

Policy Implications of the New Keynesian Phillips Curve

Stephanie Schmitt-Grohé and Martín Uribe

The theoretical framework within which optimal monetary policy was studied before the arrival of the New Keynesian Phillips curve (NKPC), but after economists had become comfortable using dynamic, optimizing, general equilibrium models and a welfare-maximizing criterion for policy analysis, was one in which the central source of nominal nonneutrality was a demand for money. At center stage in this literature was the role of money as a medium of exchange (as in cash-in-advance models, money-in-the-utility-function models, or shopping-time models) or as a store of value (as in overlapping-generations models). In the context of this family of models a robust prescription for the optimal conduct of monetary policy is to set nominal interest rates to zero at all times and under all circumstances. This policy implication, however, found no fertile ground in the boardrooms of central banks around the world, where the optimality of zero nominal rates was dismissed as a theoretical oddity, with little relevance for actual central banking. Thus, theory and practice of monetary policy were largely disconnected.

The early 1990s witnessed a profound shift in monetary economics away from viewing the role of money primarily as a medium of exchange and toward viewing money—sometimes exclusively—as a unit of account. A key insight was that the mere assumption that product prices are quoted in units of fiat money can give rise to a theory of price level determination, even if money is physically nonexistent and even if fiscal policy is irrelevant for price

Stephanie Schmitt-Grohé is affiliated with Columbia University, CEPR, and NBER. She can be reached at stephanie.schmittgrohe@columbia.edu. Martín Uribe is affiliated with Columbia University and NBER. He can be reached at martin.uribe@columbia.edu. The views expressed in this paper do not necessarily reflect those of the Federal Reserve Bank of Richmond or the Federal Reserve System. The authors would like to thank Andreas Hornstein and Alexander Wolman for many thoughtful comments.

level determination.¹ This theoretical development was appealing to those who regard modern payment systems as operating increasingly cashlessly. At the same time, nominal rigidities in the form of sluggish adjustment of product and factor prices gained prominence among academic economists. The incorporation of sticky prices into dynamic stochastic general equilibrium models gave rise to a policy tradeoff between output and inflation stabilization that came to be known as the New Keynesian Phillips curve.

The inessential role that money balances play in the New Keynesian literature, along with the observed actual conduct of monetary policy in the United States and elsewhere over the past 30 years, naturally shifted theoretical interest away from money growth rate rules and toward interest rate rules: In the work of academic monetary economists, Milton Friedman's celebrated *k*-percent growth path for the money supply gave way to Taylor's equally influential interest rate feedback rule.

In this article, we survey recent advancements in the theory of optimal monetary policy in models with a New Keynesian Phillips curve. Our survey identifies a number of important lessons for the conduct of monetary policy. First, optimal monetary policy is characterized by near price stability. This policy implication is diametrically different from the one that obtains in models in which the only nominal friction is a transactions demand for money. Second, simple interest rate feedback rules that respond aggressively to price inflation deliver near-optimal equilibrium allocations. Third, interest rate rules that respond to deviations of output from trend may carry significant welfare costs. Taken together, lessons one through three call for the adherence to an inflation targeting objective. Fourth, the zero bound on nominal interest rates does not appear to be a significant obstacle for the actual implementation of low and stable inflation. Finally, product price stability emerges as the overriding goal of monetary policy even in environments where not only goods prices but also factor prices are sticky.

Before elaborating on the policy implications of the NKPC, we provide some perspective by presenting a brief account of the state of the literature on optimal monetary policy before the advent of the New Keynesian revolution.

1. OPTIMAL MONETARY POLICY PRE-NKPC

Within the pre-NKPC framework, under quite general conditions, optimal monetary policy calls for a zero opportunity cost of holding money, a result known as the Friedman rule. In fiat money economies in which assets used for transactions purposes do not earn interest, the opportunity cost of holding money equals the nominal interest rate. Therefore, in the class of models

¹This is the case, for instance, when the monetary stance is active and the fiscal stance is passive, which is the monetary/fiscal regime most commonly studied.

commonly used for policy analysis before the emergence of the NKPC, the optimal monetary policy prescribed that the riskless nominal interest rate—the return on federal funds, say—be set at zero at all times.

In the early literature, a demand for money is motivated in a variety of ways, including a cash-in-advance constraint (Lucas 1982), money in the utility function (Sidrauski 1967), a shopping-time technology (Kimbrough 1986), or a transactions-cost technology (Feenstra 1986). Regardless of how a demand for money is introduced, the intuition for why the Friedman rule is optimal in this class of model is straightforward: A zero nominal interest rate maximizes holdings of a good—real money balances—that has a negligible production cost. Another reason why the Friedman rule is optimal is that a positive interest rate can distort the efficient allocation of resources. For instance, in the cash-in-advance model with cash and credit goods, a positive interest rate distorts the allocation of private spending across these two types of goods. In models in which money ameliorates transaction costs or decreases shopping time, a positive interest rate introduces a wedge in the consumption-leisure choice.

To illustrate the optimality of the Friedman rule, we augment a neoclassical model with a transaction technology that is decreasing in real money holdings and increasing in consumption spending. Specifically, consider an economy populated by a large number of identical households. Each household has preferences defined over processes of consumption and leisure and described by the utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t U(c_t, h_t), \tag{1}$$

where c_t denotes consumption, h_t denotes labor effort, $\beta \in (0, 1)$ denotes the subjective discount factor, and E_0 denotes the mathematical expectation operator conditional on information available in period 0. The single period utility function, U , is assumed to be increasing in consumption, decreasing in effort, and strictly concave.

Final goods are produced using a production function, $z_t F(h_t)$, that takes labor, h_t , as the only factor input and is subject to an exogenous productivity shock, z_t .

A demand for real balances is introduced into the model by assuming that money holdings, denoted M_t , facilitate consumption purchases. Specifically, consumption purchases are subject to a proportional transaction cost, $s(v_t)$, that is decreasing in the household’s money-to-consumption ratio, or consumption-based money velocity,

$$v_t = \frac{P_t c_t}{M_t}, \tag{2}$$

where P_t denotes the nominal price of the consumption good in period t . The transaction cost function, $s(v)$, satisfies the following assumptions: (a) $s(v)$

is nonnegative and twice continuously differentiable; (b) there exists a level of velocity, $\underline{v} > 0$, to which we refer as the satiation level of money, such that $s(\underline{v}) = s'(\underline{v}) = 0$; (c) $(v - \underline{v})s'(v) > 0$ for $v \neq \underline{v}$; and (d) $2s'(v) + vs''(v) > 0$ for all $v \geq \underline{v}$. Assumption (b) 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. Assumption (c) guarantees that in equilibrium money velocity is always greater than or equal to the satiation level. Assumption (d) ensures that the demand for money is decreasing in the nominal interest rate.

Households are assumed have access to risk-free pure discount bonds, denoted B_t . These bonds are assumed to carry a gross nominal interest rate of R_t when held from period t to period $t + 1$. The flow budget constraint of the household in period t is then given by

$$P_t c_t [1 + s(v_t)] + P_t \tau_t^L + M_t + \frac{B_t}{R_t} = M_{t-1} + B_{t-1} + P_t z_t F(h_t), \quad (3)$$

where τ_t^L denotes real lump sum taxes. In addition, it is assumed that the household is subject to a borrowing limit that prevents it from engaging in Ponzi-type schemes. The government is assumed to follow a fiscal policy whereby it rebates any seigniorage income it receives from the creation of money in a lump sum fashion to households.

A stationary competitive equilibrium can be shown to be a set of plans $\{c_t, h_t, v_t\}$, satisfying the following three conditions:

$$v_t^2 s'(v_t) = \frac{R_t - 1}{R_t}, \quad (4)$$

$$-\frac{U_h(c_t, h_t)}{U_c(c_t, h_t)} = \frac{z_t F'(h_t)}{1 + s(v_t) + v_t s'(v_t)}, \text{ and} \quad (5)$$

$$[1 + s(v_t)]c_t = z_t F(h_t), \quad (6)$$

given monetary policy $\{R_t\}$, with $R_t \geq 1$, and the exogenous process $\{z_t\}$. The first equilibrium condition can be interpreted as a demand for money or liquidity preference function. Given our maintained assumptions about the transactions technology, $s(v_t)$, the implied money demand function is decreasing in the gross nominal interest rate, R_t . Further, our assumptions imply that as the interest rate vanishes, or R_t approaches unity, the demand for money reaches a finite maximum level given by c_t/\underline{v} . At this level of money demand, households are able to perform transactions costlessly, as the transactions cost, $s(v_t)$, becomes nil. The second equilibrium condition shows that a level of money velocity above the satiation level, \underline{v} , or, equivalently, an interest rate greater than zero, introduces a wedge between the marginal rate of substitution of consumption for leisure and the marginal product of labor. This

wedge, given by $1 + s(v_t) + v_t s'(v_t)$, induces households to move away from consumption and toward leisure. The wedge is increasing in the nominal interest rate, implying that the larger is the nominal interest rate, the more distorted is the consumption-leisure choice. The final equilibrium condition states that a positive interest rate entails a resource loss in the amount of $s(v_t)c_t$. This resource loss is increasing in the interest rate and vanishes only when the nominal interest rate equals zero.

We wish to characterize optimal monetary policy under the assumption that the government has the ability to commit to policy announcements. This policy optimality concept is known as Ramsey optimality. In the context of the present model, the Ramsey optimal monetary policy consists in choosing the path of the nominal interest rate that is associated with the competitive equilibrium that yields the highest level of welfare to households. Formally, the Ramsey policy consists in choosing processes R_t , c_t , h_t , and v_t to maximize the household's utility function given in equation (1) subject to the competitive equilibrium conditions given by equations (4) through (6).

