsidy on capital is the fiscal treatment of profits. The formula given in equation (6.3) applies when profits are taxed at a 100 percent rate. Consider instead the case in which profit income is taxed at the same rate as capital income ($\tau_t^\phi = \tau_t^k$), which is assumed in lines 1–4 of table 6.2. Because profits are pure rents, the Ramsey planner has an incentive to confiscate them. This creates a tension between setting τ^k equal to 100 percent to fully tax profits, and setting τ^k at the negative value that equates the social and private returns to investment. This explains why the optimal subsidy to capital is 6.3 percent, a number much smaller than the 85 percent implied by equation (6.3), when the Ramsey planner is constrained to tax profits and capital income at the same rate.

Line 7 of table 6.2 displays the case in which the Ramsey planner is constrained to follow an income tax policy. That is, fiscal policy stipulates $\tau_t^h = \tau_t^k = \tau_t^\phi$. Not surprisingly, the optimal income tax rate falls between the values of the labor and capital income tax rates that are optimal when the fiscal authority is allowed to set these tax rates separately (line 5 of table 6.2). The optimal rate of inflation under an income tax is small, $\frac{1}{2}$ percent per annum, and not significantly different from the one that emerges when taxes can vary across income sources. The reason why the inflation rate is higher than in the baseline case is that in this way, the Ramsey planner can tax labor at a higher rate than capital, a point we discuss in detail later.

4 Ramsey Dynamics Under Income Taxation

In this section, we study the business-cycle implications of Ramsey-optimal policy when tax rates are restricted to be identical across all sources of income. Specifically, we study the case in which:

$$\tau_t^h = \tau_t^k = \tau_t^\phi \equiv \tau_t^y$$

for all t, where τ_t^y denotes the income tax rate.

We approximate the Ramsey equilibrium dynamics by solving a first-order approximation to the Ramsey equilibrium conditions. There is evidence that first-order approximations to the Ramsey equilibrium conditions deliver dynamics that are fairly close to those associated with the exact solution. For instance, in Schmitt-Grohé and Uribe (2004a), we compute the exact solution to the Ramsey equilibrium in a flexible-price dynamic economy with money, income taxes, and monopolistic competition in product markets. In Schmitt-Grohé and Uribe (2004b), we then compute the solution to the exact same economy using a first-order approximation to the Ramsey equilibrium conditions. We find that the exact solution is not significantly different from the one based on a first-order approximation.

It has also been shown in the context of environments with fewer distortions than the medium-scale macroeconomic model studied here that a first-order approximation to the Ramsey equilibrium conditions implies dynamics that are very close to the dynamics associated with a second-order approximation to the Ramsey system. Specifically, in Schmitt-Grohé and Uribe (2004b), we establish this result using a dynamic general equilibrium model with money, income taxes, sticky prices in product markets, and imperfect competition.[5]

Table 6.3 displays the standard deviation, serial correlation, and correlation with output of a number of macroeconomic variables of interest in the Ramsey equilibrium with income taxation. In computing these second moments, all structural parameters of the model take the values shown in table 6.1. Second moments are calculated using Monte Carlo simulations. We perform 1,000 simulations of 200 quarters each.

Table 6.3
Cyclical Implications of Optimal Policy Under Income Taxation

Variable	Steady State	Standard Deviation	Serial Correlation	Correlation with Output
τ_t^y	30	1.1	0.62	−0.51
R_t	4.53	1.43	0.74	−0.11
π_t	0.51	1.1	0.55	0.11
y_t	0.3	1.96	0.97	1
c_t	0.21	1.16	0.98	0.89
i_t	0.04	7.87	0.98	0.95
h_t	0.19	1.34	0.75	0.59
w_t	1.17	0.94	0.93	0.80
a_t	0.72	4.44	0.99	0.31

Note: R_t and π_t are expressed as a percentage per year, and τ_t^y is expressed as a percentage. The steady-state values of y_t, c_t, i_t, w_t, and a_t are expressed in levels. The standard deviations, serial correlations, and correlations with output of these 5 variables correspond to percentage deviations from their steady-state values.

For each simulation, we compute second moments and then average these figures over the 1,000 simulations.

An important result that emerges from table 6.3 is that under the optimal policy regime, inflation is remarkably stable over the business cycle. This result is akin to the one derived in the context of models with a single distortion, namely, sticky product prices and no fiscal considerations (Goodfriend and King 1997, among many others). In the canonical neo-Keynesian model studied in Goodfriend and King, the optimality of price stability is a straightforward result because, in that environment, the single cause of inefficiencies is price dispersion due to exogenous impediments to the adjustment of nominal prices. By contrast, the medium-scale model studied here features, in addition to price stickiness, distortions that in isolation would call for a highly volatile inflation rate under the Ramsey plan.

First, the fact that the government does not have access to lump-sum taxation provides an incentive for the Ramsey planner to use unexpected variations in the inflation rate as a capital levy on private holdings of nominal assets to finance innovations in the fiscal deficit. In effect, Chari et al. (1991) show, in the context of a flexible-price model, that the optimal rate of inflation volatility is extremely high (above 10 percent per year).[6] So in setting the optimal level of inflation volatility, the Ramsey planner faces a tradeoff between using inflation as a capital levy and minimizing the dispersion of nominal prices. For plausible calibrations, this tradeoff has been shown to be resolved overwhelmingly in favor of price stability. For example, we showed in earlier work (Schmitt-Grohé and Uribe 2004b) that within a sticky-price model with distorting taxes, a miniscule amount of price stickiness suffices to induce the Ramsey planner to abandon the use of inflation as a fiscal instrument in favor of almost complete price stability. Table 6.3 shows that this result survives in the much richer environment studied here, featuring a relatively large number of nominal and real rigidities.

Second, the fact that our model features sticky wages introduces an incentive for the Ramsey planner to adjust prices to bring about efficient real wage movements. As will be shown shortly, nominal wage stickiness in isolation calls for the Ramsey inflation rate to be highly volatile.

With the inflation rate not playing the role of absorber of fiscal shocks, the Ramsey planner must finance fiscal disturbances via deficits or changes in tax rates or both. Table 6.3 shows that in our model, the role of shock absorber is picked up to a large extent by fiscal deficits (i.e., by adjustments in the level of public debt). Total government liabilities, a_t, are relatively volatile and display a near-unit-root behavior. The standard deviation of government liabilities is 4.4 percent per quarter, and the serial correlation is 0.99 in our simulated sample paths. By contrast, tax rates do not vary much over the business cycle. The Ramsey planner is able to implement tax smoothing by allowing public liabilities to vary in response to fiscal shocks.

4.1 Nominal Rigidities and Optimal Policy

Table 6.4 presents the effects of changing the degree of wage or price stickiness on the behavior of policy variables. Panel A of the table considers the case of no transfers ($n_t = 0$ for all t). This case is of interest because it removes the government's incentive to tax transfers through long-run inflation, making the economy more comparable to existing related studies. When product and factor prices are fully flexible ($\alpha = \tilde{\alpha} = 0$), the optimal policy features high inflation volatility (5.8 percentage points per quarter at an annual rate) and relatively stable tax rates, with a standard deviation of 0.1 percent. In this case, as discussed earlier, variations in inflation are used as a state-contingent tax on nominal government liabilities, allowing the Ramsey planner to smooth taxes. Public debt is stationary with a serial correlation of 0.84.

Table 6.4
Degree of Nominal Rigidity and Optimal Policy

α	$\tilde{\alpha}$		τ_t^y	R_t	π_t	w_t	a_t
A. No Transfers ($n_t = 0$)							
		Mean	19.0	4.4	0.4	1.2	0.8
0	0	Std. dev.	0.1	0.2	5.8	1.4	2.5
		Ser. corr.	0.6	0.8	−0.1	0.8	0.84
		Mean	19.0	4.0	0.02	1.2	0.8
0.6	0	Std. dev.	0.4	0.7	0.1	1.4	6.3
		Ser. corr.	0.6	0.9	0.1	0.9	1
		Mean	19.0	4.4	0.4	1.2	0.8
0	0.64	Std. dev.	1.5	3.1	5.8	1.7	5.1
		Ser. corr	0.5	0.9	0.8	0.8	0.99
		Mean	19.0	4.0	0.02	1.2	0.8
0.6	0.64	Std. dev.	1.0	1.3	1.1	1	3.6
		Ser. corr.	0.6	0.7	0.6	0.9	0.99
B. Baseline Transfers							
		Mean	27.5	21.2	16.6	1.2	0.7
0	0	Std. dev.	0.5	0.5	6.8	1.5	3.0
		Ser. corr.	0.4	0.9	−0.0	0.8	0.84
		Mean	30.0	4.5	0.5	1.2	0.7
0.6	0	Std. dev.	0.6	0.9	0.2	1.3	7.0
		Ser. corr.	0.7	0.6	0.1	0.7	1
		Mean	27.5	21.2	16.6	1.2	0.7
0	0.64	Std. dev.	1.3	4.6	6.6	1.9	4.3
		Ser. corr.	0.5	0.9	0.83	0.8	0.99
		Mean	30	4.5	0.5	1.2	0.7
0.6	0.64	Std. dev.	1.1	1.4	1.1	0.9	4.4
		Ser. corr.	0.6	0.7	0.6	0.9	0.99
		Mean	30	4.5	0.5	1.2	0.7
0.6	0.87	Std. dev.	2.0	1.4	1.8	0.9	3.7
		Ser. corr.	0.5	0.6	0.7	0.9	0.99

Note: See note to table 6.3.

When prices are sticky but wages are flexible ($\alpha = 0.6$ and $\tilde{\alpha} = 0$), the optimal inflation volatility falls dramatically, from 5.8 percent to less than 0.1 percent. Because prices are costly to adjust, the Ramsey planner relinquishes the use of surprise inflation as a fiscal shock absorber. Instead, he or she uses variations in fiscal deficits and some small adjustments in the income tax rate to guarantee fiscal solvency. This practice results in a drastic increase in the serial correlation in government assets, which become a (near) random-walk process. These effects of price stickiness on optimal monetary and fiscal policy are known to emerge in the context of models without capital and fewer nominal and real frictions (see, for instance, Schmitt-Grohé and Uribe 2004b).

In the benchmark case, where both prices and wages are sticky ($\alpha = 0.6$ and $\tilde{\alpha} = 0.64$), inflation is more volatile than under product price stickiness alone. As stressed by Erceg et al. (2000) in the context of a much simpler model without a fiscal sector or capital, the reason for the increased volatility of inflation in the case of both price and wage stickiness relative to the case of price stickiness alone is that the central bank faces a tradeoff between minimizing relative product price dispersion and minimizing relative wage dispersion. Quantitatively, however, this tradeoff appears to be resolved in favor of minimizing product price dispersion rather than wage dispersion. In effect, under price stickiness alone, the volatility of inflation is 0.09 percent, whereas under wage stickiness alone, it is 5.8 percent.[7] When both nominal rigidities are present, the optimal inflation volatility falls between these two values, but at 1.1 percent, is much closer to the lower one. This result obtains even if one assumes that nominal wages are not indexed to past inflation ($\tilde{\chi} = 0$). In this case, the optimal inflation volatility is 0.9 percent, which is even lower than under full wage indexation (see table 6.5 below and the discussion around it). We note that indexation to past consumer price inflation, being an arbitrary scheme, may not necessarily be welfare improving in our model.

Panel B of table 6.4 considers the baseline case of positive transfers. All of the results obtained under the assumption of no transfers carry over to the economy with transfers.[8] In particular, it continues to be the case that inflation stability is the dominant characteristic of Ramsey-optimal policy. It is of interest that the optimality of inflation stability obtains in spite of the fact that nominal wages are set optimally less frequently than are product prices. As will be clear shortly, the fact that wages are assumed to be fully indexed to past inflation is not the crucial factor behind this result. Panel B of table 6.4 presents a further robustness check of our main result. It displays the case in which wages are reoptimized every eight quarters ($\tilde{\alpha} = 0.87$) instead of every three quarters ($\tilde{\alpha} = 0.64$), as in the baseline calibration. In this case, the optimal inflation volatility is 1.8 percent. This number is higher than the corresponding number under the baseline calibration (1.1 percent) but is still relatively small.[9]

The reason why we pick a value of 0.87 for the parameter $\tilde{\alpha}$ in our robustness test is that this number makes our model of wage rigidities comparable with the formulation in which wage stickiness results in employment heterogeneity across households introduced by Erceg et al. (2000). In effect, it can be shown that up to first-order, both specifications give rise to a Phillips curve relating current wage inflation to future expected wage inflation and the wage markup. The difference between the two specifications is that the coefficient on the wage markup is smaller in the Erceg et al. model. A value of $\tilde{\alpha}$ equal to 0.87 ensures that the coefficient on the wage markup in our model is equal to that implied by the Erceg et al. model.[10]

We close this section with a digression. One may wonder why in the case of fully flexible product and factor prices and no transfers ($\alpha = \tilde{\alpha} = n_t = 0$), the Friedman rule fails to be Ramsey optimal. The reason is that under an income-tax regime, a positive nominal interest rate allows the Ramsey planner to effectively tax labor at a higher rate than capital. The planner engineers this differential effective tax rate by exploiting the fact that firms are subject to a cash-in-advance constraint on the wage bill. The reason why it is optimal for the planner to tax labor at a higher rate than capital is clear from our analysis of the Ramsey steady state when labor and capital income can be taxed at different rates (Section 3). In this case, the Ramsey planner decides to subsidize capital and to tax labor. Under the income-tax regime studied here, the planner is unable to set different tax rates across sources of income. But he does so indirectly by levying an inflation tax on labor.

