Conventional and Unconventional Monetary Policy

Vasco Cúrdia and Michael Woodford

The authors extend a standard New Keynesian model to incorporate heterogeneity in spending opportunities and two sources of (potentially time-varying) credit spreads and to allow a role for the central bank's balance sheet in equilibrium determination. They use the model to investigate the implications of imperfect financial intermediation for familiar monetary policy prescriptions, and to consider additional dimensions of central bank policy—variations in the size and composition of the central bank's balance sheet and payment of interest on reserves—alongside the traditional question of the proper choice of setting an operating target for an overnight policy rate. The authors also give particular attention to the special problems that arise when the policy rate reaches the zero lower bound. They show that it is possible within a single unified framework to identify the criteria for policy to be optimal along each dimension. The suggested policy prescriptions apply equally well when financial markets work efficiently as when they are substantially disrupted and interest rate policy is constrained by the zero lower bound. (JEL E44, E52)

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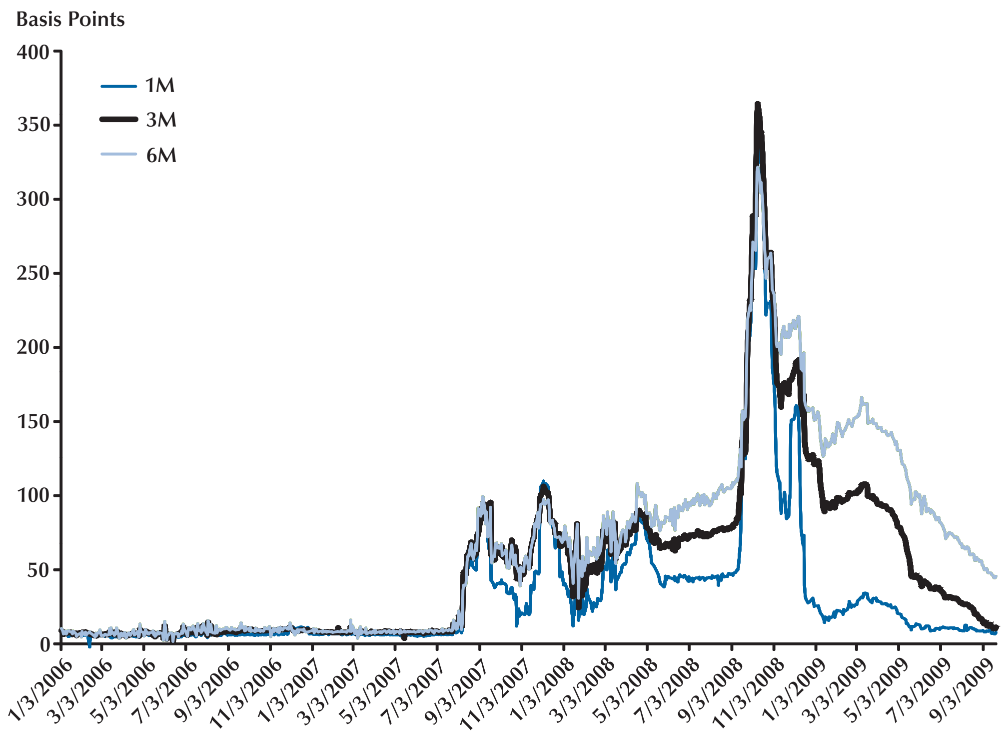
The recent global financial crisis has confronted central banks with a number of questions beyond the scope of many conventional accounts of the theory of monetary policy. For example, do projections of the paths of inflation and of aggregate real activity under some contemplated path for policy provide a sufficient basis for monetary policy decisions, or must financial conditions be given independent weight in such deliberations? That the Fed began aggressively cutting its target for the federal funds rate in late 2007 and early 2008, while inflation was arguably increasing and real GDP was not yet known to be contracting—and has nonetheless often been criticized as responding too slowly in this period—suggests that familiar prescriptions that focus on inflation and real GDP alone, such as the Taylor (1993) rule or common accounts of "flexible inflation targeting" (Svensson, 1997), may be inadequate to circumstances of the kind recently faced.[1] As a further, more-specific question, how should a central bank's interest rate policy be affected by the observation that other key interest rates no longer co-move with the policy rate (the federal funds rate in the case of the United States) in the way they typically have in the past? The dramatically different behavior of the LIBOR-OIS spread, shown in Figure 1, since August 2007, has drawn particular comment. Indeed, John Taylor

[1] See Mishkin (2008) for discussion of some of the considerations behind the Fed's relatively aggressive rate cuts in the early part of the crisis.