When one inspects the three equilibrium conditions above, it is clear that if the policymaker sets the monetary policy instrument, which we take to be the nominal interest rate, such that velocity is at the satiation level, ($v_t = \underline{v}$), then the equilibrium conditions become identical to an economy without the money demand friction, i.e., $c_t = z_t F(h_t)$ and $-U_h(c_t, h_t)/U_c(c_t, h_t) = z_t F'(h_t)$. Because the real allocation in the absence of the monetary friction is Pareto optimal, the proposed monetary policy must be Ramsey optimal. By a Pareto optimal allocation we mean a feasible real allocation (i.e., one satisfying $c_t = z_t F[h_t]$) with the property that any other feasible allocation that makes at least one agent better off also makes at least one agent worse off. It follows from equation (4) that setting the nominal interest rate to zero ($R_t = 1$) ensures that $v_t = \underline{v}$. For this reason, optimal monetary policy takes the form of a zero nominal interest rate at all times.

Under the optimal monetary policy, the rate of change in the aggregate price level varies over time. Because, to a first approximation, the nominal interest rate equals the sum of the real interest rate and the expected rate of inflation, and because under the optimal monetary policy the nominal interest rate is held constant, the degree to which the inflation rate fluctuates depends on the equilibrium variations in the real rate of interest. In general, optimal monetary policy in a model in which a role for monetary policy arises solely from the presence of money demand is not characterized by inflation stabilization.

A second important consequence of optimal monetary policy in the context of the present model is that inflation is, on average, negative. This is because, with a zero nominal interest rate, the inflation rate equals, on average, the negative of the real rate of interest.

2. THE NKPC AND OPTIMAL MONETARY POLICY

The New Keynesian Phillips curve can be briefly defined as the dynamic output-inflation tradeoff that arises in a dynamic general equilibrium model populated by utility-maximizing households and profit-maximizing firms—such as the one laid out in the previous section—and augmented with some kind of rigidity in the adjustment of nominal product prices. The foundations of the NKPC were laid by Calvo (1983) and Rotemberg (1982). Woodford (1996) and Yun (1996) completed its development by introducing optimizing behavior on the part of firms facing Calvo-type dynamic nominal rigidities.

The most important policy implication of models featuring a New Keynesian Phillips curve is the optimality of price stability (see Goodfriend and King [1997] for an early presentation of this result). We will discuss the price stability result in a variety of theoretical models, including ones with a realistic set of real and nominal rigidities, policy instruments and policy constraints, and sources of aggregate fluctuations. We start, however, with the simplest structure within which the price stability result can be obtained. To this end, we strip the model presented in the previous section from its money demand friction and instead introduce costs of adjusting nominal product prices. In the resulting model, sticky prices represent the sole source of nominal friction.

To introduce sticky prices into the model of the previous section, assume that the consumption good, c_t , is a composite good made of a continuum of intermediate differentiated goods. The aggregator function is of the Dixit-Stiglitz type. Each household/firm unit is the monopolistic producer of one variety of intermediate goods. In turn, intermediate goods are produced using a technology like the one given in the previous section. The household/firm unit hires labor, \tilde{h}_t , from a perfectly competitive market.

The demand faced by the household/firm unit for the intermediate input that it produces is of the form $Y_t d(\tilde{P}_t/P_t)$, where Y_t denotes the level of aggregate demand, which is taken as exogenous by the household/firm unit; \tilde{P}_t denotes the nominal price of the intermediate good produced by the household/firm unit; and P_t is the price of the composite consumption good. The demand function, $d(\cdot)$, is assumed to be decreasing in the relative price, \tilde{P}_t/P_t , and is assumed to satisfy $d(1) = 1$ and $-d'(1) \equiv \eta > 1$, where η denotes the price elasticity of demand for each individual variety of intermediate goods that prevails in a symmetric equilibrium. The restrictions on $d(1)$ and $d'(1)$ are necessary for the existence of a symmetric equilibrium. The monopolist sets the price of the good it supplies, taking the level of aggregate demand as given, and is constrained to satisfy demand at that price, that is, $z_t F(\tilde{h}_t) \geq Y_t d(\tilde{P}_t/P_t)$.

Price adjustment is assumed to be sluggish, à la Rotemberg (1982). Specifically, the household/firm unit faces a resource cost of changing prices that is

quadratic in the inflation rate of the good it produces:

$$\text{Price adjustment cost} = \frac{\theta}{2} \left(\frac{\tilde{P}_t}{\tilde{P}_{t-1}} - 1 \right)^2. \tag{7}$$

The parameter θ measures the degree of price stickiness. The higher is θ , the more sluggish is the adjustment of nominal prices. When θ equals zero, prices are fully flexible. The flow budget constraint of the household/firm unit in period t is then given by

$$c_t + \tau_t^L \leq (1 - \tau_t^D)w_t h_t + \left[\frac{\tilde{P}_t}{P_t} Y_t d \left(\frac{\tilde{P}_t}{P_t} \right) - w_t \tilde{h}_t - \frac{\theta}{2} \left(\frac{\tilde{P}_t}{\tilde{P}_{t-1}} - 1 \right)^2 \right],$$

where τ_t^D denotes an income tax/subsidy rate. We introduce this fiscal instrument as a way to offset the distortions arising from the presence of monopolistic competition. We restrict attention to a stationary symmetric equilibrium in which all household/firm units charge the same price for the intermediate good they produce. Letting $\pi_t \equiv P_t/P_{t-1}$ denote the gross rate of inflation, the complete set of equilibrium conditions is then given by

$$\pi_t(\pi_t - 1) = \frac{\eta c_t}{\theta} \left[\frac{w_t}{z_t F'(h_t)} - \frac{\eta - 1}{\eta} \right] + \beta E_t \frac{U_c(c_{t+1}, h_{t+1})}{U_c(c_t, h_t)} \pi_{t+1}(\pi_{t+1} - 1), \tag{8}$$

$$-\frac{U_h(c_t, h_t)}{U_c(c_t, h_t)} = (1 - \tau_t^D)w_t, \text{ and} \tag{9}$$

$$z_t F(h_t) - \frac{\theta}{2}(\pi_t - 1)^2 = c_t. \tag{10}$$

The above three equations provide solutions for the equilibrium processes of consumption, c_t , hours, h_t , and the real wage, w_t , given processes for the rate of inflation, π_t , and for the tax rate, τ_t^D , which we interpret to be outcomes of the monetary and fiscal policies in place, respectively.

The first equilibrium condition, equation (8), represents the NKPC, to which the current volume is devoted. It describes an equilibrium relationship between current inflation, π_t , the current deviation of marginal cost, $w_t/z_t F'(h_t)$, from marginal revenue, $(\eta - 1)/\eta$, and expected future inflation. Under full price flexibility, the firm would always set marginal revenue equal to marginal cost. However, in the presence of price adjustment costs, this practice is costly. To smooth out price changes over time, firms set prices to equate an average of current and future expected marginal costs to an average of current and future expected marginal revenues. This optimal price-setting behavior gives rise to a relation whereby, given expected inflation, current inflation is an increasing function of marginal costs. Intuitively, this relation is steeper the more flexible are prices (i.e., the lower is θ), the more competitive

are product markets (i.e., the higher is η), and the higher is the current level of demand (i.e., the larger is c_t). At the same time, given marginal cost, current inflation is increasing in expected future inflation. This is because, with quadratic costs of changing nominal prices, a firm expecting higher inflation in the future would like to smooth out the necessary price adjustments over time by beginning to raise prices already in the current period.

We have derived the New Keynesian Phillips curve in the context of the Rotemberg (1982) model of price stickiness. However, a similar relationship emerges under other models of nominal rigidity, such as those due to Calvo (1983), Taylor (1993), Woodford (1996), and Yun (1996). For instance, in the Calvo-Woodford-Yun model, price stickiness arises because firms are assumed to receive an idiosyncratic random signal each period indicating whether they are allowed to reoptimize their posted prices. A difference between the Rotemberg and the Calvo-Woodford-Yun models is that the latter displays equilibrium price dispersion across firms even in the absence of aggregate uncertainty. However, up to first order, the NKPCs implied by the Rotemberg and Calvo-Woodford-Yun models are identical. Indeed, much of the literature on the NKPC focuses on a log-linear approximation of this key relationship, as in equation (11).

The second equilibrium condition presented in equation (9) states that the marginal rate of substitution of consumption for leisure is equated to the after-tax real wage rate. The third equilibrium condition, equation (10), is a resource constraint requiring that aggregate output net of price adjustment costs equal private consumption.

It is straightforward to establish that, in this economy, the optimal monetary policy, that is, the policy that maximizes the welfare of the representative household, is one in which the inflation rate is nil at all times. Formally, the optimal monetary policy must be consistent with an equilibrium in which

$$\pi_t = 1$$

for all $t \geq 0$. This result holds exactly provided the fiscal authority subsidizes labor income to a point that fully offsets the distortion arising from the existence of imperfect competition among intermediate goods producers. Specifically, the income tax rate, τ_t^D , must be set at a constant and negative level given by

$$\tau_t^D = \frac{1}{1 - \eta}$$

for all $t \geq 0$.