In the flexible-price economy, the inflation bias introduced by the combination of an income tax and a cash-in-advance constraint on wages is large, above 4 percent per year. If in an economy without nominal rigidities and without government transfers, one were to lift the cash-in-advance constraint on wage payment by setting the parameter ν equal to 0, the Friedman rule would reemerge as the Ramsey outcome. But the inflation bias introduced by government transfers and the working capital constraint is small in an economy with sticky prices. In effect, under our assumed degree of price stickiness ($\alpha = 0.6$), the steady-state level of inflation falls from 0.51 percent per annum in the economy with transfers and a working-capital constraint on wage payments to −0.19 percent in an economy without transfers and without a working-capital constraint. We conclude that in our model, the dominant force determining the long-run level of inflation is not the presence of government transfers or the demand for money by firms or the demand for money by households, but rather the existence of long-run frictions in the adjustment of nominal product prices.

4.2 *Indexation and Optimal Policy*

An important policy implication of our analysis of optimal fiscal and monetary policy in a medium-scale model under income taxation is the desirability of price stability. Because our benchmark calibration assumes full indexation in factor prices but no indexation in product prices, one may worry that our central policy result may be driven too much by the assumed indexation scheme. But this turns out not to be the case.

Consider a symmetric indexation specification in which neither factor prices nor good prices are indexed ($\chi = \tilde{\chi} = 0$). This case is shown in line 1 of table 6.5.

In the non-indexed economy, the Ramsey plan calls for even more emphasis on price stability than in the environment with factor price

Table 6.5
Indexation and Optimal Policy

χ	$\tilde{\chi}$		τ_t^y	R_t	π_t	w_t	a_t
		Mean	30	4.1	0.11	1.2	0.72
0	0	Std. dev.	0.66	1.2	0.94	1	4.9
		Ser. corr.	0.56	0.6	0.44	0.96	0.99
		Mean	30	4.1	0.13	1.2	0.72
1	0	Std. dev.	0.66	1	1.1	1.1	5
		Ser. corr.	0.51	0.58	0.77	0.96	0.99
		Mean	30	4.5	0.51	1.2	0.72
0	1	Std. dev.	1.1	1.4	1.1	0.95	4.3
		Ser. corr.	0.62	0.74	0.55	0.93	0.99
		Mean	28	21	17	1.1	0.74
1	1	Std. dev.	1	2.7	2.9	1.2	4
		Ser. corr.	0.47	0.88	0.94	0.96	1

Note: See note to table 6.3.

indexation. The mean and standard deviation of inflation both fall from 0.51 and 1.1, respectively, in the economy with wage indexation to 0.11 and 0.94 in the economy without any type of indexation. The reason why the average inflation rate is lower in the absence of indexation is that removing wage indexation creates an additional source of long-run inefficiency stemming from inflation, namely, wage dispersion. The reason why inflation volatility also falls when one removes wage indexation is less clear. We simply note, as we did before, that the indexation scheme assumed here, namely, indexing to past price inflation, being arbitrary, may or may not be welfare-improving in the short run.

Consider now the case that prices are fully indexed but wages are not ($\chi = 1$ and $\tilde{\chi} = 0$). If our main result, namely, the optimality of inflation stabilization, was driven by our indexation assumption, then the indexation scheme considered now would stack the deck against short-run price stability. Line 2 of table 6.5 shows that even when prices are indexed and wages are not, the Ramsey plan calls for the same low level of inflation volatility as under the reverse indexation scheme considered in the benchmark economy (line 3 of table 6.5). The reason is that if the planner were to move prices around over the business cycle to minimize the distortions introduced by nominal wage stickiness, then such price movements still would lead to important inefficiencies in the product market because prices, although indexed, are still sticky. Indexation removes the distortions associated with nominal rigidities only in the long run, not necessarily in the short run.

The fact that indexation removes the long-run inefficiencies associated with nominal product and factor price dispersion due to price stickiness is illustrated in line 4 of table 6.5, displaying the case of indexation in both product and factor markets. The Ramsey-optimal mean inflation rate is, in this case, 17 percent per year. This large number is driven by two fiscal policy factors identified earlier in this paper: high inflation allows the Ramsey planner to tax transfers indirectly and at the same time provides an opportunity to tax labor income at a higher rate than capital income.

5 Optimized Policy Rules

Ramsey outcomes are mute on the issue of what policy regimes can implement them. The information on policy one can extract from the solution to the Ramsey problem is limited to the equilibrium behavior of policy variables such as tax rates and the nominal interest rate. But this information is in general of little use for central banks or fiscal authorities seeking to implement the Ramsey equilibrium. Specifically, the equilibrium process of policy variables in the Ramsey equilibrium is a function of all of the states of the Ramsey equilibrium. These state variables include all of the exogenous driving forces and all of the endogenous predetermined variables. Among this second set of variables are past values of the Lagrange multipliers associated with the constraints of the Ramsey problem. Even if the policymaker could observe the state of all of these variables, using the equilibrium process of the policy variables to define a policy regime would not guarantee the Ramsey outcome as the competitive equilibrium. The problem is that such a policy regime could give rise to multiple equilibria.

In this section, we do not attempt to resolve the issue of what policy implements the Ramsey equilibrium in the medium-scale model under study. Rather, we focus on finding parameterizations of monetary and fiscal rules that satisfy the following three conditions: (a) they are simple, in the sense that they involve only a few observable macroeconomic variables; (b) they guarantee local uniqueness of the rational expectations equilibrium; and (c) they minimize some distance (to be specified shortly) between the competitive equilibrium they induce and the Ramsey equilibrium. We refer to rules that satisfy criteria (a) and (b) as implementable. We refer to implementable rules that satisfy criterion (c) as optimized rules.[11]

We define the distance between the competitive equilibrium induced by an implementable rule and the Ramsey equilibrium as follows. Let $IR^{R}_{T,S,Y}$ denote the impulse response function associated with the Ramsey equilibrium of length T quarters, for shocks in the set S, and variables in the set Y. Similarly, let $IR^{CE}_{T,S,Y}$ denote the impulse responses associated with the competitive equilibrium induced by a particular policy rule. Let $x \equiv \mathrm{vec}(IR^{R}_{T,S,Y} - IR^{CE}_{T,S,Y})$. Then we define the distance between the Ramsey equilibrium and the competitive equilibrium associated with a particular implementable rule as $x'x$.

An alternative definition of the distance between the competitive equilibrium induced by an implementable rule and the Ramsey equilibrium is given by the difference in the associated welfare levels. This definition of an optimized rule is equivalent to selecting policy-rule coefficients within the set of implementable rules to maximize the level of welfare associated with the resulting competitive equilibrium. We adopt this definition in Schmitt-Grohé and Uribe (2004c, 2004d). In general, a policy rule that is optimal under this definition will not coincide with the one that is optimal according to criteria (a), (b), and (c). It is clear, however, from the quantitative welfare analysis reported later in this section that the gains from following such a strategy in lieu of the one adopted here are small.

In the present analysis, we take as reference the Ramsey equilibrium under the restriction of an income tax. We compute impulse response functions from a first-order accurate approximation to the Ramsey and competitive equilibria. We set the length of the impulse response function at twenty quarters ($T = 20$). The set of shocks is given by the three shocks that drive business cycles in the model presented above: productivity, government consumption, and government transfers shocks; that is, $S = \{z_t, g_t, n_t\}$. Finally, we include in the set Y seventeen endogenous variables. Up to first order, all variables listed in the definition of a competitive equilibrium given in the expanded version of this paper can be obtained as a linear combination of the elements of the sets Y and S. Of course, adding variables to the set Y would in general not be inconsequential because it would amount to altering the weights assigned to each impulse response in the criterion that is minimized here. However, as will be clear from the discussion that follows, expanding the set Y or altering the weights given to each individual variable would result at best in negligible welfare gains.

The family of rules that we consider here consists of an interest-rate rule and a tax-rate rule. In the interest-rate rule, the nominal interest rate depends linearly on its own lag, the rates of price and wage inflation, and the log deviation of output from its steady-state value. The tax-rate rule features the tax rate depending linearly on its own lag and log deviations of government liabilities and output from their respective steady-state values. Formally, the interest-rate and tax-rate rules are given by:

$$\ln(R_t/R^*) = \alpha_\pi \ln(\pi_t/\pi^*) + \alpha_W \ln(\pi_t^W/\pi^*) + \alpha_y \ln(y_t/y^*) \\ + \alpha_R \ln(R_{t-1}/R^*)$$

and:

$$\tau_t^y - \tau^{y*} = \beta_a \ln(a_{t-1}/a^*) + \beta_y \ln(y_t/y^*) + \beta_\tau \ln(\tau_{t-1}^y - \tau^{y*})$$

The target values R^*, π^*, y^*, τ^{y*}, and a^* are assumed to be the Ramsey steady-state values of their associated endogenous variables, given in the second column of table 6.3. The variable $\pi_t^W \equiv W_t/W_{t-1}$ denotes wage inflation. It follows that in our search for the optimized policy rule, we pick seven parameters to minimize the Euclidean norm of the vector x containing 1,020 elements. We set the initial impulse equal to one standard deviation of the innovation in the corresponding shock. That is, for impulse responses associated with shocks z_t, g_t, and n_t, the initial impulse is given by $\sqrt{\sigma^2_{\varepsilon^z}/(1-\rho_z^2)}$, $\sqrt{\sigma^2_{\varepsilon^g}/(1-\rho_g^2)}$, and $\sqrt{\sigma^2_{\varepsilon^n}/(1-\rho_n^2)}$, respectively.

The optimized rule is given by:

$$\ln(R_t/R^*) = 0.37\ln(\pi_t/\pi^*) - 0.16\ln(\pi_t^W/\pi^*) - 0.06\ln(y_t/y^*) + 0.55\ln(R_{t-1}/R^*) \quad (6.4)$$

and:

$$\tau_t^y - \tau^{y*} = -0.06\ln(a_{t-1}/a^*) + 0.02\ln(y_t/y^*) + 1.88\ln(\tau_{t-1}^y - \tau^{y*}) \quad (6.5)$$

The optimized interest-rate rule turns out to be passive, with the sum of the product-price and wage inflation coefficients less than unity. Under this rule, variations in aggregate activity do not trigger a monetary policy response, as can be seen from the fact that the output coefficient is close to 0. The optimized monetary rule exhibits interest rate inertia, implying long-run reactions to deviations of inflation from target twice the size of the short-run response.

The optimized tax-rate rule calls for a mute response to variations in output or government liabilities. In addition, it is superinertial with a coefficient on lagged tax rates of about 2. In equilibrium, this rule induces tax rates that are almost constant over the business cycle.

5.1 *Welfare Under the Optimized Rule*

We measure the welfare cost of a particular monetary/fiscal policy specification vis à vis the Ramsey policy as the increase in consumption needed to make a representative consumer indifferent between living in an economy where the particular monetary/fiscal policy considered is in place and an economy where the government follows the Ramsey policy. The welfare cost is computed conditional on the initial state of the economy being the deterministic steady state of the Ramsey equilibrium.[12] In computing welfare costs, we solve the model up to second-order of accuracy. In particular, we use the perturbation method and computer algorithm developed in Schmitt-Grohé and Uribe (2004e).

Applying this definition to evaluate the welfare cost of following the optimized policy rules given in equations (6.4) and (6.5) instead of implementing the Ramsey-optimal policy, we obtain a cost of 0.017 percent of the Ramsey consumption process. Using figures for personal consumption expenditures per person in the United States in 2003, the welfare cost amounts to $4.42 per person per annum.

5.2 *Ramsey and Optimized Impulse Responses*

To provide a sense of how close the dynamics induced by the Ramsey policy and the optimized rule are, in this section, we present theoretical impulse responses to the three shocks driving business cycles in our model economy. Figure 6.1 displays impulse response functions to a one-standard-deviation increase in productivity ($\ln z_1 = 1.2$ percent). Solid lines correspond to the Ramsey equilibrium, and dashed lines correspond to the optimized policy rules.

Remarkably, in response to an increase in productivity, hours worked fall (indeed more than one for one). The reason for this sharp decline in labor effort is the presence of significant costs of adjustment in investment and consumption. Notice that neither consumption nor investment move much on impact. As a result, the increase in productivity must be accompanied by an increase in leisure large enough to ensure that output remains little changed on impact. The contraction in hours following a positive productivity shock is in line with recent econometric studies using data from the U.S. economy (see, for example, Galí and Rabanal 2004).