Vasco Cúrdia is an economist at the Federal Reserve Bank of New York. Michael Woodford is a professor in the department of economics at Columbia University. The authors thank Michele Boldrin, Gauti Eggertsson, Marvin Goodfriend, Jamie McAndrews, John Taylor, and Kazuo Ueda for helpful discussions; Neil Mehrotra, Ging Cee Ng, and Luminita Stevens for research assistance; and the National Science Foundation for research support of the second author.

Figure 1

Spread Between the U.S. Dollar LIBOR Rate and the Corresponding OIS Rate



SOURCE: Bloomberg.

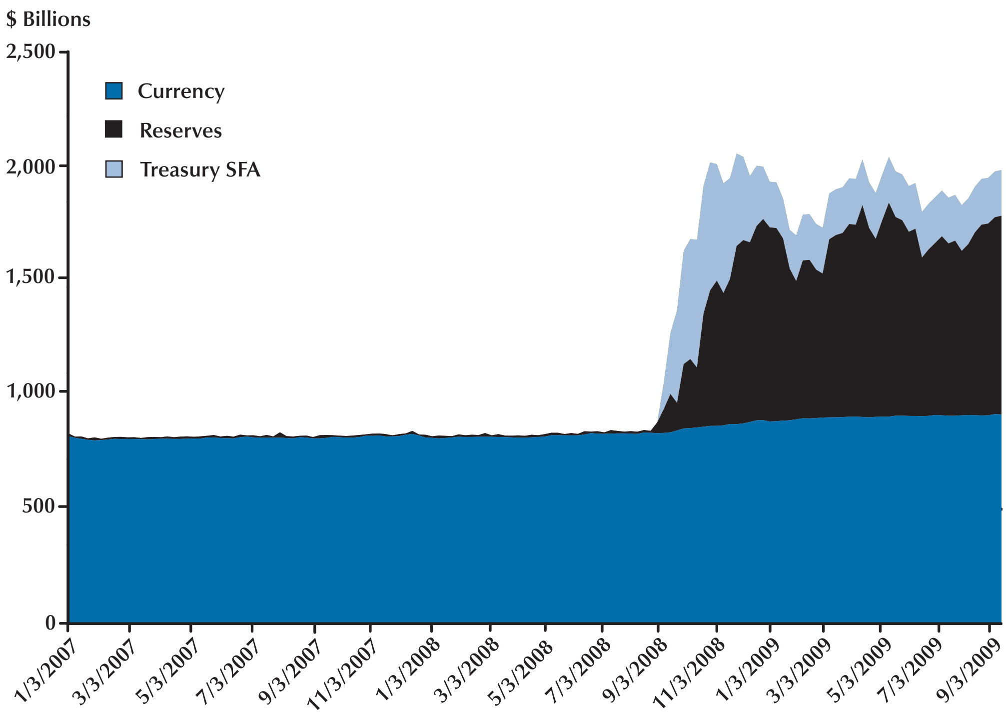
himself (Taylor, 2008) has suggested that movements in this spread should be taken into account in an extension of his famous rule.

In addition to such new questions about traditional interest rate policy, the very focus on interest rate policy as the central question about monetary policy has been called into question. The explosive growth of base money in the United States since September 2008 (shown in Figure 2) has led many commentators to suggest that the main instrument of U.S. monetary policy has changed from an interest rate policy to one often described as "quantitative easing." Does it make sense to regard the supply of bank reserves (or perhaps the monetary base) as an alternative or superior operating target for monetary policy? Does this (as some would argue) become the only important monetary policy decision once the overnight rate (the federal funds rate) has reached the zero lower bound, as it effectively has in the United States since December 2008 (Figure 3)? And now that the Federal Reserve has legal authorization to pay interest on reserves (under the Emergency Economic Stabilization Act of 2008), how should this additional potential dimension of policy be used?

The past two years have also seen dramatic developments in the composition of the asset side of the Fed's balance sheet (Figure 4). Whereas the Fed had largely held Treasury securities on its balance sheet before the fall of 2007, other kinds of assets—including both a variety of new "liquidity facilities" and new programs under which the Fed has essentially become a direct lender to certain sectors of the economy—have rapidly grown in importance. How to manage these programs has

Figure 2

Liabilities of the Federal Reserve



SOURCE: Federal Reserve Board.