To see that the proposed policy regime is optimal, we demonstrate that it implies a set of equilibrium conditions that coincide with the one that arises in an economy with fully flexible prices ($\theta = 0$) and perfect competition in product markets ($\eta = \infty$), such as the one analyzed in Section 1 in the absence of a money-demand distortion. In effect, when $\pi_t = 1$ for all t , equilibrium

condition (10) collapses to $c_t = z_t F(h_t)$. In addition, under zero inflation the NKPC (equation [8]) reduces to $w_t = z_t F'(h_t)(\eta - 1)/\eta$. Using this expression along with the proposed optimal level for the income tax rate in the equilibrium labor supply, equation (9), yields the efficiency conditions $-U_h(c_t, h_t)/U_c(c_t, h_t) = z_t F'(h_t)$, which, together with the resource constraint $c_t = z_t F(h_t)$, constitute the equilibrium conditions of a perfectly competitive flexible-price economy. As we show in Section 1, the resource allocation in this economy is Pareto optimal.

3. THE OPTIMAL INFLATION RATE

At this point, it is of interest to summarize and compare the results in this section and in previous ones. We have shown that when prices are fully flexible and the only nominal friction is a demand for money, then optimal monetary policy takes the form of complete stabilization of the interest rate at a value of zero ($R_t = 1$ for all t). We have also established that in a cashless economy in which the only source of nominal friction is given by product price stickiness, optimal monetary policy calls for full stabilization of the rate of inflation at a value of zero ($\pi_t = 1$ for all t). Under optimal policy in the monetary flexible-price economy, inflation is time varying and equal to the negative of the real interest rate on average, whereas in the cashless sticky-price economy, inflation is constant and equal to zero at all times. Also, in the monetary flexible-price economy, optimal policy calls for a constant nominal interest rate equal to zero at all times, whereas in the cashless sticky-price economy, it calls for a time-varying nominal interest rate equal to the real interest rate on average.

These results raise the question of what the characteristics of optimal monetary policy are in a more realistic economic environment in which both a demand for money and price stickiness coexist. In particular, in such an environment a policy tradeoff emerges between the benefits of targeting zero inflation—i.e., minimizing price-adjustment costs—and the benefits of deflating at the real rate of interest—i.e., minimizing the opportunity cost of holding money. In the canonical economies with only one nominal friction studied in this and previous sections, the characterization of the optimal rate of inflation is relatively straightforward. As soon as both nominal frictions are incorporated jointly, it becomes impossible to determine the optimal rate of inflation analytically. One is therefore forced to resort to numerical methods.

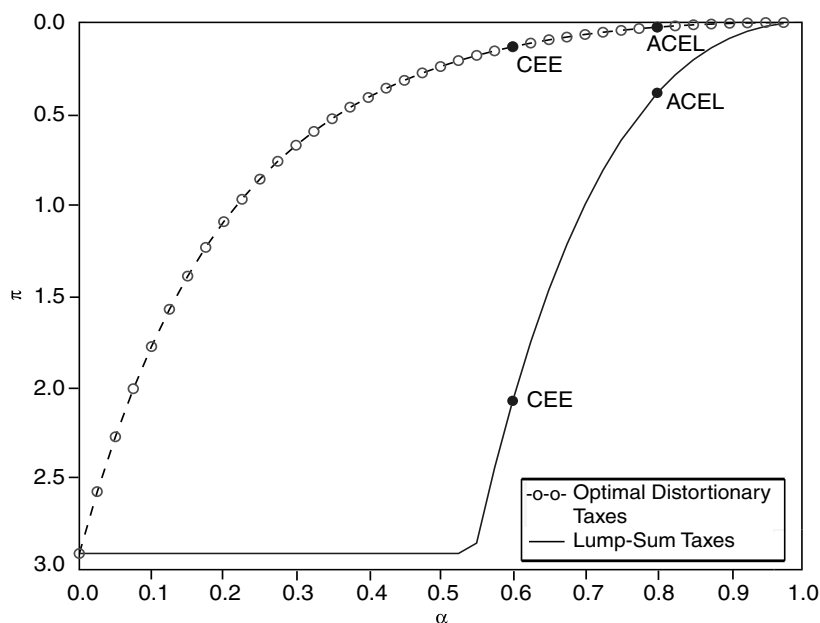
The resolution of the Friedman-rule-versus-price-stability tradeoff was studied by, among others, Khan, King, and Wolman (2003) and Schmitt-Grohé and Uribe (2004a, 2007b). As one would expect, when both the money demand and sticky-price frictions are present, the optimal rate of inflation falls between zero and the one called for by the Friedman rule. The question of interest, however, is where exactly in this interval the optimal inflation rate lies. Khan,

King, and Wolman find, in the context of a stylized model calibrated to match aspects of money demand and price dynamics in the postwar United States, that the optimal rate of inflation is -0.76 percent per year. By comparison, in their model the Friedman rule is associated with a deflation rate of 2.93 percent per year. Thus, in the study by Khan, King, and Wolman, the optimal policy is closer to price stability than to the Friedman rule. Taking these numbers at face value, one might conclude that price stickiness is the dominant friction in shaping optimal monetary policy. However, Khan, King, and Wolman (2003) and Schmitt-Grohé and Uribe (2004a, 2007b) show that the resolution of the tradeoff is quite sensitive to plausible changes in the values taken by the structural parameters of the model.

In Schmitt-Grohé and Uribe (2007b), we find that a striking characteristic of the optimal monetary regime is the high sensitivity of the welfare-maximizing rate of inflation with respect to the parameter governing the degree of price stickiness for the range of values of this parameter that is empirically relevant. The model underlying the analysis of Schmitt-Grohé and Uribe (2007b) is a medium-scale model of the U.S. economy featuring, in addition to money demand by households and sticky product prices, a number of real and nominal rigidities including wage stickiness, a demand for money by firms, habit formation, capital accumulation, variable capacity utilization, and investment adjustment costs. The structural parameters of the model are assigned values that are consistent with full- as well as limited-information approaches to estimating this particular model.

In the Schmitt-Grohé and Uribe (2007b) model, the degree of price stickiness is captured by a parameter denoted α , measuring the probability that a firm is not able to optimally set the price it charges in a particular quarter. The average number of periods elapsed between two consecutive optimal price adjustments is given by $1/(1 - \alpha)$. Available empirical estimates of the degree of price rigidity using macroeconomic data vary from two to five quarters, or $\alpha \in [0.5, 0.8]$. For example, Christiano, Eichenbaum, and Evans (2005) estimate α to be 0.6 . By contrast, Altig et al. (2005) estimate a marginal-cost-gap coefficient in the Phillips curve that is consistent with a value of α of around 0.8 . Both Christiano, Eichenbaum and Evans (2005) and Altig et al. (2005) use an impulse-response matching technique to estimate the price-stickiness parameter α . Bayesian estimates of this parameter include Del Negro et al. (2004), Levin et al. (2006), and Smets and Wouters (2007), who report posterior means of 0.67 , 0.83 , and 0.66 , respectively, and 90 percent posterior probability intervals of $(0.51, 0.83)$, $(0.81, 0.86)$, and $(0.56, 0.74)$, respectively.

Recent empirical studies have documented the frequency of price changes using microdata underlying the construction of the U.S. consumer price index. These studies differ in the sample period considered, in the disaggregation of the price data, and in the treatment of sales and stockouts. The median frequency of price changes reported by Bils and Klenow (2004) is four to five

Figure 1 Price Stickiness, Fiscal Policy, and Optimal Inflation

Notes: CEE and ACEL indicate, respectively, the values for the parameter, α , estimated by Christiano, Eichenbaum, and Evans (2005) and Altig et al. (2005).

months, the one reported by Klenow and Kryvtsov (2005) is four to seven months, and the one reported by Nakamura and Steinsson (2007) is eight to 11 months. However, there is no immediate interpretation of these frequency estimates to the parameter, α , governing the degree of price stickiness in Calvo-style models of price staggering. Consider, for instance, the case of indexation. In that case, even though firms change prices every period—implying the highest possible frequency of price changes—prices themselves may be highly sticky, for they may be only reoptimized at much lower frequencies.

Figure 1 displays with a solid line the relationship between the degree of price stickiness, α , and the optimal rate of inflation in percent per year, π , implied by the model studied in Schmitt-Grohé and Uribe (2007b). When α equals 0.5, the lower range of the available empirical evidence using macrodata, the optimal rate of inflation is -2.9 percent, which is the level called for by the Friedman rule. For a value of α of 0.8, which is near the upper range of the available empirical evidence using macrodata, the optimal level of inflation rises to -0.4 percent, which is close to price stability.

Besides the uncertainty surrounding the estimation of the degree of price stickiness, a second aspect of the apparent difficulty in establishing reliably the optimal long-run level of inflation has to do with the shape of the relationship linking the degree of price stickiness to the optimal level of inflation. The problem resides in the fact that, as is evident from Figure 1, this relationship becomes significantly steep precisely for that range of values of α that is empirically most compelling. It turns out that an important factor determining the shape of the function relating the optimal level of inflation to the degree of price stickiness is the underlying fiscal policy regime.

Fiscal considerations fundamentally change the long-run tradeoff between price stability and the Friedman rule. To see this, we now consider an economy where lump-sum taxes are unavailable ($\tau^L = 0$). Instead, the fiscal authority must finance government purchases by means of proportional capital and labor income taxes. The social planner jointly sets monetary and fiscal policy in a welfare-maximizing (i.e., Ramsey-optimal) fashion.² Figure 1 displays the relationship between the degree of price stickiness, α , and the optimal rate of inflation, π . The solid line corresponds to the case discussed earlier featuring lump-sum taxes. The dash-circled line corresponds to the economy with optimally chosen distortionary income taxes. In stark contrast to what happens under lump-sum taxation, under optimal distortionary taxation the function linking π and α is flat and very close to zero for the entire range of macrodata-based empirically plausible values of α , namely 0.5 to 0.8. In other words, when taxes are distortionary and optimally determined, price stability emerges as a prediction that is robust to the existing uncertainty about the exact degree of price stickiness. Even if one focuses on the evidence of price stickiness stemming from microdata, the model with distortionary Ramsey taxation predicts an optimal long-run level of inflation that is much closer to zero than to the level called for by the Friedman rule.