The equilibrium dynamics of endogenous nonpolicy variables induced by the optimized policy rules mimic those associated with the Ramsey economy quite well. Surprisingly, these responses are induced with settings for the policy variables that are remarkably different from those associated with the Ramsey equilibrium. In particular, the response of the income tax rate is almost flat in the competitive equilibrium, whereas under the Ramsey policy, tax rates increase sharply initially and then quickly fall to below-average levels. At the same time, the Ramsey planner responds to the productivity shock by tightening money market conditions, whereas the policy rule calls for a significant easing. It follows that the initial deceleration in inflation is not a consequence of the monetary policy action—which is expansionary—but rather a reaction to forces that are fiscal in nature. In effect, the optimized rule leaves the income tax rate unchanged. At the same time, output is expected to increase, so that the expected

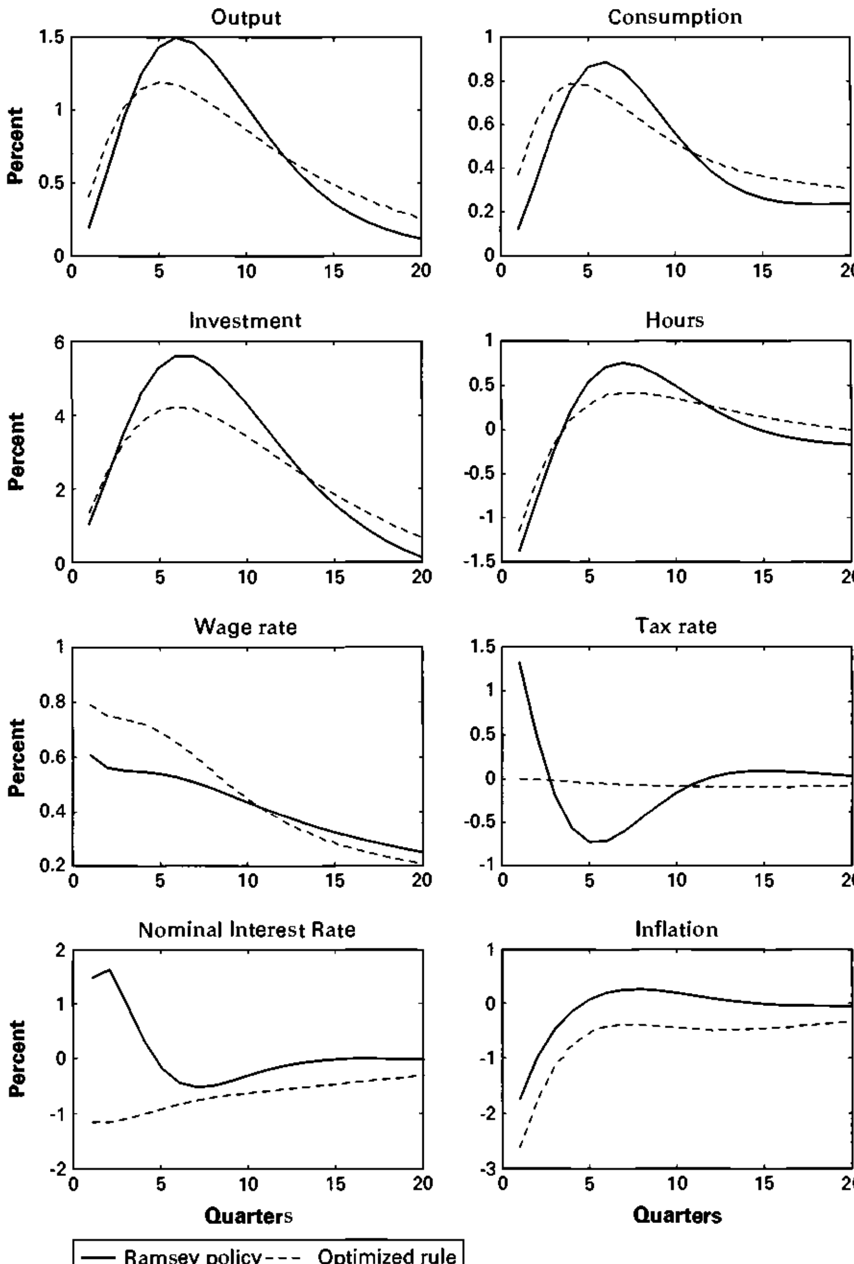

Figure 6.1
Impulse Response to a Productivity Shock
Note: The size of the initial innovation to the technology shock is one standard deviation, $\ln(z_1) = 1.2\%$. The nominal interest rate and the inflation rate are expressed as percentages per year, the tax rate is expressed in percentage points, and the remaining variables are expressed in percentage deviations from their respective steady-state values.

value of tax revenues increases. As a result, a higher level of government liabilities can be supported in equilibrium. The initial deflation, therefore, serves as a mechanism to boost the real value of outstanding government liabilities.

Figures 6.2 and 6.3 display impulse responses to a government spending shock and a government transfer shock, respectively. In both cases, the size of the initial impulse equals one standard deviation of the shock (3.2 percent for the government spending shock, and 3.5 percent for the government transfer shock). The equilibrium dynamics under the optimized policy rule appear to mimic those associated with the Ramsey policy not as closely as in the case of a productivity shock. This is understandable, however, if one takes into account that these two shocks explain only a small fraction of aggregate fluctuations. In effect, productivity shocks alone explain over 90 percent of variations in aggregate activity under the Ramsey policy. The optimization estimation procedure therefore naturally assigns a smaller weight on fitting the dynamics induced by g_t and n_t.

5.3 *Ramsey Policy with a Single Instrument*

In this section, we ask, How does optimal policy change if the government is restricted to setting optimally either monetary or fiscal policy, but not both? Of course, the answer to this question may in principle be sensitive to the details of the policy that is assumed to be set nonoptimally.

We consider two cases. In one, fiscal policy is set optimally, while the monetary authority follows a simple Taylor rule with an inflation coefficient of 1.5; that is, $R_t/R = (\pi_t/\pi)^{1.5}$. Here, the parameters R and π correspond to the steady-state values of R_t and π_t in the Ramsey equilibrium with optimal monetary and fiscal policy. We pick this particular specification for monetary policy because it has been widely used in related empirical and theoretical studies. The other policy regime we consider is one in which monetary policy is determined in a Ramsey optimal fashion but fiscal policy consists of keeping real government liabilities constant over time; that is, $a_t = a$, where a denotes the deterministic steady-state value of a_t in the Ramsey equilibrium with optimal fiscal and monetary policy. Our choice of fiscal policy in this case is motivated by the fact that in most existing studies of monetary policy, it is typically assumed implicitly or explicitly that the fiscal authority ensures fiscal solvency under all possible (equilibrium and off-equilibrium) paths of the price level.

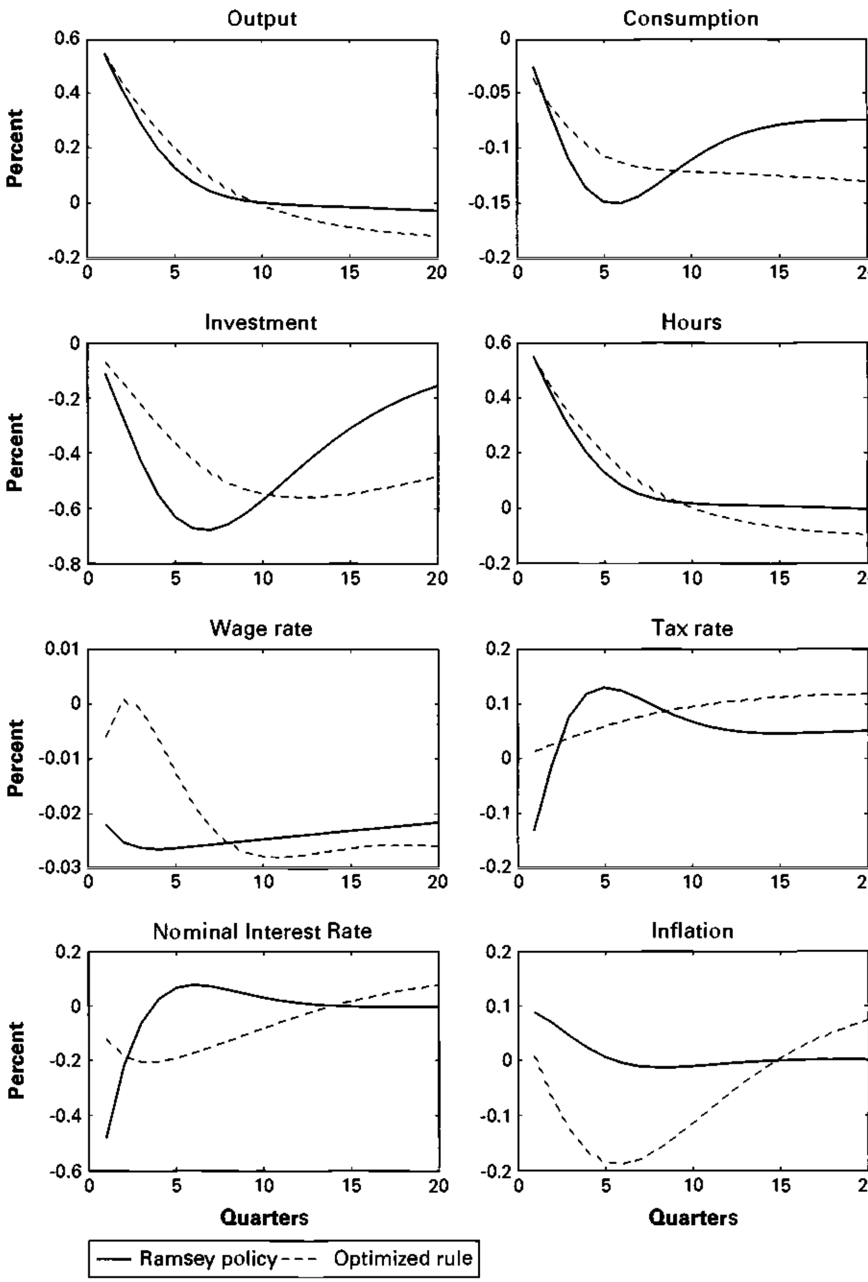

Figure 6.2
Impulse Response to a Government Spending Shock
Note: The size of the initial innovation to the government spending shock is one standard deviation, $\ln(g_1/\bar{g}) = 3.2\%$. The nominal interest rate and the inflation rate are expressed as percentages per year, the tax rate is expressed in percentage points, and the remaining variables are expressed in percentage deviations from their respective steady-state values.

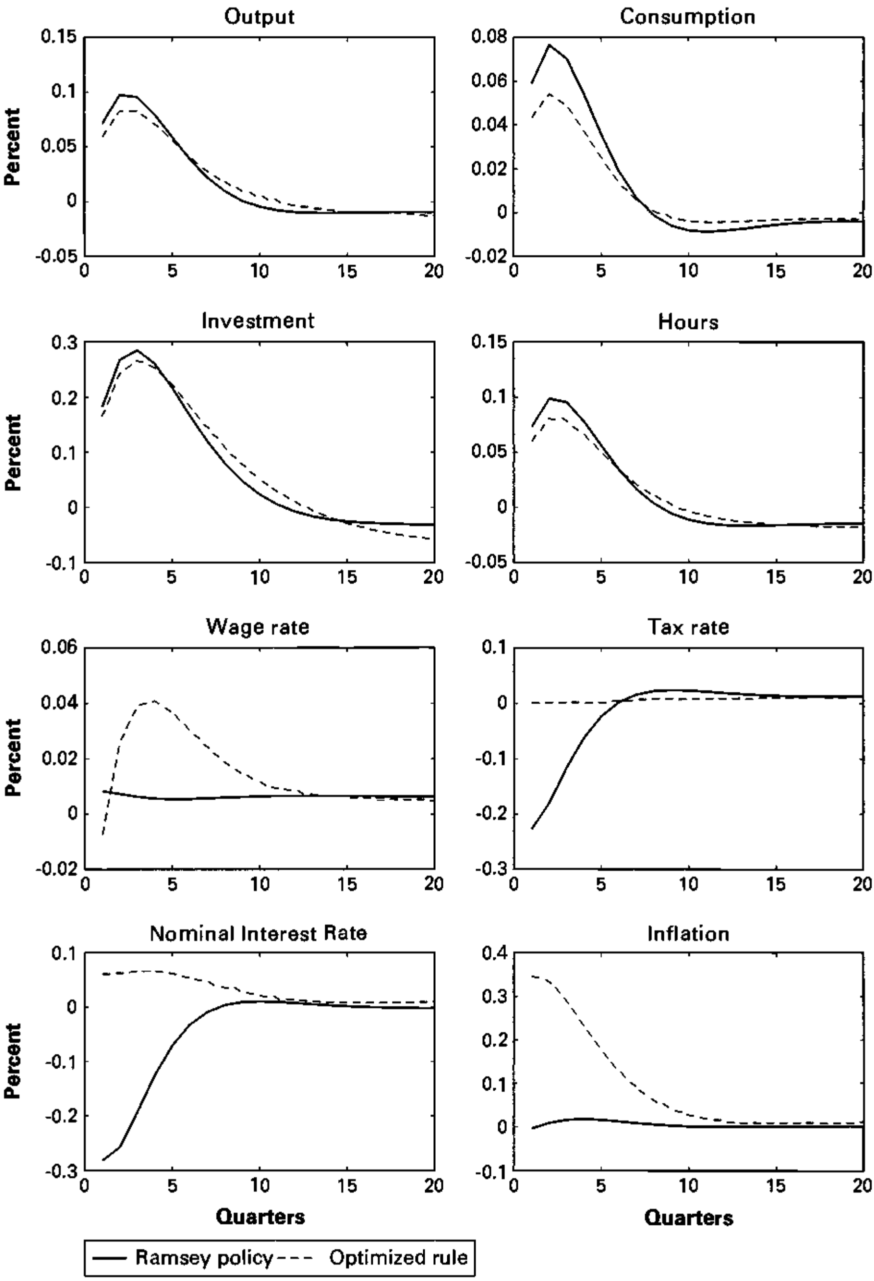

Figure 6.3
Impulse Response to a Government Transfer Shock
Note: The size of the initial innovation to the government spending shock is one standard deviation, $\ln(n_1/\bar{n}) = 3.5\%$. The nominal interest rate and the inflation rate are expressed as percentages per year, the tax rate is expressed in percentage points, and the remaining variables are expressed in percentage deviations from their respective steady-state values.