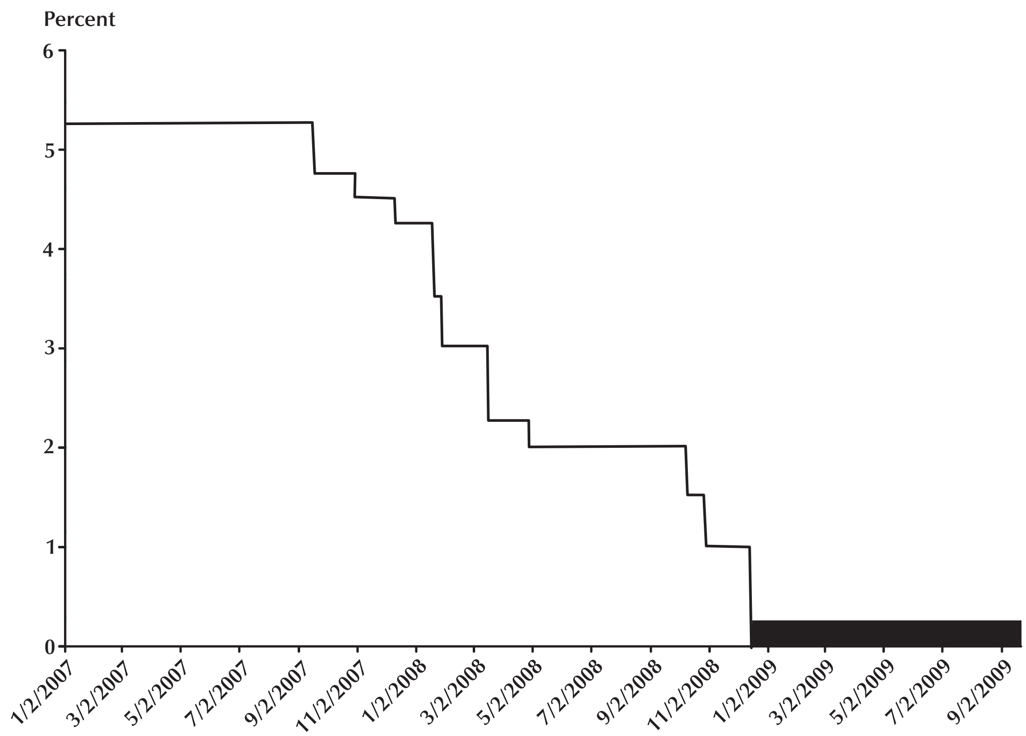
occupied much of the attention of policymakers recently. How should one think about the aims of these programs and the relation of this new component of Fed policy to traditional interest rate policy? Is Federal Reserve credit policy a substitute for interest rate policy, or should it have different goals from those of interest rate policy?

These are clearly questions that a theory of monetary policy adequate to our present circumstances must address. Yet, not only these questions received relatively little attention until recently, but the very models commonly used to evaluate the effects of alternative prescriptions for monetary policy have little to say about them. Many New Keynesian (NK) models abstract entirely from the role of financial intermediation in the economy (by assuming a representative household) or assume perfect risk-sharing (to facilitate aggregation), so that the consequences of financial disruptions cannot be addressed. Many models include only a single interest rate (or only a single interest rate of a given maturity, with long rates tied to short rates through a no-arbitrage condition) and hence cannot say anything about the proper response to changes in spreads. And many models abstract entirely from the balance sheet of the central bank, so that questions about the additional dimensions of policy resulting from the possibility of varying the size and composition of the balance sheet cannot be addressed.[2]

[2] In a representative-household model, abstraction from the role of the central bank's balance sheet in equilibrium determination is relatively innocuous; in particular, Eggertsson and Woodford (2003) show that introducing both a large range of possible choices about the composition of the balance sheet and transactions frictions that accord a special role to central bank liabilities need not imply any additional channels through which monetary policy can affect the economy when the zero lower bound is reached. However, we wish to reconsider this question in a framework where financial intermediation is both essential and costly.

Figure 3

FOMC Operating Target for the Federal Funds Rate



NOTE: Beginning with December 2008, the target rate is replaced with a target bank of 0 to 25 basis points.

SOURCE: Federal Reserve Board.