Our intuition for why price stability arises as a robust policy recommendation in the economy with optimally set distortionary taxation runs as follows. Consider the economy with lump-sum taxation. Deviating from the Friedman rule (by raising the inflation rate) has the benefit of reducing price adjustment costs. Consider next the economy with optimally chosen income taxation and no lump-sum taxes. In this economy, deviating from the Friedman rule still provides the benefit of reducing price adjustment costs. However, in this economy, increasing inflation has the additional benefit of increasing seigniorage revenue, thereby allowing the social planner to lower distortionary income tax rates. Therefore, the Friedman rule versus price stability tradeoff is tilted in favor of price stability.

²The details of this environment are contained in Schmitt-Grohé and Uribe (2006). The structure of this economy is identical to that studied in Schmitt-Grohé and Uribe (2007b), except for the inclusion of fiscal policy.

It follows from this intuition that what is essential in inducing the optimality of price stability is that, on the margin, the fiscal authority trades off the inflation tax for regular taxation. Indeed, it can be shown that if distortionary tax rates are fixed, even if they are fixed at the level that is optimal in a world without lump-sum taxes, and the fiscal authority has access to lump-sum taxes on the margin, the optimal rate of inflation is much closer to the Friedman rule than to zero. In this case, increasing inflation no longer has the benefit of reducing distortionary taxes. As a result, the Ramsey planner has less incentives to inflate.

We close this section by drawing attention to the fact that, quite independently of the precise degree of price stickiness, the optimal inflation target is below zero. In light of this robust result, it is puzzling that all countries that self-classify as inflation targeters set inflation targets that are positive. In effect, in the developed world inflation targets range between 2 and 4 percent per year. Somewhat higher targets are observed across developing countries. An argument often raised in defense of positive inflation targets is that negative inflation targets imply nominal interest rates that are dangerously close to the zero lower bound on nominal interest rates and, hence, may impair the central bank's ability to conduct stabilization policy. In Schmitt-Grohé and Uribe (2007b) we find, however, that this argument is of little relevance in the context of the medium-scale estimated model within which we conduct policy evaluation. The reason is that under the optimal policy regime, the mean of the nominal interest rate is about 4.5 percent per year with a standard deviation of only 0.4 percent. This means that for the zero lower bound to pose an obstacle to monetary stabilization policy, the economy must suffer from an adverse shock that forces the interest rate to be more than ten standard deviations below target. The likelihood of such an event is practically nil.

4. THE OPTIMAL VOLATILITY OF INFLATION

Two distinct branches of the existing literature on optimal monetary policy deliver diametrically opposed policy recommendations concerning the cyclical behavior of prices and interest rates. One branch follows the theoretical framework laid out in Lucas and Stokey (1983). It studies the joint determination of optimal fiscal and monetary policy in flexible-price environments with perfect competition in product and factor markets. In this strand of the literature, the government's problem consists of financing an exogenous stream of public spending by choosing the least disruptive combination of inflation and distortionary income taxes.

Calvo and Guidotti (1990, 1993) and Chari, Christiano, and Kehoe (1991) characterize optimal monetary and fiscal policy in stochastic environments with nominal nonstate-contingent government liabilities. A key result of these papers is that it is optimal for the government to make the inflation rate highly

volatile and serially uncorrelated. For instance, Schmitt-Grohé and Uribe (2004b) show, in the context of a flexible-price model calibrated to the U.S. economy, that under the optimal policy the inflation rate has a standard deviation of 7 percent per year and a serial correlation of -0.03 . The intuition for this result is that, under flexible prices, highly volatile and unforecastable inflation is nondistorting and at the same time carries the fiscal benefit of acting as a lump-sum tax on private holdings of government-issued nominal assets. The government is able to use surprise inflation as a nondistorting tax to the extent that it has nominal, nonstate-contingent liabilities outstanding. Thus, price changes play the role of a shock absorber of unexpected innovations in the fiscal deficit. This “front-loading” of government revenues via inflationary shocks allows the fiscal authority to keep income tax rates remarkably stable over the business cycle.

However, as discussed in Section 2, the New Keynesian literature, aside from emphasizing the role of price rigidities and market power, differs from the earlier literature described above in two important ways. First, it assumes, either explicitly or implicitly, that the government has access to (endogenous) lump-sum taxes to finance its budget. An important implication of this assumption is that there is no need to use unanticipated inflation as a lump-sum tax; regular lump-sum taxes take on this role. Second, the government is assumed to be able to implement a production (or employment) subsidy to eliminate the distortion introduced by the presence of monopoly power in product and factor markets.

The key result of the New Keynesian literature, which we presented in Sections 2 and 3, is that the optimal monetary policy features an inflation rate that is zero or close to zero at all times (i.e., both the optimal mean and volatility of inflation are near zero). The reason price stability is optimal in environments of the type described there is that it minimizes (or completely eliminates) the costs introduced by inflation under nominal rigidities.

Together, these two strands of research on optimal monetary policy leave the monetary authority without a clear policy recommendation. Should the central bank pursue policies that imply high or low inflation volatility? In Schmitt-Grohé and Uribe (2004a), we analyze the resolution of this policy dilemma by incorporating in a unified framework the essential elements of the two approaches to optimal policy described above. Specifically, we build a model that shares two elements with the earlier literature: (a) The only source of regular taxation available to the government is distortionary income taxes. As a result, the government cannot implement production subsidies to undo distortions created by the presence of imperfect competition, and (b) the government issues only nominal, one-period, nonstate-contingent bonds. At the same time, the setup shares two important assumptions with the more recent body of work on optimal monetary policy: (a) Product markets are imperfectly competitive, and (b) product prices are assumed to be sticky and,

hence, the model features a New Keynesian Phillips curve. Schmitt-Grohé and Uribe (2004a) introduce price stickiness as in the previous section by assuming that firms face a convex cost of price adjustment (Rotemberg 1982).

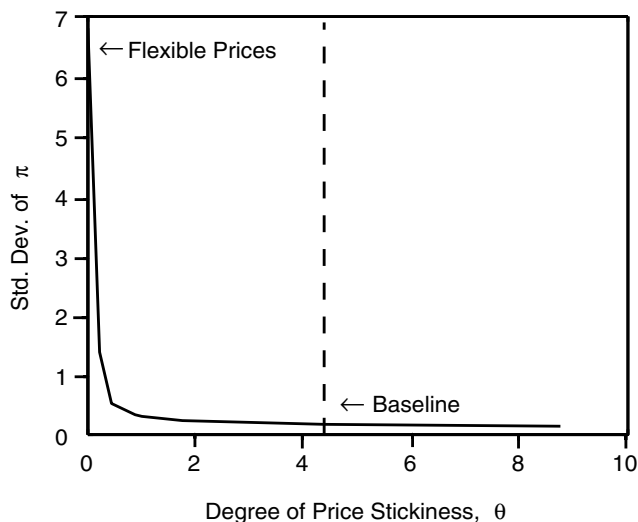
In this environment, the government faces a tradeoff in choosing the path of inflation. On the one hand, the government would like to use unexpected inflation as a nondistorting tax on nominal wealth. In this way, the fiscal authority could minimize variations in distortionary income taxes over the business cycle. On the other hand, changes in the rate of inflation come at a cost, for firms face nominal rigidities.

When price changes are brought about at a cost, it is natural to expect that a benevolent government will try to implement policies consistent with a more stable behavior of prices than when price changes are costless. However, the quantitative effect of an empirically plausible degree of price rigidity on optimal inflation volatility is not clear a priori. In Schmitt-Grohé and Uribe (2004a), we show that for the degree of price stickiness estimated for the U.S. economy, this tradeoff is overwhelmingly resolved in favor of price stability. The Ramsey allocation features a dramatic drop in the standard deviation of inflation from 7 percent per year under flexible prices to a mere 0.17 percent per year when prices adjust sluggishly.³

Indeed, the impact of price stickiness on the optimal degree of inflation volatility turns out to be much stronger than suggested by the numerical results reported in the previous paragraph. Figure 2, taken from Schmitt-Grohé and Uribe (2004a), shows that a minimum amount of price stickiness suffices to make price stability the central goal of optimal policy. Specifically, when the degree of price stickiness, embodied in the parameter θ (see equation [7]), is assumed to be ten times smaller than the estimated value for the U.S. economy, the optimal volatility of inflation is below 0.52 percent per year, 13 times smaller than under full price flexibility.

A natural question elicited by Figure 2 is why even a modest degree of price stickiness can turn undesirable the use of a seemingly powerful fiscal instrument, such as large revaluations or devaluations of private real financial wealth through surprise inflation. Our conjecture is that in the flexible-price economy, the welfare gains of surprise inflations or deflations are very small. Our intuition is as follows. Under flexible prices, it is optimal for the central bank to keep the nominal interest rate constant over the business cycle. This means that large surprise inflations must be as likely as large deflations, as variations in real interest rates are small. In other words, inflation must have a near-i.i.d. behavior. As a result, high inflation volatility cannot be used by the Ramsey planner to reduce the average amount of resources to be collected via distortionary income taxes, which would be a first-order effect. The volatility

³ This price stability result is robust to augmenting the model to allow for nominal rigidities in wages and indexation in product or factor prices (Schmitt-Grohé and Uribe 2006, Table 6.5).