Table 6.6
Optimal Policy with One Policy Instrument

Variable	Standard Deviation: Optimal Monetary and Fiscal Policy	Standard Deviation: Optimal Fiscal Policy	Standard Deviation: Optimal Monetary Policy	Serial Correlation: Optimal Monetary and Fiscal Policy	Serial Correlation: Optimal Fiscal Policy	Serial Correlation: Optimal Monetary Policy
τ_t^y	1.09	0.71	1.74	0.62	0.93	0.85
R_t	1.43	2.25	1.4	0.74	0.53	0.53
π_t	1.1	1.5	1.33	0.55	0.53	0.55
y_t	1.98	1.74	2.5	0.97	0.97	0.98
c_t	1.17	1.1	1.52	0.98	0.97	0.99
i_t	8.01	6.88	10.6	0.98	0.99	0.99
h_t	1.34	1.13	1.96	0.75	0.80	0.87
w_t	0.96	1.07	0.99	0.94	0.9	0.9
a_t	4.43	6.28	0	0.99	1	0
Welfare cost	\$0.00	\$9.10	\$2.30			

Note: In the case of optimal fiscal policy only, monetary policy takes the form of a Taylor rule, $R_t/R = (\pi_t/\pi)^{1.5}$ (in this formula, we use the notation used in the exposition of the paper, so that R_t and π_t are expressed in gross quarterly rates), where R and π denote, respectively, the steady-state values of R_t and π_t in the Ramsey equilibrium with optimal fiscal and monetary policy. In the case of optimal monetary policy only, fiscal policy consists of keeping real government liabilities constant, that is, $a_t = a$, where a denotes the steady-state value of a_t in the Ramsey equilibrium with optimal fiscal and monetary policy. The variables R_t and π_t are expressed as percentages per year, and τ_t^y is expressed as a percentage. The standard deviations and serial correlations of output, consumption, investment, hours, wages, and government liabilities correspond to percentage deviations from their steady-state values. The welfare cost is measured in 2003 dollars per person per year and is defined as the compensation needed to make the representative agent indifferent between living in a world with the policy indicated in the respective column heading and living in a world where both monetary and fiscal policy are Ramsey optimal.

Table 6.6 displays second moments of endogenous variables of interest and welfare of the representative agent conditional on the initial state being the Ramsey steady state with optimal fiscal and monetary policy. The economy with nonoptimal fiscal policy is significantly more volatile than the economy with nonoptimal monetary policy. The reason is that in the economy with nonoptimal fiscal policy, the government is forced to adjust tax rates over the business cycle to ensure constancy of real public liabilities. Higher volatility of real variables, however, is not associated with lower welfare. On the contrary, the welfare cost of not being able to conduct optimal monetary policy is much larger than the welfare cost of not being able to conduct optimal fiscal policy.

6 Capital and Labor Taxation

In this section, we characterize dynamic Ramsey policy under the assumption that the fiscal authority has access to three tax instruments: taxes on capital income (τ_t^k), taxes on labor income (τ_t^h), and taxes on pure profits (τ_t^ϕ). Clearly, the optimal tax rate on profits is 100 percent. Thus, we set $\tau_t^\phi = 1$ for all t for the remainder of the section.

We analyzed the Ramsey steady state of this economy earlier in Section 3. As shown in line 5 of table 6.2, in the Ramsey steady state, the labor income tax rate is 38.2 percent and the capital subsidy is 44.3 percent. For the calibration shown in table 6.1, we find that the standard deviation of the capital income tax rate under the Ramsey policy is 148 percent. The natural reaction to this number is that, in this economy, the constraint that capital subsidies and taxes should be less than 100 percent will be frequently violated and in this regard, the optimal policy makes little economic sense.[13] Qualitatively, however, the intuition for why the volatility of the capital income tax is high is clear. Because capital is a predetermined state variable, unexpected variations in the capital income tax rate act as a nondistorting levy, which the fiscal authority uses to finance innovations in the government budget. The (population) serial correlation of capital tax rates is very close to 0 at -0.07. When capital income tax rates can play the role of a fiscal shock absorber, government liabilities no longer display the near random walk behavior, as in the case of an income tax. In fact, the (population) serial correlation of a_t now is only 0.6.

To put the number we obtain for the optimal volatility of τ_t^k into perspective, we use as a point of reference two simpler but related economies. First, Chari et al. (1995) study optimal taxation in a standard real-business-cycle model with exogenous long-run growth and report a standard deviation of the capital income tax rate of 40 percentage points for the stochastic steady state of the Ramsey equilibrium.[14]

The second economy we study as a point of reference is a stationary version of the RBC model of Chari et al. (1995). We find that if one assumes no long-run growth in the Chari et al. economy, the standard deviation of capital income taxes shoots up to about 60 percent (assuming that the level of government assets in the steady state is the same as in the economy with growth). This result illustrates that relatively minor modifications in the economic environment can lead to drastic changes in the optimal volatility of capital income tax rates. Still, these values are not as high as the ones we find in our much more complex model economy. In what follows, we complete the reconciliation of our finding with those available in the existing literature.

6.1 Time to Tax

Two modifications to our medium-scale macroeconomic model allow us to drive the optimal volatility of capital tax rates down to a level that is comparable to the one that obtains in the standard real business-cycle model without growth. First, the model studied by Chari et al. features no impediments to adjusting the level of investment over the business cycle, whereas our model economy incorporates significant investment adjustment costs. Lowering the investment adjustment cost parameter κ by a factor of 1,000 reduces the optimal capital income tax volatility from 148 percent to 66 percent, which is close to the volatility of the RBC model without growth. If, in addition, we assume that tax rates are set one period in advance, then the optimal capital tax volatility falls to 20 percent. The reason why adjustment costs induce a higher optimal volatility of the capital income tax is that investment adjustment costs make capital more akin to a fixed factor of production, thereby making movements in the capital tax rate less distorting.

Second, the time unit in the Chari et al. model is one year. By contrast, the time unit in our model is one quarter. Our choice of a time unit is guided by the fact that we study optimal monetary policy as well as optimal fiscal policy. It is unrealistic to assume that the government adjusts monetary policy only once a year. For example, in the United States, the Federal Open Market Committee (FOMC) meets every eight weeks. At the same time, it is equally unrealistic to assume that tax rates change every quarter. One possible way to resolve this conflict is to continue to assume that the time unit is one quarter and to impose that tax rates are determined several quarters in advance, that is, that there are tax lags.

Figure 6.4 depicts the standard deviation of the capital income tax as a function of the number of tax lags. It shows the results for the economy calibrated using the parameter values shown in table 6.1. The graph illustrates that the optimal volatility of the capital income tax

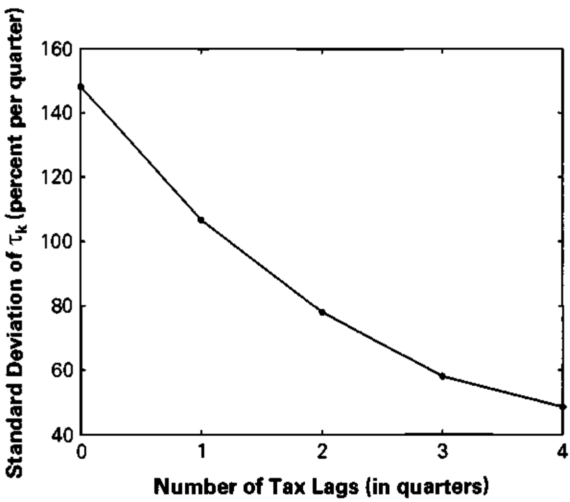

Figure 6.4
Time to Tax and Capital Tax Rate Volatility
Note: The standard deviation of the capital income tax rate is expressed in percentage points.

rate falls steadily with the number of tax lags. Under the assumption that tax rates are determined four quarters in advance, the optimal volatility of capital taxes is driven down to about 49 percentage points. This level of volatility is lower than the values obtained in a nongrowing RBC model.

6.2 Capital Tax Volatility and the Cost of Varying Capacity Utilization

Another difference between the simple RBC model of Chari et al. (1995) and the model studied here is that our model economy incorporates variable capacity utilization. One may think that the presence of variable capacity utilization could induce lower capital income tax volatility because, in this case, the effective stock of capital is no longer predetermined. As a result, one would expect that variations in the capital income tax rate should be more distorting and hence used less. It turns out, however, that the volatility of the capital income tax rate is not significantly affected when the cost of varying the intensity of capacity utilization falls (in our model, when γ_2 is reduced). For example, when we hold γ_1 constant and reduce γ_2 by a factor of 2, the optimal capital tax volatility increases from 149 percent to 153 percent.

7 Conclusion

We study Ramsey-optimal fiscal and monetary policy in a medium-scale model of the U.S. business cycle. The model features a rich array of real and nominal rigidities that have been identified in the recent empirical literature as salient in explaining observed aggregate fluctuations.

We find that price stability appears to be a central goal of optimal monetary policy. The optimal rate of inflation under an income tax regime is $\frac{1}{2}$ percent per year with a standard deviation of 1.1 percent. This result is somewhat surprising given that the model features a number of frictions that, in isolation, would call for a volatile rate of inflation—particularly nonstate-contingent nominal public debt, no lump-sum taxes, and sticky wages.

Under an income tax regime, the Ramsey-optimal income tax rate is quite stable, with a standard deviation of 1.1 percent around a mean of 30 percent. In addition, the Ramsey outcome features a near random walk in real public debt. Taken together, these results suggest that shocks to the fiscal budget are financed neither through surprise inflation (as in models with flexible nominal prices) nor through adjustments in the income tax rate, but rather through variations in the fiscal deficit. It follows that the Ramsey equilibrium has little resemblance to a world operating under a balanced-budget rule.

We show that simple monetary and fiscal rules implement a competitive equilibrium that mimics well the one induced by the Ramsey policy. These rules bring about welfare levels that are almost identical to the ones associated with the Ramsey policy. The optimized interest-rate rule is passive, in the sense that the inflation coefficient is less than unity, and features a mute response to output and a mild degree of interest-rate inertia. At the same time, the optimized fiscal-policy rule is acyclical in the sense that tax rates do not respond to changes in either output or the level of public debt. The fiscal rule is super inertial, with a coefficient on the lagged tax rate of about 2. Thus, for example, an increase in taxes today is expected to be followed by further tax increases in the future. In equilibrium, this property of the fiscal rule renders tax rates almost constant over the business cycle.

When the fiscal authority is allowed to tax capital and labor income at different rates, optimal fiscal policy is characterized by a large capital subsidy of over 40 percent, with an enormous volatility of about 150 percent. The introduction of four quarters of time to tax brings this volatility down to 50 percent. While significant, this decline leaves the Ramsey-optimal capital-income-tax volatility impractically large.

The present study could be extended in a number of directions. One is to allow for a richer set of underlying shocks. Altig et al. (2004), for instance, allow for an additional productivity shock that is specific to the investment sector. Also, Smets and Wouters (2004) estimate a model with ten shocks. Additionally, one could assume that the shocks driving business cycles are nonstationary, as in Altig et al. (2004). These extensions are of interest because optimal stabilization policy will in general be shaped by the number and nature of the exogenous shocks generating aggregate fluctuations. A word of caution, however, is in order before taking this route. In econometrically estimated versions of the model studied in this paper (or variations thereof), it is often the case that a large number of shocks is estimated as a by-product. A number of these shocks are difficult to interpret economically. In effect, these shocks, to a large extent, represent simple econometric residuals reflecting the distance between model and data. A case in point are shocks to Euler equations or uncovered interest parity conditions. Before incorporating this type of residual as a driving force, it is perhaps more productive to give theory a chance to get closer to the data.

Possibly the most urgent step in this research program, however, is to characterize credible policy in large macroeconomic models. The Ramsey plans derived in the present study are time inconsistent in the sense that at each point in time, a social planner who cares about the welfare of people from that moment on has incentives to abandon promises made from a timeless perspective. In the past two decades, a growing literature in macroeconomics has been focusing on game-theoretic approaches to policymaking. This literature focuses on identifying credible punishment schemes by the public should the government default on its policy promises. The aim is to find credible policies that maximize welfare. Thus far, applications of this line of research to fiscal and monetary policy has been limited to highly stylized, small-scale models. Extending the study of credible monetary and fiscal policy to large-scale models would be an important milestone for the theory of stabilization policy.

Endnotes

We thank Jesús Fernández-Villaverde, Marc Giannoni, Mark Gertler, Andy Levin, Kenneth Rogoff, and Mike Woodford for comments.

1. Examples of this line of research include Ireland (1997); Rotemberg and Woodford (1997); Woodford (2003); and Clarida, Galí, and Gertler (1999); among many others.

2. A formal analytical derivation of the result that the Friedman rule fails in the presence of government transfers is given in Schmitt-Grohé and Uribe (2005a).

3. The model presented in Judd can be interpreted alternatively as one where the depreciation rate is positive and the production function represents output net of depreciation. Under this interpretation, however, Judd's measure of the markup would not be directly comparable to ours.

4. To see why the level of capacity utilization u_t is less than 1 (which is necessary for $(a(u_t))$ to be negative) in the Ramsey equilibrium, recall that in the competitive equilibrium used for the calibration of the function $a(\cdot)$, the tax rate on capital was set at 40.7 percent, and u_t was set at unity. In the Ramsey equilibrium, τ^k is negative, which induces a larger level of capital. With a higher capital stock, its rate of return at full utilization falls, which induces capitalists to lower its degree of utilization. In the steady state shown in line 5 of table 6.2, u equals 0.85.

5. More recently, Benigno and Woodford (2005) arrive at a similar conclusion in the context of optimal taxation in the standard RBC model. They show that the first- and second-order approximations of the Ramsey equilibrium conditions are similar to the approximation based on a minimum-weighted-residual method reported in Chari et al. (1995).

6. To the best of our knowledge, Chari et al. (1991) represent the first quantitative demonstration that the Ramsey rate of inflation in a flexible-price economy is highly volatile and unforecastable. However, the idea that surprise inflation is a tax on the stock of outstanding nominal government liabilities and that, as a result, the Ramsey rate of inflation should have dynamic properties akin to the Ramsey capital-income tax rate has been articulated by Turnovsky and Brock (1980), Judd (1992), and Calvo and Guidotti (1990, 1993).