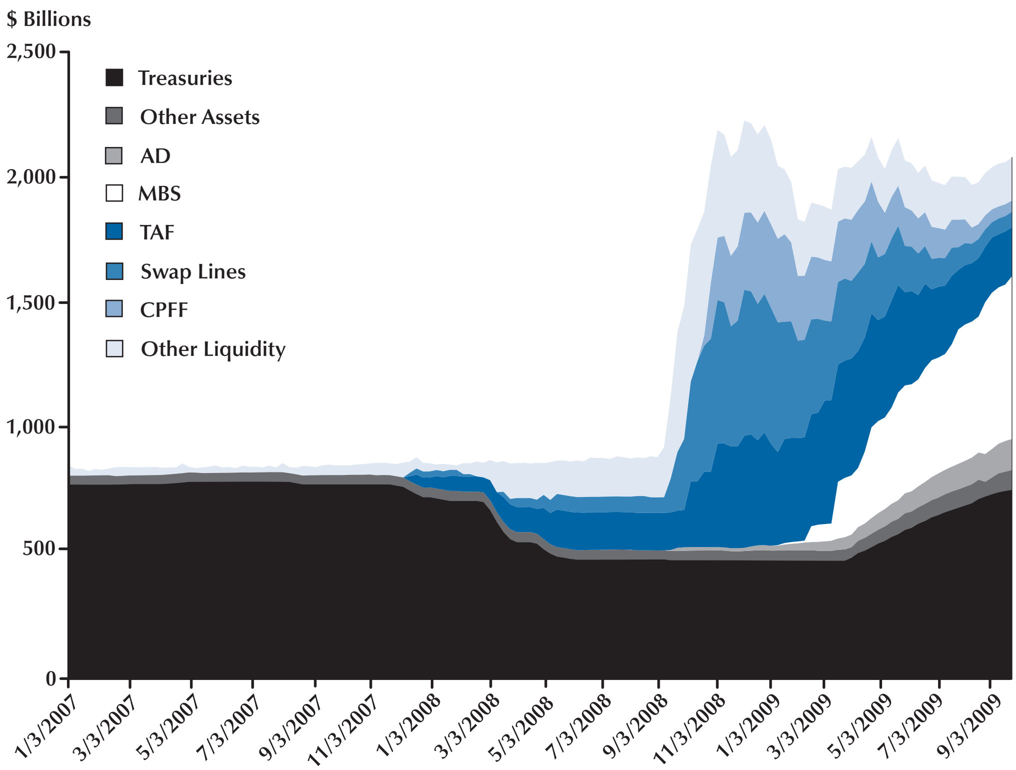
The aim of the research summarized here[3] is to show how such issues can be addressed in a dynamic stochastic general equilibrium (DSGE) framework. We extend a basic NK model in directions that are crucial for analysis of the questions just posed: We introduce (i) nontrivial heterogeneity in spending opportunities, so that financial intermediation matters for the allocation of resources; (ii) imperfections in private financial intermediation and the possibility of disruptions to the efficiency of intermediation for reasons taken here as exogenous; and (iii) additional dimensions of central bank policy, by explicitly considering the role of the central bank's balance sheet in equilibrium determination and by allowing central bank liabilities to supply transactions services. Unlike some other recent approaches to the introduction of financial intermediation into NK DSGE models[4]—which arguably include some features that allow for greater quantitative realism—our aim has been to develop a model that departs from a standard (representative-household) model in only the most minimal ways necessary to address the issues raised above. In this way, we can nest the standard (and extensively studied) model as a special case of our model so that the sources of our results and the precise significance of the new model elements introduced can be more clearly understood.

[3] This paper summarizes results that are explained in greater detail in Cúrdia and Woodford (2009a, 2009b, 2010).

[4] This has been a very active literature of late. See, for example, Christiano, Motto, and Rostagno (2007), Faia and Monacelli (2007), Gerali et al. (2008), and Gertler and Karadi (2009).

Figure 4

Assets of the Federal Reserve



SOURCE: Federal Reserve Board.

1. A MODEL WITH MULTIPLE DIMENSIONS OF MONETARY POLICY

Here we sketch the key elements of our model, which extends the model introduced in Cúrdia and Woodford (2009a), to introduce the additional dimensions of policy associated with the central bank's balance sheet. (See this earlier paper, especially its technical appendix, for more details.) We stress the similarity between the model developed there and the basic NK model and show how the standard model is recovered as a special case of the extended model.