Figure 2 Degree of Price Stickiness and Optimal Inflation Volatility

Notes: The parameter, θ , governs the cost of adjusting nominal prices as defined in equation (7). Its baseline value is 4.4, in line with available empirical estimates. The standard deviation of inflation is measured in percent per year.

of inflation primarily serves the purpose of smoothing the process of income tax distortions—a second-order source of welfare losses—without affecting their average level.

Another way to gain intuition for the dramatic decline in optimal inflation volatility that occurs even at very modest levels of price stickiness is to interpret price volatility as a way for the government to introduce real state-contingent public debt. Under flexible prices, the government uses state-contingent changes in the price level as a nondistorting tax or transfer on private holdings of government assets. In this way, nonstate-contingent nominal public debt becomes state-contingent in real terms. So, for example, in response to an unexpected increase in government spending, the Ramsey planner does not need to increase tax rates by much because by inflating away part of the public debt he can ensure intertemporal budget balance. It is, therefore, clear that introducing costly price adjustment is the same as if the government were limited in its ability to issue real state-contingent debt. It follows that the larger the welfare gain associated with the ability to issue real state-contingent public debt—as opposed to nonstate-contingent debt—the larger the amount of price stickiness required to reduce the optimal degree of inflation volatility. Aiyagari et al. (2002) show that indeed the level of welfare under the Ramsey

policy in an economy without real state-contingent public debt is virtually the same as in an economy with state-contingent debt. Our finding that a small amount of price stickiness is all it takes to bring the optimal volatility of inflation from a very high level to near zero is thus perfectly in line with the finding of Aiyagari et al. (2002).

If this intuition is correct, then the behavior of tax rates and public debt under sticky prices should resemble that implied by the Ramsey allocation in economies without real state-contingent debt. Indeed, in financing the budget, the Ramsey planner replaces front-loading with standard debt and tax instruments. For example, in response to an unexpected increase in government spending, the planner does not generate a surprise increase in the price level. Instead, he chooses to finance the increase in government purchases partly through an increase in income tax rates and partly through an increase in public debt. The planner minimizes the tax distortion by spreading the required tax increase over many periods. This tax-smoothing behavior induces near-random walk dynamics into the tax rate and public debt. By contrast, under full price flexibility (i.e., when the government can create real-state-contingent debt), tax rates and public debt inherit the stochastic process of the underlying shocks.

An important conclusion of this analysis is, thus, that the Aiyagari et al. (2002) result, namely, that optimal policy imposes a near-random walk behavior on taxes and debt, does not require the unrealistic assumption that the government can issue only nonstate-contingent real debt. This result emerges naturally in economies with nominally nonstate-contingent debt—clearly the case of greatest empirical relevance—and a minimum amount of price rigidity.⁴ However, if government debt is assumed to be state contingent, the presence of sticky prices may introduce no difference in the Ramsey real allocation, depending on the precise specification of the demand for money (see Correia, Nicolini, and Teles 2008). The reason for this result is that, as shown in Lucas and Stokey (1983), if government debt is state-contingent and prices are fully flexible, the Ramsey allocation does not pin down the price level uniquely. In this case, there is an infinite number of price-level processes (and thus of money supply processes) that can be supported as Ramsey outcomes.

⁴ It is of interest to relate the near-random walk in taxes and debt that emerges as the optimal policy outcome in a model featuring a New Keynesian Phillips curve with the celebrated tax-smoothing result of Barro (1979). In Barro's formulation, the objective function of the government is the expected present discounted value of squared deviations of tax rates from a target or desired level. The government minimizes this objective function subject to a sequential budget constraint, which is linear in debt and tax rates. The resulting solution resembles the random walk model of consumption with taxes taking the place of consumption and public debt taking the place of private debt. The analysis in Schmitt-Grohé and Uribe (2004a) departs from Barro's ad hoc loss function and replaces it with the utility function of the representative optimizing household inhabiting a fully-articulated, dynamic, stochastic, general-equilibrium economy. In this environment, the random walk result obtains from a more subtle channel, namely, the introduction of a minuscule amount of nominal rigidity in product prices.

Loosely speaking, the introduction of price stickiness simply “uses this degree of freedom” to pin down the equilibrium process of the price level without altering other aspects of the Ramsey solution.

5. IMPLEMENTATION OF OPTIMAL POLICY

We established that in the simple New Keynesian model presented in Section 2, the optimal policy consists of setting the inflation rate equal to zero at all times ($\pi_t = 1$) and imposing a constant output subsidy ($\tau_t^D = 1/[1 - \eta]$). The question we pursue in this section is how to implement the optimal policy. Because central banks in the United States and elsewhere use the short-term nominal interest rate as the monetary policy instrument, it is of empirical interest to search for interest rate rules that implement the optimal allocation.

Using the Ramsey-Optimal Interest Rate Process as a Feedback Rule

One might be tempted to believe that implementation of optimal policy is trivial once the interest rate associated with the Ramsey equilibrium has been found. Specifically, in the Ramsey equilibrium, the nominal interest rate can be expressed as a function of the current state of the economy. Then, the prescription would be simply to use this function as a policy rule in setting the nominal interest rate at all dates and under all circumstances. It turns out that conducting policy in this fashion would, in general, not deliver the intended results. The reason is that although such a policy would be consistent with the optimal equilibrium, it would at the same time open the door to other (suboptimal) equilibria. It follows that the solution to the optimal policy problem is mute with respect to the issue of implementation of such policy. To see this, it is convenient to consider as an example a log-linear approximation to the equilibrium conditions associated with the cashless, sticky-price model presented in Section 2. It can be shown that the resulting linear system is given by⁵

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \kappa \hat{c}_t - \gamma \hat{z}_t \quad (11)$$

and

$$-\sigma \hat{c}_t = \hat{R}_t - \sigma E_t \hat{c}_{t+1} - E_t \hat{\pi}_{t+1}, \quad (12)$$

where σ , κ , and $\gamma > 0$ are parameters. Hatted variables denote percent deviations of the corresponding unhatted variables from their respective values

⁵ The log-linearization is performed around the nonstochastic steady state of the Ramsey equilibrium. In performing the linearization, we assume that the period utility function is separable in consumption and hours and that the production function is linear in labor.

in the deterministic steady state of the Ramsey equilibrium. Equation (11) results from combining equations (8), (9), and (10) and is typically referred to as the New Keynesian Phillips curve.⁶ Equation (12) is a linearized version of an Euler equation that prices nominally risk-free bonds, where R_t denotes the gross nominal risk-free interest rate between periods t and $t + 1$. This equation is typically referred to as the intertemporal IS equation.

Substituting the welfare-maximizing rate of inflation, $\hat{\pi}_t = 0$, into the intertemporal IS curve (12) implies that the nominal interest rate is given by $\hat{R}_t = \sigma E_t(\hat{c}_{t+1} - \hat{c}_t)$, which states that under the optimal policy the nominal and real interest rates coincide. Suppose that the central bank adopted this expression as a policy feedback rule for the nominal interest rate. The question is whether this proposed rule implements the Ramsey equilibrium uniquely. The answer to this question is no. To see why, consider a solution of the form $\hat{\pi}_t = \epsilon_t$, where ϵ_t is i.i.d. normal with mean zero and an arbitrary standard deviation $\sigma_\epsilon \geq 0$. Notice that for all positive values of σ_ϵ , the proposed solution for inflation is different from the optimal one. It is straightforward to see that the proposed solution satisfies the intertemporal IS equation (12). The solution for consumption can be read off the NKPC as being $\hat{c}_t = \gamma/\kappa \hat{z}_t + (1/\kappa)\epsilon_t$. We have, therefore, constructed a competitive equilibrium in which a nonfundamental source of uncertainty, embodied in the random variable ϵ_t , causes stochastic deviations of consumption and inflation from their optimal paths. Notice that in this example there exists an infinite number of different equilibria indexed by the parameter, σ_ϵ , governing the volatility of the nonfundamental shock, ϵ_t .

One possible objection against the interest rate feedback rule proposed in the previous paragraph is that it is cast in terms of the endogenous variable, c_t . In particular, one may wonder whether this endogeneity is responsible for the inability of the proposed rule to implement the Ramsey equilibrium uniquely. This concern is indeed unfounded. For, even if the interest rate feedback rule were cast in terms of exogenous fundamental variables, the failure of the strategy of using the Ramsey solution for R_t as an interest rate feedback rule remains. Specifically, substituting the optimal rate of inflation, $\hat{\pi}_t = 0$, into the New Keynesian Phillips curve (11) yields $\hat{c}_t = \gamma\kappa^{-1}\hat{z}_t$. In turn, substituting this expression into the intertemporal IS curve (12) implies that in the optimal equilibrium the nominal interest rate is given by $\hat{R}_t = \hat{r}_t^n \equiv \sigma\gamma\kappa^{-1}E_t(\hat{z}_{t+1} - \hat{z}_t)$. The variable r_t^n denotes the risk-free real (as well as nominal) interest rate that prevails in the Ramsey optimal equilibrium and is referred to as the natural rate of interest. Using this expression, equations (11)–(12) become a system of two linear stochastic difference equations

⁶ For detailed derivations of this expression, see, for instance, Woodford (2003). This linear expression is the NKPC studied in the papers by Nason and Smith (2008) and Schorfheide (2008) that appear in this issue.

in the endogenous variables $\hat{\pi}_t$ and \hat{c}_t . This system possesses one eigenvalue inside the unit circle and one outside. It follows that the solution for inflation and consumption is of the form $\hat{\pi}_{t+1} = \zeta_{\pi\pi}\hat{\pi}_t + \zeta_{\pi z}\hat{z}_t + \epsilon_{t+1}$ and $\hat{c}_t = \zeta_{c\pi}\hat{\pi}_t + \zeta_{cz}\hat{z}_t$, where $\hat{\pi}_0$ is arbitrary, ϵ_t is a nonfundamental shock such as the one introduced above, and the parameter $\zeta_{\pi\pi}$ is less than unity in absolute value. Clearly, the competitive equilibrium that the proposed rule implements displays persistent and stochastic deviation from the optimal solution. We conclude that the use of the Ramsey-optimal interest rate process as a policy feedback rule fails to implement the desired competitive equilibrium.