7. The result that inflation volatility rises significantly when product prices are allowed to be flexible but wages are sticky is sensitive to the battery of shocks driving business cycles. Chugh (2005) shows that when the sole source of uncertainty is innovations in government spending, then the Ramsey outcome implies low inflation volatility when prices are flexible but wages are sticky. Indeed, in our model, when prices are flexible but wages are sticky, the volatility of inflation is 5.8 percent in the environment with productivity and government spending shocks, but it is only 0.3 percent in an environment with only government purchases shocks. The intuition for why adding productivity shocks increases the optimal volatility of inflation when prices are flexible and wages are sticky stems from the fact that in response to productivity shocks, the real wage tends to move more than in response to government spending shocks and that the role of inflation is to bring real wages closer to their efficient level. It follows that the high volatility of inflation in the case of sticky wages and flexible prices is not fiscal in nature.

8. One exception is the fact that the mean rate of inflation increases dramatically when product prices are flexible. As discussed earlier in Section 3.1, the reason why the Ramsey planner chooses to inflate when all prices are flexible is that inflation is an indirect tax on transfer payments.

9. Under this higher level of wage stickiness and price flexibility (i.e., $\tilde{\alpha} = 0.87$ and $\alpha = 0$), the optimal inflation volatility is 7.8 percent. On the other hand, under sticky

prices and flexible wages (i.e., $\tilde{\alpha} = 0$ and $\alpha = 0.6$), the optimal inflation volatility is 0.2 percent. Hence, when price stickiness takes its baseline value but wage stickiness is higher than in the baseline case (i.e., $\tilde{\alpha} = 0.87$ and $\alpha = 0.6$), the inflation volatility is closer to the figure associated with product-price rigidity alone.

10. Formally, the wage-inflation Phillips curve can be written up to first order as $\hat{\pi}_t^W = \beta E_t \hat{\pi}_{t+1}^W - \kappa \hat{\tilde{\mu}}_t$, where $\pi_t^W \equiv W_t / W_{t-1}$ denotes wage inflation and $\tilde{\mu}_t$ denotes the wage markup. The difference between our approach to modeling the labor market and the one adopted in Erceg et al. (2000) is the size of the parameter κ. Under our specification, $\kappa = \kappa^{SGU} \equiv (1 - \tilde{\alpha})(1 - \tilde{\alpha}\beta)/\tilde{\alpha}$. The Erceg et al. specification implies that $\kappa = \kappa^{SGU}/(1 + EHL)$, where EHL is a positive constant.

11. A further criterion one could impose is that the nominal interest rate not violate the zero bound. In Schmitt-Grohé and Uribe (2004c), we approximate this constraint by requiring that, in the competitive equilibrium, the standard deviation be less than a fraction of the steady-state value of the nominal interest rate.

12. A formal derivation of this welfare cost measure is presented in the expanded version of this paper (Schmitt-Grohé and Uribe 2005b).

13. Our computational strategy does not allow us to consider the case when tax rates are bounded above and below explicitly. But even if one were to use an alternative computational method, one should find that Ramsey capital income tax rates vary significantly over the business cycle.

14. Chari et al. consider an annual calibration (which is somewhat different from the one considered here), with business cycles driven by government purchases and technology shocks. Recently, Benigno and Woodford (2005), using a different numerical technique, replicate this finding. As a test of our numerical procedure, we also study this economy and are able to reproduce the numbers reported in Benigno and Woodford.

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Comment

Jesús Fernández-Villaverde, University of Pennsylvania, NBER, and CEPR

Introduction

This paper is an ambitious and engaging project. It aims to answer one of the basic questions in macroeconomics: How should a benevolent government conduct fiscal and monetary policy? More concretely, it investigates issues as important as: Should we lower taxes in a recession? Or should we keep the government budget balanced? Should we aggressively reduce inflation and achieve price stability? Or does inflation have positive effects on the economy?

Stephanie and Martín (SM hereon) build their paper around three key elements. First, SM specify a rich dynamic equilibrium model with those real and nominal rigidities that have been shown to be important in accounting for aggregate fluctuations in the U.S. economy. Second, they use a form of policy commitment recently proposed by Woodford (2003) known as the timeless perspective. Third, SM follow a quantitative approach: they calibrate and compute the model to generate concrete numbers to characterize the optimal policy. As bonus material, SM present simple monetary and fiscal rules that implement a competitive equilibrium close to the one induced by the optimal timeless perspective. These simple policy rules eliminate the problem of multiplicity of equilibria that may appear if we directly implement the optimal policy.

Among SM's main findings, I would highlight the importance of price stability as the central goal of optimal monetary policy. Under an income tax regime, the optimal rate of inflation is 0.5 percent a year with a volatility of 1.1 percent. A second important finding is that governments should smooth taxation: the optimal tax on income is 30 percent with a 1.1 percent standard deviation. Finally, the paper shows how, if we let labor and capital income be taxed at different rates, it is optimal to provide a large and volatile subsidy to capital.

I strongly agree with SM that we should use dynamic equilibrium models to conduct optimal policy exercises in the spirit and style of the exercises conducted in this paper. In addition, I find their results appealing and intuitive. I enjoyed thinking about the paper a lot. I hope a large audience of macroeconomists will read this work over the next few years. SM have offered a thorough review and consolidation of the literature on optimal policy and have pushed the frontier of macroeconomics several steps ahead.

Having said that, I do not have much to add to the content of the paper beyond a few minor points. First, I will talk about the strengths and weaknesses of the medium-scale model specified by SM. Second, I will discuss the formulation of the policy problem. Third, I will offer a few suggestions regarding the empirical strategy of the exercise. Finally, I will evaluate the results.

Model

SM build their model around the recent and influential paper of Christiano, Eichenbaum, and Evans (2005). I will refer to the authors of this paper as CEE from now on. CEE's paper is an important contribution because it shows how we can formulate and estimate a model of the business cycle compatible with the evidence gathered from an identified vector autoregression (VAR).

CEE prove how dynamic equilibrium models of the business cycle have come a long way since the pioneering contribution of Kydland and Prescott (1982). Thanks to advances in economic theory and progress in numerical techniques over the last twenty-five years, macroeconomists know how to build rich and powerful models of the business cycle. Old challenges, such as the modeling of monopolistic competition, sticky prices and wages, credit market imperfections, and others are today much better understood than they were a few years ago.

These developments are important, not only because they allow us to formulate better models but also because these better models have a nontrivial role for fiscal and monetary policy. This more active role for policy requires that macroeconomists think carefully about the advice we provide, especially because policymakers are noticing the success of equilibrium theory. A growing number of policy institutions (the European Central Bank, the Federal Reserve Board, the Riksbank, the

International Monetary Fund, the Bank of Canada, the Bank of Spain, and the Bank of Italy, among others) are formulating and estimating dynamic equilibrium models of the business cycle similar to CEE's for policy analysis.

But before these models play in the big leagues of conducting actual monetary and fiscal policy, we want to coach them to ensure that their debut is successful. To help in this task, I discuss some potential problems of CEE's and SM's models and suggest some potential avenues for improvement.

Potential Problems of the Model

CEE's and SM's models are an impressive achievement. With a moderate amount of real and nominal rigidities, CEE and SM account for a surprising amount of aggregate dynamics. However, it is wise to keep a critical eye on some shortcomings of the models to help us both improve upon them and assess how much confidence we should place in the policy recommendations they generate.

The first concern is the high level of price and wage stickiness required by CEE to achieve their results. SM set the average duration of firms' prices to be ten months. However, Bils and Klenow (2004) report that, according to Consumer Price Index (CPI) data, half of the prices for goods last less than 4.3 months. This excessively high degree of price stickiness is not unique to CEE or SM. Smets and Wouters (2003), whose paper is a close relative of CEE's, need to fit the data that firms change their prices, on average, every twenty-seven months. Galí and Gertler (1999) and Eichenbaum and Fisher (2004) ask for firms changing prices only every eighteen months.

To answer this criticism, Altig et al. (2005) have modified CEE. In CEE, as in basic Real Business Cycle (RBC) models, capital is freely and instantaneously movable across firms. Altig et al. assume that the capital stock of each firm is predetermined in each given period. Thus, the marginal cost of the firm is rapidly increasing in its own output. Altig et al. note that, in this environment, firms change prices only by a small amount. Consider a firm that wishes to raise its price in response to a monetary shock. Since a rise in price will imply a drop in output, the firm will have a much lower marginal cost and, hence, a lower optimal price. Both effects, a higher price in response to a monetary shock and a lower price because of lower marginal cost, will nearly cancel each other. Moreover, Altig et al. show that the computation of this model is nearly as simple as the solution of CEE. The theoretical results and the easiness of computation suggest that SM could extend their model to introduce firm-specific capital. Hence, SM could reduce the required level of price and wage stickiness and investigate optimal policy in this more flexible, yet empirically successful, environment.

A second related problem of CEE is its relatively weak built-in persistence. In CEE's theoretical model, output response to a monetary shock is positive right after the policy innovation, and it peaks after four quarters. In the identified VAR estimated by CEE, output does not rise until two quarters after the shock, and it peaks at six quarters, with a much slower decay after the peak than in the theoretical model. This lack of persistence is worrisome because it casts some doubts on the internal propagation mechanism of the model and its adequacy to serve as a laboratory for policy and especially because CEE estimate their model to match the VAR impulse-response functions.

A third issue is SM's assumption that labor decisions are made by a union that supplies labor monopolistically to firms. This assumption goes against the evidence on wage posting by firms (Manning 2003) and likely against the observation that only 12.5 percent of American workers are union members. This criticism is relevant because in the type of models exemplified by CEE, wage rigidities are more important than price rigidities in accounting for the dynamics of the aggregate quantities. An alternative and more positive interpretation is that the wage rigidities in CEE are a reduced form for some underlying structure of the labor market that implies a high degree of rigidity on wages. However, we still do not understand that structure very well.

Finally, I would like to offer some comments about the microfoundations of CEE and SM. A basic thread of macroeconomics is the search for general equilibrium models soundly built around explicit assumptions about preferences and technology. How well do CEE's and SM's models perform on the microfoundations test?

The metric of what we consider assumptions about preferences and technology displays an uneasy degree of arbitrariness. For example, working with an aggregate production function or with putty-putty capital does not raise an eyebrow nowadays, but it was the object of furious discussion not so long ago in the nearly forgotten Cambridge Controversies (Cohen and Harcourt 2003). But even keeping these ambiguities in perspective, several aspects of CEE's and SM's models are troublesome.

Among those, I could discuss the mechanism behind Calvo pricing, the investment adjustment costs, or the union labor market structure. In the interest of concreteness, I will focus on the introduction of a demand for money through the joint assumption of a proportional transaction cost for households and a cash-in-advance constraint for firms. We could equivalently present this joint assumption as a statement about the productivity of real money balances.

Wallace (2001) has forcefully criticized those models in which real balances are assumed to be productive. He argues, first, that the models contain hidden inconsistencies that are difficult to reconcile with standard theory. Second, the relation between the fundamental models of money (those where the environment is such that money is essential) and the reduced-form structure embodied by productive real balances is often not clear. Moreover—and this point is especially important for my discussion—we do not know whether that relation is invariant to changes in monetary policy. The reader can recognize how this last concern is nothing more than the Lucas critique slightly disguised. SM are proposing a model for designing monetary policy, and a crucial component of that model, the money demand, is a black box whose response to changes in the systematic component of monetary policy is hidden from the researcher.

There are two answers to this attack. First, the behavioral responses to a variation in the systematic component of monetary policy reflected in the reduced form of the money demand are likely to be small. Even if this may well be the case, defenders of productive real balances models of money do not provide a procedure to verify this claim. The second and more compelling answer is that fundamental models of money have not delivered an operational alternative to reduced-form models. We do not have a well-founded model of money that can be taken to the data and applied to policy analysis. Ricardo Lagos and Randy Wright have recently made important progress on this front (Lagos and Wright 2005). However, there is still a lot of space to cover before Lagos-Wright or a similar model can compete in terms of empirical fit and flexibility with CEE. In the meantime, models of money where real balances are productive, like SM's, need to fill the void.

Suggestions for Enhancing the Model

We can use a model like SM's for two different purposes. First, we may want to develop intuition about how the different real and nominal rigidities shape optimal policy. In this type of exercise, even if numbers are important, they somehow play a secondary role behind the qualitative results. The goal is to further our understanding of economic theory and its implications. Second, we may want to use the model to provide policy recommendations or at least broad guidelines for action. My reading of the paper is that SM's model aspires to fill this second role as an instrument for thinking about the real world. But if this is the objective, the hurdle we need to overcome is more challenging since we need to pick the most salient features of the data to provide sufficient trust in the results of the exercise.

The selection of these prominent components is a daunting task. Even if I do not have special insights with respect to this choice of modeling features, in the interest of the discussion, I will dare to offer three suggestions: first, to model long-run growth explicitly; second, to introduce investment-specific technological change; and third, to think about the open-economy implications of the model.

Growth SM's model lacks long-run growth. In the basic CEE model, this is not a big concern. We know that the cyclical properties of the basic RBC model and its descendents, like CEE, are not affected much by the presence of growth. We handle the issue of long-run growth either by ignoring or (since detrending is usually straightforward) by working with detrended variables.

However, long-run growth might not be so innocuous when we investigate optimal policy. SM recognize this point when they report that in the Chari et al. (1995) model, the standard deviation of capital income tax increases by 60 percent when we eliminate long-run growth. This result begets the question: Are there more cases where the absence of long-run growth will change the conclusions of the paper? Since the marginal cost of introducing long-run growth seems low, it may be a worthwhile addition to the model.