1.1 Heterogeneity and the Allocative Consequences of Credit Spreads

Our model is a relatively simple generalization of the basic NK model used by Goodfriend and King (1997), Clarida, Gali, and Gertler (1999), Woodford (2003), and others to analyze optimal monetary policy. The model is still highly stylized in many respects; for example, we abstract from the distinction between the household and firm sectors of the economy and instead treat all private expenditure as the expenditure of infinitely lived household-firms. Similarly, we abstract from the consequences of investment spending for the evolution of the economy's productive capacity, instead treating all private expenditure as if it were nondurable consumer expenditure (yielding immediate utility at a diminishing marginal rate).

We depart from the assumption of a representative household in the standard model by supposing that households differ in their preferences. Each household *i* seeks to maximize a discounted intertemporal objective of the form

$$(1)\quad E_0 \sum_{t=0}^{\infty} \beta^t \left[u^{\tau_t(i)}\left(c_t(i);\xi_t\right) - \int_0^1 v^{\tau_t(i)}\left(h_t(j;i);\xi_t\right) dj \right],$$

where $\tau(i) \in \{b,s\}$ indicates the household's "type" in period t. Here $u^b(c;\xi)$ and $u^s(c;\xi)$ are two different period utility functions, each of which may also be shifted by the vector of aggregate taste shocks, ξ_t and $v^b(h;\xi)$ and $v^s(h;\xi)$ are correspondingly two different functions indicating the period disutility from working for the two types. As in the basic NK model, there is assumed to be a continuum of differentiated goods, each produced by a monopolistically competitive supplier; $c_t(i)$ is a Dixit-Stiglitz aggregator of the household's purchases of these differentiated goods. The household similarly supplies a continuum of different types of specialized labor, indexed by j, that are hired by firms in different sectors of the economy; the additively separable disutility of work, $v^\tau(h;\xi)$, is the same for each type of labor, though it depends on the household's type and the common taste shock.

Each agent's type, $\tau_t(i)$, evolves as an independent two-state Markov chain. Specifically, we assume that each period, with probability $1-\delta$ (for some $0 \le \delta < 1$), an event occurs that results in a new type for the household being drawn; otherwise it remains the same as in the previous period. When a new type is drawn, it is b with probability π_b and s with probability π_s, where $0 < \pi_b, \pi_s < 1$, $\pi_b + \pi_s$ +1. (Hence the population fractions of the two types are constant at all times and equal to π_τ for each type τ.) We assume moreover that $u_c^b(c;\xi) > u_c^s(c;\xi)$ when expenditure, c, falls in the range of values that occur in equilibrium. (See Figure 5, where these functions are graphed in the case of the calibration, which shows the functions $u_c^b(c)$ and $u_c^s(c)$ used in the numerical work reported here.) Hence a change in a household's type changes its relative impatience to consume, given the aggregate state ξ_t; in addition, each household's current impatience to consume depends on the aggregate state ξ_t. We also assume that the marginal utility of additional expenditure diminishes at different rates for the two household types (see Figure 5); type b households (who are borrowers in equilibrium) have a marginal utility that varies less with the current level of expenditure, resulting in a greater degree of intertemporal substitution of their expenditures in response to interest rate changes. Finally, the two types are also assumed to differ in the marginal disutility of working a given number of hours; this difference is calibrated so that the two types choose to work the same number of hours in steady state, despite their differing marginal utilities of income. For simplicity, the elasticities of labor supply of the two types are not assumed to differ.