Can the Taylor Rule Implement Optimal Policy?

A Taylor-type rule is an interest rate feedback rule whereby the nominal interest rate is set as an increasing linear function of inflation and deviations of real output from trend, with an inflation coefficient greater than unity and an output coefficient greater than zero. Formally, a Taylor-type interest rate rule can be written as $\hat{R}_t = \alpha_\pi\hat{\pi}_t + \alpha_y\hat{y}_t$, where $\alpha_\pi > 1$ and $\alpha_y > 0$ are parameters and \hat{y}_t represents the percent deviation of real output from trend. Taylor's rule has been widely studied in monetary economics since the publication of Taylor's (1993) seminal article. It has been advocated as a desirable policy specification and is considered by some to be a reasonable approximation of actual monetary policy in the United States and many other developed countries. For this reason, we now consider the question of whether a Taylor rule can implement the optimal allocation. The answer is that, in general, an interest rate feedback rule of the type proposed by Taylor is unable to support the Ramsey optimal equilibrium. This issue was first analyzed by Woodford (2001).

To establish whether the Taylor rule presented above can implement the optimal allocation, we set the inflation rate at its optimal value of zero ($\hat{\pi}_t = 0$) and combine the intertemporal IS equation (12) with the Taylor rule. This yields $\alpha_y\hat{c}_t = \sigma(E_t\hat{c}_{t+1} - \hat{c}_t)$. Now, replacing \hat{c}_t with its optimal value of $\gamma/\kappa\hat{z}_t$, we obtain $E_t\hat{z}_{t+1} = (1 + \alpha_y/\sigma)\hat{z}_t$. This expression represents a contradiction because the productivity shock, \hat{z}_t , is assumed to be an exogenous stationary process with a law of motion independent of the policy parameter, α_y , and the preference parameter, σ . We have established that the proposed Taylor rule fails to implement the optimal equilibrium. One can show that this result also obtains when the nominal interest rate is assumed to respond to deviations of output from its natural level, which is defined as the level of output associated with the optimal equilibrium and is given by $y_t^n \equiv \gamma/\kappa\hat{z}_t$.

However, the optimal allocation can indeed be implemented by a modified Taylor rule of the form $\hat{R}_t = \hat{r}_t^n + \alpha_\pi\hat{\pi}_t$ as long as $\alpha_\pi > 1$. In this rule, \hat{r}_t^n denotes the natural rate of interest defined earlier. The first term in the modified Taylor rule makes the Ramsey allocation feasible as an equilibrium outcome.

The second term makes it unique. The key difference between the standard and modified Taylor rules is that the latter features a time-varying intercept that allows the nominal interest rate to accommodate movements in the real interest rate one-for-one without requiring changes in the price level. More generally, the optimal competitive equilibrium can be implemented via rules of the form $\hat{R}_t = \hat{r}_t^n + \alpha_\pi \hat{\pi}_t + \alpha_y (\hat{y}_t - \hat{y}_t^n)$, with policy parameters α_π and α_y satisfying the restrictions imposed by the definition of a Taylor-type rule given above.

Applying this type of rule can be quite impractical, for it would require knowledge on the part of the central bank of current and expected future values taken by all of the shocks that affect the real interest rate, as well as of the function mapping such values to the natural rate of interest. This difficulty raises the question of how close a less sophisticated interest rate rule would get to implementing the optimal equilibrium. We turn to this issue next.

Optimal, Simple, and Implementable Rules

In this subsection, we analyze the ability of simple, implementable interest rate rules to approximate the outcome of optimal policy. We draw from our previous work (Schmitt-Grohé and Uribe 2007a), where we evaluate policy in the context of a calibrated model of the U.S. business cycle featuring monopolistic competition, sticky prices in product markets, capital accumulation, government purchases financed by lump-sum or distortionary taxes, and with or without a transactional demand for money.⁷ In the model, business cycles are driven by stochastic variations in the level of total factor productivity and government consumption. We impose two requirements for an interest rate rule to be implementable. First, the rule must deliver a unique rational expectations equilibrium. Second, it must induce nonnegative equilibrium dynamics for the nominal interest rate. For an interest rule to be simple, we require that the interest rate be set as a function of a small number of easily observable macroeconomic indicators. Specifically, we study interest rate feedback rules that respond to measures of inflation, output, and lagged values of the nominal interest rate. The family of rules we consider is of the form

$$\begin{aligned} \ln(R_t/R^*) &= \alpha_R \ln(R_{t-1}/R^*) + \alpha_\pi E_t \ln(\pi_{t-i}/\pi^*) + \alpha_y E_t \ln(y_{t-i}/y^*); \\ i &= -1, 0, 1, \end{aligned} \tag{13}$$

where y^* denotes the nonstochastic Ramsey steady-state level of aggregate demand, and R^* , π^* , α_R , α_π , and α_y are parameters. The index, i , can take three values: 1, 0, and -1 . When $i = 1$, we refer to the interest rate rule as backward-looking, when $i = 0$ as contemporaneous, and when $i = -1$ as

⁷ See also Rotemberg and Woodford (1997).

Table 1 Evaluating Interest Rate Rules

	α_π	α_y	α_R	Welfare Cost	σ_π	σ_R
Ramsey Policy	—	—	—	0.000	0.01	0.27
Optimized Rules						
Contemporaneous ($i = 0$)						
Smoothing	3	0.01	0.84	0.000	0.04	0.29
No Smoothing	3	0.00	—	0.001	0.14	0.42
Backward ($i = 1$)	3	0.03	1.71	0.001	0.10	0.23
Forward ($i = -1$)	3	0.07	1.58	0.003	0.19	0.27
Nonoptimized Rules						
Taylor Rule ($i = 0$)	1.5	0.5	—	0.522	3.19	3.08
Simple Taylor Rule	1.5	—	—	0.019	0.58	0.87
Inflation Targeting	—	—	—	0.000	0.00	0.27

Notes: The interest rate rule is given by $\ln(R_t/R^*) = \alpha_R \ln(R_{t-1}/R^*) + \alpha_\pi E_t \ln(\pi_{t-i}/\pi^*) + \alpha_y E_t \ln(y_{t-i}/y^*)$; $i = -1, 0, 1$. In the optimized rules, the policy parameters α_π , α_y , and α_R are restricted to lie in the interval $[0, 3]$. The welfare cost is defined as the percentage decrease in the Ramsey-optimal consumption process necessary to make the level of welfare under the Ramsey policy identical to that under the evaluated policy. Thus, a positive figure indicates that welfare is higher under the Ramsey policy than under the alternative policy. The standard deviation of inflation and the nominal interest rate is measured in percent per year.

forward-looking. The optimal simple and implementable rule is the simple and implementable rule that maximizes welfare of the representative agent. Specifically, we characterize values of α_π , α_y , and α_R that are associated with the highest level of welfare of the representative agent within the family of simple and implementable interest rate feedback rules defined by equation (13). As a point of comparison for policy evaluation, we also compute the real allocation associated with the Ramsey optimal policy.

The first row of Table 1 shows that under the Ramsey policy inflation is virtually equal to zero at all times.⁸ The remaining rows of Table 1 report policy evaluations. The welfare associated with each interest rate feedback rule is compared to the level of welfare associated with the Ramsey-optimal policy. Specifically, the welfare cost is defined as the fraction, in percentage points, of the consumption stream an agent living in the Ramsey economy would be willing to give up to be as well off as in an economy in which

⁸ In the deterministic steady state of the Ramsey economy, the inflation rate is zero. One may wonder why, in an economy featuring sticky prices as the single nominal friction, the volatility of inflation is not exactly equal to zero at all times under the Ramsey policy. The reason is that we do not follow the standard practice of subsidizing factor inputs to eliminate the distortion introduced by monopolistic competition in product markets. Introducing such a subsidy would result in a constant Ramsey-optimal rate of inflation equal to zero.

monetary policy takes the form of the respective interest rate feedback rule shown in the table.