Investment-Specific Technological Shocks The work of Greenwood, Hercowitz, and Krusell (1997, 2000) and Fisher (2003) has emphasized the role of investment-specific technological change as a main driving force behind economic growth and business-cycle fluctuations. Fisher (1999) documents two observations to support this view. First, the relative price of business equipment in terms of consumption goods has fallen in nearly every year since the 1950s. Second, the fall in the relative price of capital is faster during expansions than during recessions.

The role of investment-specific technological change appears clearly in models similar to SM's. For example, Boivin and Giannoni (2005) estimate a model by Smets and Wouters (2003) using a rich data set and a factor structure. They report that investment-specific technological change accounts for 42 percent of the variance of output at an eight-quarter horizon. If we compare this finding with the role of government expenditure (8 percent of the variance) or with monetary policy (21 percent), the case for modeling investment-specific technological change appears strong.

An attractive characteristic of investment-specific technological change is how easily we can introduce it in our models. The law of motion of capital for SM would become:

$$k_{t+1} = (1-\delta)k_t + \varsigma_t i_t \left[1 - \frac{\kappa}{2}\left(\frac{i_t}{i_{t-1}} - 1\right)^2\right]$$

where ς_t is the investment-specific technological shock. We can assume, as SM do for the other shocks in the model, that the logarithm of ς_t follows a first-order autoregressive process of the form:

$$\log \varsigma_t = \rho_i \log \varsigma_{t-1} + \varepsilon_t^i, \quad \varepsilon_t^i \sim N(0, \sigma_{\varepsilon^i})$$

where $\rho_i \leq 1$.

Beyond a better empirical fit, investment-specific technological change has the potential for qualifying some of SM's results. An investment shock has a different impact on aggregate quantities than a regular productivity shock. The fall in the relative price of investment induces an increase in hours worked and a relative fall in consumption and labor productivity in the short run (in opposition to the standard model, where hours and productivity increase at impact). These dynamics hint at the possibility of different behavior, for example, of the tax on capital over the cycle. The main argument of Judd (2002) about justifing the subsidies to capital relies on equating the social rate of return of capital and the private rate of return. Those rates of return are directly affected by investment-specific technological change. Thus, the properties of the tax on capital, in particular its correlation with the business cycle, may change in this richer environment.

Open Economy Even a cursory following of the media reveals that open-economy considerations are an important component of economic policy. Discussions regarding the exchange rate of the dollar or the U.S. trade deficit fill the pages of the *New York Times* or *The Economist* and preoccupy both the Treasury and the Federal Reserve System.

SM chose to skip all these open-economy considerations in their paper. Their choice is the correct one. SM already advance our understanding of optimal policy models with real and nominal rigidities by several important steps. Attempting to deal with open-economy considerations in the same paper risks lack of focus and clarity.

However, I am eager to see this research agenda develop in the next few years to model open economies. Just to sketch how such a model can be built, I will offer a summary of Adolfson et al. (2004). These authors extend CEE, the model of reference chosen by SM, by adding open-economy components. The model requires modification of only three aspects.

First, the model has three categories of firms: domestic firms, importing firms, and exporting firms. The intermediate domestic-good firms behave as in SM, producing an intermediate good that is aggregated into a final good. The importing firms transform a generic imported good bought in the world market into a differentiated imported good, which is sold to domestic households. The exporting firm buys the final good and differentiates it by brand name.

Second, the consumption of the household c_t can be defined as:

$$c_t = [(1-\omega)^{1/\eta_c}(c_t^d)^{(\eta_c-1)/\eta_c} + \omega^{1/\eta_c}(c_t^m)^{(\eta_c-1)/\eta_c}]^{\eta_c/\eta_{c-1}}$$

where c_t^d is a composite of all the domestic differentiated goods, c_t^m is a composite of all the goods produced by importing firms from the generic imported good bought in the world market, ω is the share of imports in consumption, and η_c is the elasticity of substitution across consumption goods.

Finally, Adolfson et al. follow Beningno (2001) and close their model with a premium on foreign bond holdings, which depends on the real aggregate net foreign asset position of the domestic economy. This premium induces stationarity in the model by making it more costly to borrow when the economy has a lower net foreign asset position.

Adolfson et al. estimate their model using Euro area data and Bayesian techniques. They show how the model can capture the volatility and persistence of the real exchange rate and the observed large home bias in trade. These results seem to be a promising line of research, and I invite SM to extend their results to a model with open-economy components. Since SM are leaders in the field of both open macro and optimal policy, they may have a great comparative advantage in that undertaking.

Fiscal Policy Instruments The tradition in Ramsey taxation problems has focused on the question: How should we tax in order to raise the resources to finance an exogenous stream of government expenditure? SM follow this tradition. In practice, however, governments often employ public expenditure as a powerful policy instrument. This intervention may be explicitly targeted toward stabilizing the economy, following the Keynesian tradition, or implicitly targed, as in the military buildups of the early 1980s and after 9/11 (I do not want to enter into the discussion of whether the military buildups were exogenous; suffice it to say that they were in part freely chosen by the different U.S. administrations). Burnside, Eichenbaum, and Fisher (2003) document how a persistent increase in government purchases leads to a persistent increase in aggregate hours and a decline in real wages.

The intuitive answer to this suggestion—we do not really use public expenditure any longer to stabilize the economy—can be turned around: maybe we should! A suitably modified version of SM could address questions such as: Does the use of government expenditure increase welfare? Is it a better or a worse alternative than tax policy?

I should disclose here that my prior is that playing with government expenditure is unlikely to be a sound policy recommendation. However, I would like to have a model to back up my belief. A version of SM may play that role.

A Caveat At this moment, it is important to offer a caveat regarding the complexity of the model. This warning will, up to some point, contradict my own words in the last pages. When do we know enough is enough? When should we stop the process of enriching the models we want to use for policy analysis?

As I mentioned before, this problem is more complicated in an environment like SM's than in purely theoretical papers since we want to use the model for real policy evaluation. On one hand, we want enough detail to capture the dynamics of the data. On the other hand, too much detail may imply the loss of intuition and too many confounding effects. For example, in SM's model, the policymaker faces a tradeoff between minimizing relative product price dispersion and minimizing relative wage dispersion. This tradeoff is solved quantitatively in favor of minimizing price dispersion. However, this result is sensitive to the shocks driving the business cycle. As SM point out, Chugh (2005) reports how, with government expenditure shocks but without productivity shocks, volatile inflation may increase welfare even with nominal rigidities. How many of these results reversals are hidden in a complicated model? The point of the example is to illustrate how the interaction between shocks and rigidities may get too complicated to provide a thorough understanding of the behavior of our model.

I do not want to construct this example as a criticism of rich models. I want to present it as a warning. After having absorbed the shock of *The General Theory*, macroeconomists in the 1950s built and estimated models such as Klein-Goldberger's, which showed a fantastic fit for the standards of the time and great promise for future development. Unfortunately, the models from the 1950s did not scale well in the 1960s. Models such as the Brookings model or the FRB-MIT-PENN model became too cumbersome. They were difficult to handle and nearly impossible to understand, and their forecasting power was very poor (Nelson 1972).

We may now be in a situation similar to the 1950s. We are creating and formulating models that show a fantastic fit for the standards of our time and great promise for future development. We do not want to end up saddled with models too complicated and too cumbersome to understand.

Timeless Perspective

SM follow a form of policy commitment recently proposed by Woodford (2003) known as the timeless perspective. This perspective differs from the standard Ramsey solution in that the timeless form imposes time invariance on the optimal policy of the government. In that way, the behavior of models such as Chari et al. (1994), where the government levies a large tax on capital in the first period, is not allowed.

I like the application of the timeless perspective in the paper. Timeless perspective has an intuitive appeal that the standard Ramsey solution concept lacks because of its first-period peculiar behavior. I will comment only on two issues.

First, the difference between standard Ramsey and timeless perspective may be important in some cases. Most of the welfare gains in Chari et al. (1994) come from the first period taxation of capital. The reason is that taxing capital at a high rate in the first period is a nondistortionary procedure to build public assets. The income from these public assets will allow future reductions in taxes. In the timeless perspective, all those welfare gains disappear, and since the government needs to tax more in each period, the economy will converge to a different stochastic steady state than under Ramsey. Even if we prefer the timeless perspective to standard Ramsey, it would be interesting to have a more thorough understanding of the differences between the two approaches.

Second, we must keep in mind that the results from the timeless perspective can be very different from the results from a sustainable equilibrium. The assumption of commitment has nontrivial implications, for example, with respect to the taxation of capital. This observation is well known. I will, however, cite my paper, Fernández-Villaverde and Tsyvinski (2002), just because I understand it better. Aleh and I show that the best equilibrium in a stochastic business-cycle model with taxation implies a tax on capital that fluctuates around 25 percent. This is quite different from the result in Chari et al. (1994), where capital income tax fluctuates around 0 percent. This shows how important the quantitative effects of lack of commitment are.

However, the problem of handling lack of commitment is not trivial since we need to resort to the Abreu-Pierce-Stacchetti toolbox (Abreu et al. 1990), which imposes a considerable computational burden. Nothing like my exercise with Aleh can be attempted at the moment for a model like SM's. Thus, I want to emphasize only that we should remember the importance of the assumption of commitment behind SM's results.

Empirical Strategy

SM's model is profligately parameterized. Table 6.1 in the paper lists twenty-eight parameters. Because the models are so close, SM borrow most of their parameters from the empirical work of CEE and Altig et al. (2005). In addition, SM have several explicit calibration targets for the remaining parameters. This mixed strategy is a reasonable compromise between a thorough empirical implementation of the model and complexity.

However, I would like to draw attention to two different potential problems. First, structural parameters do not have a life of their own. There is no β or η out there waiting to be discovered. Parameters are only meaningful within the context of a model. Even if CEE and Altig et al. (2005) are models very similar to SM's, they are not the same model. Consequently, we do not have any reassurance that the parameters are structural with respect to the change of models.

A more consistent approach will attempt to estimate the parameters of the model using U.S. data. There are many procedures to do this: different versions of method of moments, indirect inference (as in CEE, when they match impulse responses of an identified VAR), maximum likelihood, etc., but my favorite empirical strategy is Bayes. The Bayesian approach is a powerful procedure to take dynamic economic models to the data. Fernández-Villaverde and Rubio-Ramírez (2004a, 2004b) show that Bayes has good asymptotic and small sample properties, even if the model is misspecified. Also, a Bayesian approach can handle nonlinear models much better than classical methods. Moreover, it offers a formal mechanism to incorporate prior information, such as the estimates of CEE and Altig et al. (2005). Thanks to all these attractive properties, over the last few years, the Bayesian paradigm has been applied to numerous dynamic equilibrium models. Two recent examples are in this macroeconomics annual, where Levin et al. (2005) use Bayes to study monetary policy under uncertainty and Lubik and Schorfheide (2005) implement the Bayes approach to estimate open-economy models.

There are several additional advantages of an explicit estimation procedure. First, it is easier to sell to policymakers since they appreciate formal approaches that are reproducible. Second, it allows us to assess the fit of the model and compare it with alternatives. Third, it gauges uncertainty regarding parameters. Finally, estimation allows the evaluation of the robustness of policy recommendations toward changes in parameter values within empirically relevant ranges.[1]

A second potential problem is to evaluate how "structural" the structural parameters are. In particular, I am worried about the Calvo parameters determining the fraction of firms not setting prices optimally and labor markets not setting wages optimally each quarter. The reason why we model price and wage stickiness with a time-dependent model like Calvo's (or alternative Taylor pricing) is tractability. Exogenous and staggered timing allows for simple aggregation of individual pricing policies. This aggregation facilitates the computation of equilibria with standard methods. However, time-dependent models lack microfoundations. Why are firms allowed to change prices only in a fraction α of quarters?

The typical answer to this lack of microfoundations is to defend time-dependent models as a simpler version of a more complicated, state-dependent pricing model, where firms change prices endogenously subject to a menu cost. The hope is that, in a low-inflation economy like the United States, the difference between time-dependent and state-dependent models will be small. This is, for example, the finding of Klenow and Kryvstov (2005), who estimate that the intensive margin of price changes (the average size of the change) accounts for 95 percent of the variance of monthly inflation, while the extensive margin (the fraction of items changing price) accounts only for 5 percent. Since the time-dependent models can account for the intensive margin, Klenow and Kryvstov (2005) conclude that these models do a fair job of capturing inflation dynamics.

However, Klenow and Kryvstov study 1988–2003 data, when inflation was low and stable in the United States. In that environment, there is bound to be too little variation in the data to tell time-dependent and state-dependent models apart. If we want to evaluate alternative monetary policies, we would need to know that both types of models are still going to be close under the different policy regimes.

Unfortunately, the answer may be negative. We know that state-dependent models often have radically different implications than time-dependent models. Caplin and Spulber (1987) present the most radical example. Under certain assumptions about the money process and price distribution, Caplin and Spulber find that money is neutral. More recently, Dotsey et al. (1999) have presented a dynamic equilibrium model that shows how the patterns of price adjustment in a state-dependent model change dramatically when systematic policy changes. Based on Dotsey et al.'s results, I find it difficult to accept that the Calvo parameters of SM are really "structural." It is more plausible to assume that firms will change their prices more often if we implement a policy regime with a higher variance of inflation.

This observation has implications for policy recommendations. Chari et al. (1995) show that, in the context of a flexible-price model, the optimal rate of inflation volatility is extremely high, above 10 percent a year. The reason is that unexpected variations in inflation make nominal assets state-contingent in practice. In SM, this desire for inflation volatility is overcome by the cost of price dispersion induced by nominal stickiness. But if the government implemented a high volatility inflation policy, firms would adjust their prices much more often, and we could get a reversal of SM's results back to Chari et al.'s results. I emphasize the word *could*. Maybe price stability would still be a prime goal of monetary policy in a state-dependent pricing model. But I would like to know how many of SM's results survive in a state-dependent pricing environment.