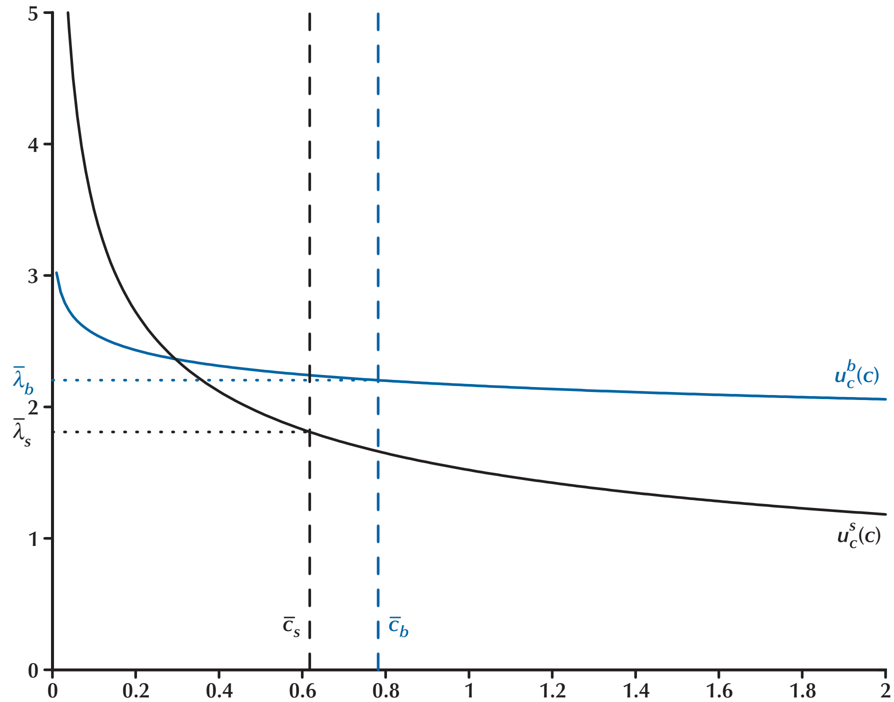
The coexistence of the two types with differing impatience to consume creates a social function for financial intermediation. In the present model, as in the basic NK model, all output is consumed either by households or by the government; hence intermediation serves an allocative function only to the extent that there are reasons for the intertemporal marginal rates of substitution of households to differ in the absence of financial flows. The present model reduces to the standard representative-household model in the case that one assumes that $u^b(c;\xi) = u^s(c;\xi)$ and $v^b(h;\xi) = v^s(h;\xi)$.

We assume the following: that households generally are able to spend an amount different from their current income *only* by depositing funds with or borrowing from financial intermediaries; that the same nominal interest rate i_t^d is available to all savers; and that a (possibly) different nominal interest i_t^b is available to all borrowers,[5] independent of the quantities that a given household chooses to save or to borrow. For simplicity, we also assume that only one-period riskless nominal contracts with the intermediary are possible for either savers and borrowers. The assumption that households cannot engage in financial contracting other than through the inter-

[5] Here "savers" and "borrowers" identify households according to whether they choose to save or borrow and not according to their type.

Figure 5

Marginal Utilities of Consumption for Two Household Types



NOTE: The values of $\bar{c}^s$ and $\bar{c}^b$ indicate steady-state consumption levels of the two types, and $\bar{\lambda}^s$ and $\bar{\lambda}^b$ their corresponding steady-state marginal utilities.

mediary sector represents one of the key financial frictions. We also allow households to hold one-period riskless nominal government debt. But, because government debt and deposits with intermediaries are perfect substitutes as investments, households must pay the same interest rate i_t^d in equilibrium and their decision problem is the same as the case in which they have only one decision about how much to deposit with or borrow from intermediaries.

Aggregation is simplified by assuming that households are able to sign state-contingent contracts with one another, through which they may insure one another against both aggregate risk and the idiosyncratic risk associated with a household's random draw of its type, but also assuming that households are *only intermittently* able to receive transfers from the insurance agency; between these infrequent occasions when a household has access to the insurance agency, it can only save or borrow through the financial intermediary sector mentioned previously. The assumption that households are *eventually* able to make transfers to one another in accordance with an insurance contract signed earlier means that they continue to have identical expectations regarding their marginal utilities of income far enough in the future, regardless of their differing type histories.

It then turns out that in equilibrium, the marginal utility of a given household at any point in time depends *only* on its type $\tau_t(i)$ at that time; hence the entire distribution of marginal utilities of income at any time can be summarized by two state variables, λ_t^b and λ_t^s, indicating the marginal utilities of each of the two household types. The expenditure level of type τ is also the same for all households of that type and can be obtained by inverting the marginal-utility functions (graphed in Figure 5) to yield an expenditure demand function $c^{\tau}(\lambda;\xi_t)$ for each type. Aggregate demand Y_t for the Dixit-Stiglitz composite good can then be written as

$$(2)\quad Y_t = \pi_b c^b\left(\lambda_t^b;\xi_t\right) + \pi_s c^s\left(\lambda_t^s;\xi_t\right) + G_t + \Xi_t,$$

where G_t indicates the (exogenous) level of government purchases, and Ξ_t indicates resources consumed by intermediaries (the sum of two components, Xi_t^p representing costs of the private intermediaries and Ξ_t^{cb} representing costs of central bank activities, each discussed further below). Thus the effects of financial conditions on aggregate demand can be summarized by tracking the evolution of the two state variables λ_t^{τ}. The marginal-utility ratio $\Omega_t \equiv \lambda_t^b/\lambda_t^s \geq 1$ provides an important measure of the inefficiency of the allocation of expenditure owing to imperfect financial intermediation—since, in the case of frictionless financial markets, we would have $\Omega_t = 1$ at all times.