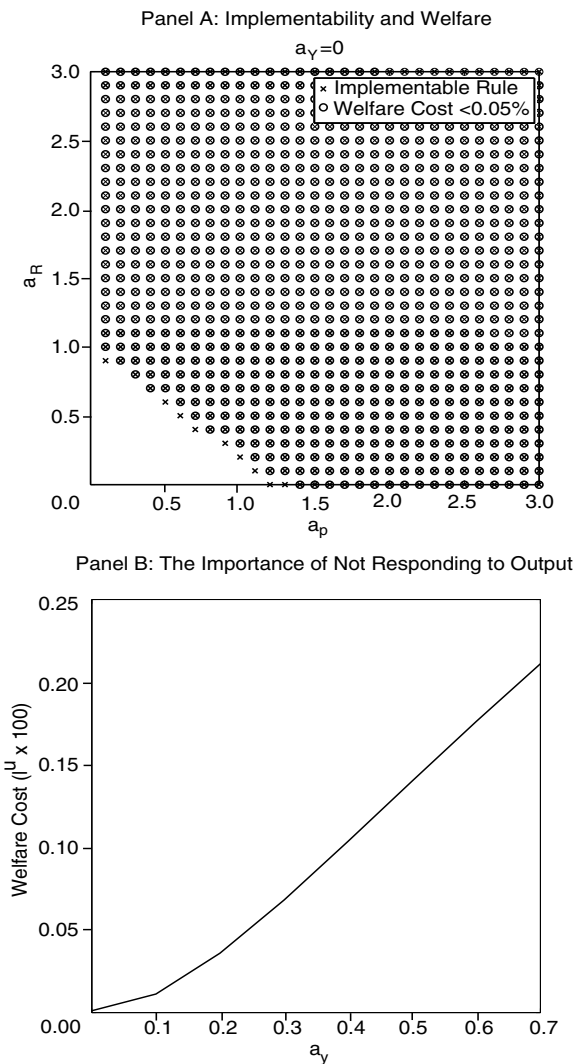
We consider seven different monetary policies: Four constrained-optimal interest rate feedback rules and three nonoptimized rules. In the constrained-optimal rule labeled no-smoothing, we search over the policy coefficients, α_π and α_y , keeping α_R fixed at zero. The second constrained-optimal rule, labeled smoothing in the table, allows for interest rate inertia by setting optimally all three coefficients, α_π , α_y , and α_R .

We find that the best no-smoothing interest rate rule calls for an aggressive response to inflation and a mute response to output. The inflation coefficient of the optimized rule takes the largest value allowed in our search, namely 3. The optimized rule is quite effective as it delivers welfare levels remarkably close to those achieved under the Ramsey policy. At the same time, the rule induces a stable rate of inflation, a feature that also characterizes the Ramsey policy. Taking together this finding and those obtained in the previous subsection, we conclude that although a Taylor rule cannot exactly implement the Ramsey allocation, it delivers outcomes that are so close to the optimum in welfare terms that, for practical purposes, it can be regarded as implementing the Ramsey allocation.

We next study a case in which the central bank can smooth interest rates over time. Our numerical search yields that the optimal policy coefficients are $\alpha_\pi = 3$, $\alpha_y = 0.01$, and $\alpha_R = 0.84$. The fact that the optimized rule features substantial interest rate inertia means that the monetary authority reacts to inflation much more aggressively in the long run than in the short run. The finding that the interest rule is not superinertial (i.e., α_R does not exceed unity) means that the monetary authority is backward-looking. So, again, as in the case without smoothing, optimal policy calls for a large response to inflation deviations in order to stabilize the inflation rate and for no response to deviations of output from the steady state. The welfare gain of allowing for interest rate smoothing is insignificant. Taking the difference between the welfare costs associated with the optimized rules with and without interest rate smoothing reveals that agents would be willing to give up less than 0.001 percent of their consumption stream under the optimized rule with smoothing to be as well off as under the optimized policy without smoothing.

The finding that allowing for optimal smoothing yields only negligible welfare gains spurs us to investigate whether rules featuring suboptimal degrees of inertia or responsiveness to inflation can produce nonnegligible welfare losses at all. Panel A of Figure 3 shows that, provided the central bank does not respond to output, $\alpha_y = 0$, varying α_π and α_R between 0 and 3 typically leads to economically negligible welfare losses of less than 0.05 percent of consumption. In the graph, crosses represent combinations of α_π and α_R that are implementable and circles represent combinations that are implementable

Figure 3 The Cashless Economy



and that yield welfare costs less than 0.05 percent of consumption relative to the Ramsey policy.

The blank area in the figure identifies α_π and α_R combinations that are not implementable either because the equilibrium fails to be locally unique or because the implied volatility of interest rates is too high. This is the case for values of α_π and α_R such that the policy stance is passive in the long run, that is, $\frac{\alpha_\pi}{1-\alpha_R} < 1$. For these parameter combinations the equilibrium is not

locally unique. This finding is a generalization of the result that, when the inflation coefficient is less than unity ($\alpha_\pi < 1$), the equilibrium is indeterminate, which obtains in the absence of interest rate smoothing ($\alpha_R = 0$). We also note that the result that passive interest rate rules render the equilibrium indeterminate is typically derived in the context of models that abstract from capital accumulation. It is, therefore, reassuring that this particular abstraction appears to be of no consequence for the finding that (long run) passive policy is inconsistent with local uniqueness of the rational expectations equilibrium. Similarly, we find that determinacy obtains for policies that are active in the long run, $\frac{\alpha_\pi}{1-\alpha_R} > 1$.

More importantly, Panel A of Figure 3 shows that virtually all parameterizations of the interest rate feedback rule that are implementable yield about the same level of welfare as the Ramsey equilibrium. This finding suggests a simple policy prescription, namely, that any policy parameter combination that is irresponsive to output and active in the long run, is equally desirable from a welfare point of view.

One possible reaction to the finding that implementability-preserving variations in α_π and α_R have little welfare consequences may be that in the class of models we consider, welfare is flat in a large neighborhood around the optimum parameter configuration, so that it does not really matter what the government does. This turns out not to be the case. Recall that in the welfare calculations underlying Panel A of Figure 3, the response coefficient on output, α_y , was kept constant and equal to zero. Indeed, interest rate rules that lean against the wind by raising the nominal interest rate when output is above trend can be associated with sizable welfare costs. Panel B of Figure 3 illustrates the consequences of introducing a cyclical component to the interest rate rule. It shows that the welfare costs of varying α_y can be large, thereby underlining the importance of not responding to output. The figure shows the welfare cost of deviating from the optimal output coefficient ($\alpha_y \approx 0$) while keeping the inflation coefficient of the interest rate rule at its optimal value ($\alpha_\pi = 3$) and not allowing for interest rate smoothing ($\alpha_R = 0$). Welfare costs are monotonically increasing in α_y . When $\alpha_y = 0.7$, the welfare cost is over 0.2 percent of the consumption stream associated with the Ramsey policy. This is a significant figure in the realm of policy evaluation at business-cycle frequency.⁹ This finding suggests that bad policy can have significant welfare costs in our model and that policy mistakes are committed when policymakers are unable to resist the temptation to respond to output fluctuations.

⁹ A similar result obtains if one allows for interest rate smoothing with α_R taking its optimized value of 0.84.

It follows that sound monetary policy calls for sticking to the basics of responding to inflation alone.¹⁰ This point is conveyed with remarkable simplicity by comparing the welfare consequences of a simple interest rate rule that responds only to inflation with a coefficient of 1.5 to those of a standard Taylor rule that responds to inflation as well as output with coefficients 1.5 and 0.5, respectively. Table 1 shows that the Taylor rule that responds to output is significantly welfare inferior to the simple interest rate rule that responds solely to inflation. Specifically, the welfare cost of responding to output is about half a percentage point of consumption.¹¹

The Ramsey-optimal monetary policy implies near complete inflation stabilization (see Table 1). It is reasonable to conjecture, therefore, that inflation targeting, interpreted to be any monetary policy capable of bringing about zero inflation at all times ($\pi_t = 1$ for all t), would induce business cycles virtually identical to those associated with the Ramsey policy. We confirm this conjecture by computing the welfare cost associated with inflation targeting. The welfare cost of targeting inflation relative to the Ramsey policy is virtually nil.

An important issue in monetary policy is determining what measures of inflation and aggregate activity the central bank should respond to. In particular, a question that has received considerable attention among academic economists and policymakers is whether the monetary authority should respond to past, current, or expected future values of output and inflation. Here we address this question by computing optimal backward- and forward-looking interest rate rules. That is, in equation (13) we let i take the values -1 and $+1$. Table 1 shows that there are no welfare gains from targeting expected future values of inflation and output as opposed to current or lagged values of these macroeconomic indicators. Also, a muted response to output continues to be optimal under backward- or forward-looking rules.

Under a forward-looking rule without smoothing ($\alpha_R = 0$), the rational expectations equilibrium is indeterminate for all values of the inflation and output coefficients in the interval $[0,3]$. This result is in line with that obtained by Carlstrom and Fuerst (2005). These authors consider an environment similar to ours and characterize determinacy of equilibrium for interest rate rules that depend only on the rate of inflation. Our results extend the findings of Carlstrom and Fuerst to the case in which output enters in the feedback rule.

We close this section by noting that most of the results presented here, extend to a model economy with a much richer battery of nominal and real rigidities. In Schmitt-Grohé and Uribe (2007b), we consider an economy featuring four real rigidities: habit formation, variable capacity utilization,

¹⁰ Other authors have also argued that countercyclical interest rate policy may be undesirable (e.g., Ireland 1997 and Rotemberg and Woodford 1997).

¹¹ The simple interest rate rule that responds solely to inflation is implementable, whereas the standard Taylor rule is not, because it implies too high a volatility of nominal interest rates.

investment adjustment costs, and monopolistic competition in product and labor markets. The economy in that study also includes four nominal frictions, namely, sticky prices, sticky wages, money demand by households, and money demand by firms. Finally, the model features a more realistic shock structure that includes permanent stochastic variations in total factor productivity, permanent stochastic variations in the relative price of investment, and stationary stochastic variations in government spending. The values assigned to the structural parameters are based on existing econometric estimations of the model. These studies, in turn, argue that the model explains satisfactorily observed short-term fluctuations in the postwar United States. We find that the Ramsey policy calls for stabilizing price inflation. More importantly, a simple interest rate rule that responds only to inflation (with mute responses to wage inflation or output) attains a level of welfare remarkably close to that associated with the Ramsey optimal equilibrium.