Evaluating the Results

SM do a fantastic job of presenting the results of the paper. Thus, I will not repeat them here. As I mentioned in the introduction, I am very happy with the main results: low and stable inflation, a large subsidy on capital, smooth taxation, etc. But the fact that I am so sympathetic to the results worries me a little. Either I have a special sense for policy recommendations—something I doubt—or we may have committed the sin of "specification searches" (Leamer 1978).

I have always feared that CEE may have already incurred that problem when they estimated their VAR: the results are sometimes too close to what our educated intuition tells us they should be. But how do we know that our educated intuition was right to begin with? Similarly, the different ingredients added by SM deliver answers that beautifully fit with what we thought was a sensible policy. Of course, CEE and SM could argue that their assumptions are explicit and that we can always check their robustness. Since CEE and SM are probably right, I do not want to further elaborate on the problem of specification searches but rather leave it behind us as a phantom menace.

The two results I want to discuss in more detail are the low inflation and the large subsidies to capital. SM defend a very low rate of inflation (0.2–0.5 percent). However, most central banks target, explicitly or implicitly, higher levels (1–3 percent). What is the source of this divergence? There are different alternatives. One is that SM have missed an important margin. For example, central bankers are awfully worried about the possibility of financial meltdowns. They will even claim that avoiding those meltdowns is their foremost job. SM's model does not capture any of these systemic problems and, consequently, it may miss the channel for this higher inflation. However, it is not clear why a little bit higher inflation may avoid financial meltdowns. Because it allows policymakers to engineer negative real interest rates? A second possibility is that central banks are too liberal. However, accusing central banks of leniency seems a bit dramatic (although it has been done; see, for example, Cukierman 2002). Finally, we can argue that the objects of theory and measurement are different possibly because of the bias in our indexes of inflation induced by quality improvements (see Bils and Klenow 2001).

The second result I want to comment on is that SM find that large subsidies to capital are optimal. We do not observe these large subsidies in the real world and proposing such a scheme would probably seem too radical to have a realistic chance of being accepted by our current political system. Again, we have different possibilities. First, SM could have missed an important margin. The lack of commitment of governments I discussed above is the usual suspect, but there may be others. For example, Aiyagari (1995) links a positive tax on capital income and incomplete markets. In this environment, a positive tax on capital income reduces the overaccumulation of capital created by borrowing constraints. Second, the perceptions of the public and politicians could be very far away from sound policy recommendations. The attitudes of the general population toward international trade are probably a good example of how there can exist dissonances between the general opinion of economists and the intuition of the representative agent. Finally, maybe there is a good political-economic reason precluding a move toward subsidies for capital (Heathcote 2005).

Concluding Remarks

I conclude by emphasizing once more the importance of this paper. SM have offered us a synthesis of what was known plus many new results on optimal policy design. At the moment, this paper represents the frontier of the field of policy analysis in equilibrium models of the business cycle. I have discussed several aspects of the paper where I see room for improvement, but none of my comments should be construed as diminishing the importance and beauty of SM's work, only as pointers for follow-up articles.

There is one more great thing about this paper. If the reader goes to the companion web page of the paper at http://www.econ.duke.edu/~uribe/research.html, he or she can find an expanded version and the MATLAB code required to run the experiments in the paper. Even if SM do not want to brag too much about it, a final contribution of the paper is a set of numerical tools to compute Ramsey policy problems in a general class of dynamic equilibrium economies. I would encourage all interested readers to visit the web page and experiment with the code themselves.

Endnote

1. There is, however, one difficulty hidden in the closet of estimation of dynamic models. How do we estimate government policy? Do we estimate its whole strategy? Or do we specify simple rules like the ones proposed by SM? But are these rules similar to anything the government follows? Can we use them for counterfactuals? I will not elaborate on this issue further since it will take me away from the main theme of my discussion.

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Comment

Michael Woodford, Columbia University and NBER

This paper contributes to a rapidly growing literature on the analysis of alternative rules for monetary and/or fiscal policy in the context of fully articulated dynamic stochastic general equilibrium (DSGE) models, a development in which these authors have played a leading role. The novelty of the present paper is that (1) it analyzes monetary and fiscal policy rules jointly, in a single coherent framework, and (2) it offers quantitative characterizations of optimal policy in a model that is intended to be quantitatively realistic and, as a consequence, is of at least modest complexity. These authors have previously considered the joint problems of optimal monetary and fiscal policy (Schmitt-Grohé and Uribe 2004a) in a more stylized DSGE model with sticky prices, and they have previously considered optimal monetary policy in the context of a model of the monetary transmission mechanism similar to the one assumed in this paper, while abstracting from tax distortions (Schmitt-Grohé and Uribe 2004b). But this is the first time that their analysis has been ambitious in both directions simultaneously, and the paper is the first effort in this vein that I have seen.[1] The paper also extends the analysis of optimal monetary and fiscal policy in Schmitt-Grohé and Uribe (2004a) by considering not just the state-contingent allocation and evolution of prices that one would like to bring about, but also the kind of simple monetary and fiscal policy rules that could serve to implement a desirable equilibrium.

The model used for the analysis is a fairly complex one by the standards of the recent literature on optimal macroeconomic policies, though it is still fairly simple relative to many of the quantitative models that are used for quantitative policy simulations in central banks. On the one hand, it incorporates a number of features of the most recent generation of econometrically estimated DSGE models of the monetary transmission mechanism. Among these features are internal habit formation in consumption; endogenous capital accumulation, with a convex cost of adjusting the rate of investment spending; variable capital utilization; a production technology with modestly increasing returns to scale; transactions frictions that result in a demand for money balances on the part of both households and firms; monopolistic competition in both goods and labor markets; staggered adjustment of both nominal wages and prices; indexation of wages to a lagged price index; and several different types of exogenous disturbances, the largest of which is a technology shock. The quantitative calibration of most of these aspects of the model is based on econometric estimates drawn from the work of Christiano et al. (2005), Altig et al. (2005), Smets and Wouters (2004), and Levin et al. (2005), where arguments were first given for the inclusion of such elements in an empirically realistic account of short-run fluctuations in the U.S. economy.

At the same time, the model used here also includes complications not present in any of the econometric models just cited, which are needed to allow an analysis of how monetary policy interacts with tax distortions. There are assumed to be no lump-sum taxes (unlike what is implicitly assumed in the papers just mentioned, which abstract from supply-side effects of tax changes), and as a result, the dynamics of the government debt must be explicitly modeled. Proportional taxes on labor income, on capital income, and on dividend income (that may or may not be set at different rates) are allowed as sources of government revenue, and the resulting distortions are taken into account in the various model equations. The government is allowed to issue a single type of debt instrument, one-period riskless nominal debt.

These aspects of the model result in a nontrivial tax policy problem and give rise to important linkages between monetary stabilization policy and optimal tax policy. The formulations adopted are also fairly standard in the recent literature on optimal dynamic Ramsey taxation that abstracts from problems of monetary stabilization policy (surveyed in Chari and Kehoe 1999). However, the quantitative specifications adopted are not based on econometric models of U.S. debt dynamics or of the effects of tax distortions on the U.S. economy, as is true of other aspects of the model. This is a shame, given the authors' aspiration to quantitative realism, but at present, few econometric DSGE models suitable for the analysis of both monetary and fiscal policy have been estimated,[2] and the authors have undertaken no new econometric work in this paper.

Another respect in which the model used makes little attempt at quantitative realism is in the specification of driving shocks. The model allows for only three types of shocks: a stationary technology shock, exogenous variation in government purchases, and exogenous variation in the size of transfer programs. But no reason is offered to suppose that these three types of shocks subsume all relevant disturbances to the U.S. economy. The latter two types of shocks are often considered in analyses of optimal dynamic tax policy because they raise obvious questions about how changes in government spending should be financed, but there exist no econometric studies suggesting that these particular shocks are primary sources of aggregate fluctuations. Furthermore, none of the econometric studies that are used to motivate the model's calibration support the view that these three shocks are the only important ones. While Altig et al. (2005) do not provide a structural interpretation of all of the sources of aggregate volatility in their model, they do identify the effects of investment-specific technology shocks and conclude that these have been an important source of aggregate volatility in the U.S. economy.[3] Smets and Wouters (2004) instead offer a complete account of the data-generating process for the set of seven aggregate variables that they model; in their estimated model, there are ten different shocks, including six kinds of real disturbances not allowed for in the model here.[4]

The omission of other shocks, including some that may be important sources of aggregate variability, is of no importance when the optimal responses to the three shocks considered here are as characterized in Section 4; in the linear approximation to Ramsey policy that is computed here, the optimal response to each type of shock is independent of other types of shocks that may also affect the economy. But it *is* of importance for the computation of optimal simple rules for monetary and fiscal policy, and for the welfare comparisons that are offered in Sections 5.1 and 5.3. Calculations of this kind are correct only insofar as the kinds of shocks taken into account represent all of the non-negligible sources of variation in the variables relevant for welfare. Hence, policy analysis that could claim to be based on an empirically valid model would have to estimate a complete set of disturbance processes.[5]

The joint consideration of monetary and fiscal policy issues is an important achievement only if it turns out that the conclusions reached are different than those that would be obtained by considering each of the two policy problems in isolation. In fact, the authors do obtain a number of unexpected results; in particular, their conclusions about the nature of optimal monetary policy differ in some notable respects from those obtained in previous analyses that are abstracted from tax distortions, including their own previous work (Schmitt-Grohé and Uribe 2004a).

One novel conclusion here is their finding that the optimal long-run inflation target is slightly above zero. The distortions that result from staggered price-setting of the kind assumed here are minimized by an inflation rate of zero since any change in the aggregate price index, in either direction, requires that newly chosen prices differ from existing prices that have not yet been reconsidered, and this distorts the composition of output and consumption. Benigno and Woodford (2005) show that the optimal long-run inflation rate continues to be exactly zero in a model with Calvo-style staggered pricing, even when distortions resulting from monopolistic competition and/or taxes imply that the steady-state level of output associated with stable prices is inefficiently low.[6] This result refers to a model that abstracts from the transactions frictions that create a demand for money balances. If transactions frictions are added in any of several conventional ways, the long-run inflation rate under Ramsey policy is instead slightly *negative*—a rate somewhere between the deflation at the rate of time preference that would minimize the distortions resulting from the transactions frictions, as argued by Friedman (1969), and the zero rate that would minimize the distortions resulting from staggered pricing.[7]

The different result obtained here depends on the authors' simultaneous consideration of the optimal role of the inflation tax among sources of government revenue, in a model where only distorting sources of revenue exist, and the government does have positive (exogenously specified) revenue needs. The reason for their result essentially is that when the private sector must receive an exogenously specified level of (after-tax) transfers, taxing money balances is an indirect way of taxing consumption and hence households' income from transfers.

This result shows the potential importance of considering optimal tax policy and monetary policy simultaneously. But should we believe the result? It is not obviously plausible to treat the real after-tax value of transfers as a constraint on the policy problem. If one could tax transfers directly, there would obviously be no need to do so indirectly through the inflation tax (which creates undesired distortions). One might suppose, of course, that some political constraint (or objective of policy)—say, a concern with the standard of living of certain members of the population who depend on these transfers—makes it imperative that the after-tax value of the transfers not fall below some floor. But in this case, it would make more sense for the constraint to impose a floor on *the quantity of consumption goods that can be purchased with the transfer,* rather than on the after-tax value of the transfer, as assumed here. That is, the constraint should be of the form:

$$n_t \geq [1 + \varphi(v^*(i_t))]\bar{c}$$

rather than of the form:

$$n_t \geq \bar{n}$$

as assumed by Schmitt-Grohé and Uribe. Here, $\varphi(v)$ indicates the transaction cost per unit of consumption as a function of velocity v, $v^*(i_t)$ represents a household's optimal velocity choice as a function of the nominal interest rate i_t, and $\bar{c}$ is the quantity of consumption that the recipients of transfers must be able to purchase with those transfers after the transactions costs are also paid for. With this more reasonable specification of the constraint, it would no longer be possible to use the inflation tax to tax transfer income indirectly; an increased steady-state inflation rate that raises the steady-state nominal interest and hence increases $\varphi(v^*(i))$ would require a corresponding increase in the level of transfers n and thus would not improve the government's budget. And without such an effect, the argument for a positive long-run inflation rate vanishes.

The specification used in this paper appears to exaggerate the fiscal advantages from inflation in other respects as well. When there is only an income tax, the optimal long-run inflation target is found to be higher (compare line 7 of table 6.2 in the present paper with line 1) because inflation effectively shifts more of the tax burden onto wage income, which one would wish to do directly if labor income and income from capital could be taxed separately (as on line 1). The inflation tax effectively taxes labor more than it does capital, in the model used here, owing to the cash-in-advance constraint that is assumed to apply to the firm's wage bill but not to payments for capital services. But it is not obvious that this is a realistic assumption. The literature on the distortions resulting from inflation has more often emphasized the way that inflation increases the effective taxation of *capital* as a result of the non-indexation of depreciation allowances (e.g., Feldstein 1999). This is probably a quantitatively more important effect on effective tax rates since it does not make sense to suppose that cash balances must be held for a long period of time in order for wages to be paid, while the time over which capital goods are depreciated is typically several years. Hence, it is likely that inflation shifts the tax burden away from labor income and toward capital income, contrary to what is assumed in this paper. That would mean, in the event that only an income tax is available, a *lower* inflation rate would be optimal—quite possibly a negative one—to partially offset the positive rate of taxation of income from capital.