6. CONCLUSION

In this article, we present a selective account of recent developments on the policy implications of the New Keynesian Phillips curve. The main lesson derived from our analysis is that price stability emerges as a robust policy prescription in models with product price rigidities. In fact, a minimum amount of price stickiness suffices to make inflation stabilization the overriding goal of monetary policy.

The desirability of price stability obtains in several variations of the standard New Keynesian framework that include expanding the set of nominal and real rigidities to allow for government spending financed by distortionary taxes, a transactional demand for money by households and firms, nominal wage rigidity, habit formation, variable capacity utilization, and investment adjustment costs.

A second important message that emerges is that a simple interest rate feedback rule that responds aggressively only to a measure of consumer price inflation delivers outcomes that are remarkably close to the Ramsey optimal equilibrium. In particular, to emulate optimal monetary policy it is not necessary that in setting the nominal rate the monetary authority respond to deviations of output from trend or past values of the interest rate itself. In this sense, the policy implications of the NKPC identified in this survey are consistent with a pure inflation targeting objective.

We have left out a number of important issues in the theory of inflation stabilization. For example, we limit attention to monetary policy under commitment. There is an active literature exploring the policy implications of the NKPC when the government is unable to commit to future actions. A central theme in this literature is to ascertain whether lack of commitment gives rise to an optimal inflation bias. A second omission in the present analysis concerns

models with asymmetric costs of price adjustment. Here again, the central question is whether in the presence of downwardly rigid prices or wages, the policymaker should pursue a positive inflation target. Finally, our article does not discuss the recent literature on optimal monetary policy in models with credit constraints. An important focus of this literature is whether this type of friction introduces reasons for the central bank to respond to financial variables in setting the short-term interest rate.

REFERENCES

- Aiyagari, S. Rao, Albert Marcet, Thomas J. Sargent, and Juha Seppälä. 2002. "Optimal Taxation Without State-Contingent Debt." *Journal of Political Economy* 110 (December): 1220–54.
- Altig, David, Lawrence J. Christiano, Martin Eichenbaum, and Jesper Lindé. 2005. "Firm-Specific Capital, Nominal Rigidities, and the Business Cycle." Working Paper 11034. Cambridge, Mass.: National Bureau of Economic Research. (January).
- Barro, Robert J. 1979. "On the Determination of Public Debt." *Journal of Political Economy* 87 (October): 940–71.
- Bils, Mark, and Pete Klenow. 2004. "Some Evidence on the Importance of Sticky Prices." *Journal of Political Economy* 112 (October): 947–85.
- Calvo, Guillermo. 1983. "Staggered Prices in a Utility-Maximizing Framework." *Journal of Monetary Economics* 12 (September): 383–98.
- Calvo, Guillermo A., and Pablo E. Guidotti. 1990. "Indexation and Maturity of Government Bonds: An Exploratory Model." In *Capital Markets and Debt Management*, edited by R. Dornbusch and M. Draghi. New York: Cambridge University Press, 52–82.
- Calvo, Guillermo A., and Pablo E. Guidotti. 1993. "On the Flexibility of Monetary Policy: The Case of the Optimal Inflation Tax." *Review of Economic Studies* 60 (July): 667–87.
- Carlstrom, Charles T., and Timothy S. Fuerst. 2005. "Investment and Interest Rate Policy: A Discrete Time Analysis." *Journal of Economic Theory* 123 (July): 4–20.
- Chari, Varadarajan V., Lawrence J. Christiano, and Patrick J. Kehoe. 1991. "Optimal Fiscal and Monetary Policy: Some Recent Results." *Journal of Money Credit and Banking* 23 (August): 519–39.

- Christiano, Lawrence J., Martin Eichenbaum, and Charles L. Evans. 2005. "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy." *Journal of Political Economy* 113 (February): 1–45.
- Correia, Isabel, Juan Pablo Nicolini, and Pedro Teles. 2008. "Optimal Fiscal and Monetary Policy: Equivalence Results." *Journal of Political Economy* 168: 141–70.
- Del Negro, Marco, Frank Schorfheide, Frank Smets, and Raf Wouters. 2004. "On the Fit and Forecasting Performance of New-Keynesian Models." Manuscript (November).
- Feenstra, Robert C. 1986. "Functional Equivalence Between Liquidity Costs and the Utility of Money." *Journal of Monetary Economics* 17 (March): 271–91.
- Goodfriend, Marvin, and Robert G. King. 1997. "The New Neoclassical Synthesis and the Role of Monetary Policy." In *NBER Macroeconomics Annual*, edited by Ben S. Bernanke and Julio J. Rotemberg. Cambridge, Mass.: MIT Press, 231–83.
- Ireland, Peter. 1997. "A Small, Structural, Quarterly Model for Monetary Policy Evaluation." *Carnegie-Rochester Conference Series on Public Policy* 47 (December): 83–108.
- Khan, Aubhik, Robert G. King, and Alexander Wolman. 2003. "Optimal Monetary Policy." *Review of Economic Studies* 70 (October): 825–60.
- Kimbrough, Kent P. 1986. "The Optimum Quantity of Money Rule in the Theory of Public Finance." *Journal of Monetary Economics* 18 (November): 277–84.
- Klenow, Pete, and Oleksiy Kryvtsov. 2005. "State-Dependent or Time-Dependent Pricing: Does It Matter for Recent U.S. Inflation?" Mimeo, Stanford University (July).
- Levin, Andrew, Alexei Onatski, John Williams, and Noah Williams. 2006. "Monetary Policy Under Uncertainty in Micro-Founded Macroeconometric Models." In *NBER Macroeconomics Annual 2005*, vol. 20, edited by Mark Gertler and Kenneth Rogoff. Cambridge, Mass.: MIT Press.
- Lucas, Robert E., Jr. 1982. "Interest Rates and Currency Prices in a Two-Country World." *Journal of Monetary Economics* 10: 335–60.
- Lucas, Robert E., Jr., and Nancy L. Stokey. 1983. "Optimal Fiscal and Monetary Policy in an Economy Without Capital." *Journal Monetary Economics* 12: 55–93.
- Nakamura, Emi, and Jón Steinsson. 2007. "Five Facts About Prices: A Reevaluation of Menu Cost Models." Mimeo, Harvard University (May).

- Nason, James M., and Gregory W. Smith. 2008. "The New Keynesian Phillips Curve: Lessons from Single-Equation Econometric Estimation." Federal Reserve Bank of Richmond *Economic Quarterly* 94 (Fall): 361–96.
- Rotemberg, Julio J. 1982. "Sticky Prices in the United States." *Journal of Political Economy* 90 (December): 1187–211.
- Rotemberg, Julio J., and Michael Woodford. 1997. "An Optimization-Based Econometric Framework for the Evaluation of Monetary Policy." In *NBER Macroeconomics Annual 1997*, edited by Ben S. Bernanke and Julio J. Rotemberg. Cambridge, Mass. and London: MIT Press, 297–346.
- Schmitt-Grohé, Stephanie, and Martín Uribe. 2004a. "Optimal Fiscal and Monetary Policy under Sticky Prices." *Journal of Economic Theory* 114 (February): 198–230.
- Schmitt-Grohé, Stephanie, and Martín Uribe. 2004b. "Optimal Fiscal and Monetary Policy under Imperfect Competition." *Journal of Macroeconomics* 26 (June): 183–209.
- Schmitt-Grohé, Stephanie, and Martín Uribe. 2006. "Optimal Fiscal and Monetary Policy in a Medium-Scale Macroeconomic Model." In *NBER Macroeconomics Annual 2005*, edited by Mark Gertler and Kenneth Rogoff. Cambridge, Mass. and London: MIT Press, 383–425.
- Schmitt-Grohé, Stephanie, and Martín Uribe. 2007a. "Optimal Simple and Implementable Monetary and Fiscal Rules." *Journal of Monetary Economics* 54 (September): 1702–25.
- Schmitt-Grohé, Stephanie, and Martín Uribe. 2007b. "Optimal Inflation Stabilization in a Medium-Scale Macroeconomic Model." In *Monetary Policy Under Inflation Targeting*, edited by Klaus Schmidt-Hebbel and Rick Mishkin. Santiago, Chile: Central Bank of Chile, 125–86.
- Schorfheide, Frank. 2008. "DSGE Model-Based Estimation of the New Keynesian Phillips Curve." Federal Reserve Bank of Richmond *Economic Quarterly* 94 (Fall): 397–434.
- Sidrauski, Miguel. 1967. "Rational Choice and Patterns of Growth in a Monetary Economy." *American Economic Review Papers and Proceedings* 57: 534–44.
- Smets, Frank, and Raf Wouters. 2007. "Shocks and Frictions in U.S. Business Cycles: A Bayesian DSGE Approach." *American Economic Review* 97 (June): 586–606.
- Taylor, John B. 1993. "Discretion Versus Policy Rules in Practice." *Carnegie Rochester Conference Series on Public Policy* 39 (December): 195–214.

- Woodford, Michael. 1996. "Control of the Public Debt: A Requirement for Price Stability?" Working Paper 5684. Cambridge, Mass.: National Bureau of Economic Research. (July).
- Woodford, Michael. 2001. "The Taylor Rule and Optimal Monetary Policy." *American Economic Review Papers and Proceedings* 91 (May): 232–7.
- Woodford, Michael. 2003. *Interest and Prices*. Princeton, N.J.: Princeton University Press.
- Yun, Tack. 1996. "Nominal Price Rigidity, Money Supply Endogeneity, and Business Cycles." *Journal of Monetary Economics* 37 (July): 345–70.