Consideration of tax distortions also affects the authors' conclusions regarding the optimal responses to shocks, including the optimal responses of nominal variables such as the inflation rate. But here the results are not dramatically different than those obtained in the literature on optimal monetary policy that abstracts from tax distortions: the main result is once again that it is optimal for inflation to be quite stable, despite the occurrence of various types of real disturbances. The fact that it is not desirable for inflation to vary much, even when only distorting sources of government revenue exist and government debt is not inflation-indexed, had already been shown in calibrated models with a simpler structure (Schmitt-Grohé and Uribe 2004a, Benigno and Woodford 2003). So it is perhaps not too surprising that the same result is obtained in the more elaborate model considered here.

Finally, the authors' conclusions regarding the type of simple policy rules that can achieve the best approximation to Ramsey optimal policy suggest a very different type of monetary policy rule than the one found to be optimal in their own previous work (Schmitt-Grohé and Uribe 2004b) that abstracted from tax distortions. The optimized monetary policy rule indicated by equation (6.4) is a "passive" rule in the sense that a persistently higher inflation rate (holding fixed the paths of both output and the real wage) will result in an eventual rise in the nominal interest rate that is not large enough to keep *real* interest rates from *falling*.[8] In their previous paper, the optimal monetary policy rule instead implied that persistently higher inflation should *raise* the real interest rate, in conformity with the "Taylor principle," and that conclusion was in agreement with many previous analyses that had similarly abstracted from tax distortions.[9]

This is a provocative conclusion; it is a shame that more insight is not offered in the paper as to why a rule of this kind is optimal in the context of the sort of model assumed here, and the extent to which the conclusion depends on assumptions about the character of fiscal policy. The paper asserts only that the passive monetary rule is optimal (within the class of rules considered) in the case that fiscal policy is given by rule in equation (6.5). The fiscal rule in equation (6.5) is itself asserted to be optimal (within the class of rules considered) in the context of the authors' model, but it represents an even more unconventional prescription. A higher level of existing real public debt results in a *decrease* in the income tax rate, even though this implies even greater accumulation of public debt. Furthermore, the coefficient through which the tax rate depends on the lagged tax rate is greater than 1, implying explosive tax-rate dynamics in the event of almost all arbitrary, bounded paths for the real public debt and output. For both of these reasons, the fiscal rule in equation (6.5) is not one that ensures intertemporal government solvency. This does not mean that it is *inconsistent* with intertemporal solvency, however, only that the set of paths for inflation and output consistent with solvency must satisfy certain restrictions. As Eric Leeper (1991) and I (Woodford 2001), among others, have shown, a non-Ricardian fiscal rule of this kind can be part of a coherent policy specification that results in a determinate rational-expectations equilibrium. Hence, there is no a priori reason why the authors should have excluded from consideration policy regimes of the kind that they eventually judge to be optimal.

But how much confidence should we have in the conclusion that the combination of a passive monetary policy and a non-Ricardian fiscal rule would represent the best policy regime for the United States? The paper leaves one with many questions. The extent to which the recommended rules are preferable, even with the class of simple rules considered, is not made too clear. Presumably these represent at least a local optimum within that class, according to the criterion that has been applied, but can one be sure that they represent a *global* optimum? No details are given of any efforts to check this. One would like to know, in particular, if there does not exist another local optimum among regimes with an active monetary policy and a locally Ricardian fiscal policy, how much worse that one is than the policy combination discussed in the paper, and what it is about the more conventional policy regime that makes it so different from Ramsey policy. In fact, one would expect that the same desirable equilibria can be implemented equally well by an active/Ricardian regime or by a passive/non-Ricardian regime; the only question is whether the policy rules required to implement the equilibrium in question might be *simpler* in one case than in the other. It is possible that, among the particular class of simple rules that are considered, the passive/non-Ricardian regimes allow a closer approximation to optimal policy.[10] But equally good rules of the other sort should exist if sufficient flexibility is allowed in the specification of the rules, and it would be interesting to know, in the case of the present model, which kinds of additional flexibility are needed.

Nor is it clear to what extent the pair of rules that optimize the criterion considered in Section 5 are also optimal from the point of view of the welfare of the representative household. The authors select the rule, from within the class that they consider, that implies impulse responses to three particular types of shocks that are as close as possible (on a certain quadratic measure of distance) to the impulse response to those shocks under Ramsey policy. If the class of rules considered included a policy regime that perfectly reproduced the responses associated with Ramsey policy, then that regime would be selected by their criterion, and it would indeed represent an optimal policy commitment from the timeless perspective that I have elsewhere proposed as a basis for the selection of a policy rule (Woodford 2003, Chapter 7). However, if none of the rules in the simple class can fully reproduce the responses associated with Ramsey policy, as is evidently the case here, it is not obvious that the arbitrary distance criterion proposed by the authors makes the right tradeoff among the *different* ways in which different rules are like or unlike Ramsey policy.[11] Ranking alternative rules according to their implications for welfare is the only compelling basis for arguing that a particular pair of rules is superior to other equally simple rules. Benigno and Woodford (2005) show how simple rules can be ranked on welfare grounds, while penalizing rules for departing from the initial commitments that would be made under policy that is optimal from a timeless perspective; in this way, one can apply a welfare-based criterion with the property that if one considers a rule that achieves the same responses as under Ramsey policy, that rule will be judged optimal.

The authors argue that their method for selecting an optimal simple rule is accurate enough on the grounds that welfare is not too much lower in the equilibrium resulting from rules in equations (6.4) and (6.5) than under Ramsey policy. However, this shows only that, according to the metric that they propose, getting the responses to the shocks that they consider to match those associated with Ramsey policy does not matter too much. It is in no way a demonstration that the rules that they select are better on welfare grounds than other very different rules would be.

Moreover, even if a welfare criterion were used to rank alternative equilibria, the authors' conclusions would still depend on their selection of a particular set of disturbances to consider. But as noted above, there seems little reason to think that the three kinds of disturbances considered here together exhaust the main sources of aggregate instability in the U.S. economy. This also makes it unclear how much we should care about the ability of the rules in equations (6.4) and (6.5) to generate (somewhat) desirable responses to those particular types of shocks.

And finally, conclusions about the optimal simple rule obviously depend on the class of rules considered. The rules considered are indeed simple, and they allow for feedback from a few variables to which it might seem especially important to respond. However, as noted above, the responses argued to be optimal are not the conventional ones (for example, the tax rate does not respond to the level of public debt in such a way as to stabilize the path of the public debt). This gives one reason to doubt that the particular restrictions that are assumed a priori—for example, that the current level of the public debt may affect the tax rate but not the interest-rate decision—lead to rules with notably desirable characteristics, even relative to other equally simple rules.

One also wonders whether simple *targeting rules* might have more desirable properties than any of the simple instrument rules that are considered here. A targeting rule would express a relationship among endogenous variables that the policy authorities are committed to seek to maintain through the adjustment of the instruments at their disposal. Giannoni and Woodford (2002) show that particularly robust specifications of optimal policy—in the sense that the same form of policy rule remains optimal in the case of a large number of alternative kinds of disturbances—will often take this form. In the context of a model as complex as this one, the kind of fully optimal rule that Giannoni and Woodford discuss would be much more complex than the kinds of policies considered here, and surely it is of interest to examine the desirability of much simpler rules that may nonetheless be nearly optimal. But experience with simpler variants of the kind of model studied here (as, for example, in Giannoni and Woodford 2005) would suggest that simple targeting rules should be among the first prescriptions to be considered.

Endnotes

I would like to thank Marc Giannoni for helpful discussions, and the National Science Foundation for research support through a grant to the National Bureau of Economic Research.

1. Levin et al. (2005) also consider optimal monetary policy in a model of similar complexity and empirical realism, but they abstract from tax distortions; Benigno and Woodford (2003) also consider jointly optimal monetary and fiscal policy, but in a model that lacks many of the complications that increase the realism of the model used here.

2. Coenen and Straub (2004) offer one example of such a model. They argue that realistic modeling of the effects of fiscal policy requires the introduction of additional complications (notably allowance for a significant proportion of households that do not participate in financial markets) not present in the model used in this paper.

3. They also attribute importance to neutral technology shocks, but the dynamics of this disturbance in the econometric model of Altig et al. do not match those assumed in the calibration of this paper.

4. Two of the types of shocks present in the Smets-Wouters model—the neutral technology shock and the exogenous variation in government purchases—do appear here, but the present authors do not parameterize these disturbance processes to agree with estimated shock processes obtained either by Smets and Wouters (2004) or Levin et al. (2005).

5. This is not necessary in the exercise undertaken by Giannoni and Woodford (2005) because there, the estimated structural equations are used to derive a policy rule that is optimal *regardless* of the nature of the (additive) shock processes that may perturb the model equations. But such an approach is not taken here.

6. Khan et al. (2003) obtain a similar conclusion in the case of a slightly different model of staggered pricing.

7. See, for example, Woodford (2003, Chapter 7), Khan et al. (2003), or Schmitt-Grohé and Uribe (2004a).

8. A persistent increase in the inflation rate by one percentage point will eventually result in the real interest rate being lower by fifty-three basis points.

9. See, for example, the studies collected in Taylor (1999).

10. In earlier work (Woodford 1998), I give an example of a simple model with flexible prices in which the Ramsey-optimal equilibrium can be (exactly) implemented with an especially simple pair of policy rules that involve passive monetary policy and non-Ricardian fiscal policy; so a result of this kind is clearly possible.

11. Marc Giannoni has shown, in the context of the simpler model used in my earlier work (Woodford 1999), that use of the authors' proposed criterion to select the best monetary policy rule from among the two-parameter family of simple Taylor rules would lead one to choose a Taylor rule with very different coefficients than the one that actually results in welfare-maximizing responses to shocks; for example, not even the signs of the response coefficients that are selected may be correct. Even though the model is quite simple, the optimal (Ramsey) policy is history-dependent and involves responses to shocks that are qualitatively different from those that can be implemented by any simple

Taylor rule (which is necessarily a purely forward-looking policy). Because none of the rules considered result in responses that match those under optimal policy very closely, the use of a minimum-distance criterion that happens not to be very closely related to welfare can result in the choice of a quite different rule.

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Discussion

Several participants commented on the microfoundations of the model.

Robert Hall noted that this model's estimated markup ratio is significantly higher than the consensus in the industrial organization community. He also questioned the choice of having the fixed cost parameter calibrated to absorb all of the profit arising from the markup, and suggested that endogenous entry to absorb profit might be more desirable.

Andrew Levin cautioned about drawing conclusions about long-term optimal fiscal policy (for example, optimal tax rates) from a model that has been designed to fit short-term business cycles. In the long run, Levin explained, profit taxation and capital taxation influence the amount of product differentiation. Therefore, any model that seeks to represent the long run adequately needs endogenous innovation and a patent system—a complication that Levin believes might take several years to incorporate into these models. But until these long-run aspects are fleshed out, Levin worries about using the model to analyze monetary policy over the short-run as well.

Daron Acemoglu wondered whether the model has the right microfoundations for taxes at all. He questioned why the authors imposed an income tax when there is no reason why they could not instead have modeled lump-sum taxes, or progressive taxes of some sort. Given that taxes have effects in the short run, Acemoglu worried that the model was giving wrong conclusions even about short-run fiscal policy.

Martín Uribe shared these concerns. But he emphasized that fiscal and monetary policy cannot be separated. He mentioned the inflation tax as an example of a fiscal aspect of monetary policy: if inflation is a tax, it will affect capital accumulation. Therefore, these models do not have the microfoundations to analyze monetary policy either. Does this mean we should do nothing, Uribe asked, until someone comes up with the "right" model?

Ken Rogoff remarked that the implications of the inflation tax for monetary and fiscal policy are even more important when considering the underground economy, which the OECD has estimated to be around 20–25 percent of some European economies. Rogoff noted that central bank surveys estimate that 80 percent of currency is in the underground economy, and 60 to 70 percent of U.S. currency is held abroad. Thus, a large sector of the economy is not taxed—an important point for serious fiscal policy.

Carl Walsh noted that the model implies a particular decomposition of the data into a time series implied by a model without nominal frictions, and a residual that is presumably attributable to the nominal friction. He suggested that one way to evaluate the fit of the model is to look at that kind of decomposition and to see how much of the action is coming about through nominal rigidities, or whether it is in fact replicating a real business-cycle result.

Olivier Blanchard noted that in the presence of nominal rigidities, fiscal policy could potentially affect the demand for goods in the short run. In this respect, he would have preferred that government consumption be one of the instruments of policy, rather than an exogenous shock as currently modeled.

John Williams suggested that the framework allow a dichotomization of fiscal and monetary policy in terms of stabilization. The basic view in the United States, he noted, is that monetary policy does stabilization, and fiscal policy should be doing optimal taxation and the optimal provision of public goods. He thought the model could help assess the welfare costs of this dichotomization. If there are costs to this dichotomization, he speculated, that might mean we need a more activist fiscal policy in terms of stabilization, as Blanchard suggested.

Simon Gilchrist agreed that more thought needs to go into the fiscal policy side of this model. He noted that micro data is providing much evidence about household responses to anticipated versus unanticipated changes in tax rates, and this should be considered when calibrating these types of models.

And Mark Gertler focused on the results. He noted that the original Barro intuition survives for the most part: keep labor taxes smooth and let government debt be a shock absorber. He was interested in the robustness of this result given that a subsequent literature argues taxes should be a random walk. Stephanie Schmitt-Grohé replied that in models of this type—with distortionary rather than lump-sum taxes—you always want to smooth taxes and that, as a result, government debt is a random walk. Gertler also thought the result that capital taxes should be adjusted cyclically makes sense because in recessions, governments often take actions to adjust investment tax credits, dividend taxes, and the like. But he was concerned that the model might be too biased toward cyclical fiscal policy since in the United States, monetary policy is set every six weeks by the Federal Open Market Committee (FOMC), but there are a lot more lags and adjustment costs to changing tax rates.