In the presence of heterogeneity, instead of a single Euler equation each period relating the path of the marginal utility of income of the representative household to the model's single interest rate, we have *two* Euler equations each period, one for each household type and each involving a different interest rate: i_t^b for type b households (who choose to borrow in equilibrium) and i_t^d for type s households (who choose to save). If we log-linearize these Euler equations,[6] and combine them with a log-linearized version of (2), we obtain a structural relation of the form

$$(3)\quad \begin{aligned}\hat{Y}_t = &-\bar{\sigma}\left(\hat{\imath}_t^{avg} - E_t\pi_{t+1}\right) + E_t\hat{Y}_{t+1} - E_t\Delta g_{t+1} \\ &- E_t\Delta\hat{\Xi}_{t+1} - \bar{\sigma}s_{\Omega}\hat{\Omega}_t + \bar{\sigma}\left(s_{\Omega} + \psi_{\Omega}\right)E_t\hat{\Omega}_{t+1},\end{aligned}$$

generalizing the "intertemporal IS relation" of the basic NK model. Here $\hat{Y}_t \equiv \log(Y_t/\bar{Y})$ measures the percentage deviation of aggregate output from its steady-state level;

$$\hat{\imath}_t^{avg} \equiv \pi_b\hat{\imath}_t^b + \pi_s\hat{\imath}_t^d$$

is the average of the interest rates that are relevant (at the margin) for all of the savers and borrowers in the economy, where we define $\hat{\imath}_t^{\tau} \equiv \log(1 + i_t^{\tau}/1 + \bar{\imath}^{\tau})$ for $\tau \in \{b,d\}$;[7] g_t is a composite "autonomous expenditure" disturbance as in Woodford (2003, pp. 80, 249), taking account of exogenous fluctuations in G_t, as well as exogenous variation in the spending opportunities facing the two types of households (reflected in the dependence of the functions $u^{\tau}(c;\xi_t)$ on the state vector ξ_t); $\hat{\Xi}_t \equiv (\Xi_t - \bar{\Xi})/\bar{Y}$ measures departures of the quantity of resources consumed by the intermediary sector from its steady-state level[8]; and $\hat{\Omega}_t \equiv \log(\Omega_t/\bar{\Omega})$ measures the gap between the marginal utilities of the two household types.

Note that the first four terms on the right-hand side of (3) are exactly as in the basic NK model, except for these differences: (i) instead of "the" interest rate we have an average interest rate; (ii) $\bar{\sigma}$ is no longer the intertemporal elasticity of substitution for the representative household, but instead a weighted average of the corresponding parameters for the two types; and (iii) the composite disturbance, g_t, similarly averages the changes in spending opportunities for the two types. The crucial differences are the presence of the new terms involving $\hat{\Xi}_t$ and $\hat{\Omega}_t$, which exist only in the case of financial frictions. The sign of the coefficient s_{Ω} depends on the asymmetry of the degrees of interest sensitivity of expenditure by the two types; in the case shown in Figure 5 (which we regard as the empirically relevant case), $s_{\Omega} > 0$ because the intertemporal elasticity of expenditure is higher for type b.[9] In this case, a larger value of $\hat{\Omega}_t$ reduces aggregate demand for given expectations about the forward path of average

6 Here and in the case of all other log-linearizations discussed below, we log-linearize around a deterministic steady state in which the inflation rate is zero and aggregate output is constant.

7 One can show that, for a log-linear approximation, the average marginal utility of income in the population depends only on the expected path of this particular average of the interest rates in the economy.

8 We adopt this notation so that $\hat{\Xi}_t$ is defined even when the model is parameterized so that $\bar{\Xi} = 0$.

9 In our calibration, ψ_{Ω} is a small negative quantity, but because it is small its sign is not of great importance.

real interest rates; this can be thought of as representing "financial headwinds" of a kind sometimes discussed within the Federal Reserve system.[10]

Log-linearization of the two Euler equations also implies that

$$(4)\quad \hat{\Omega}_t = \hat{\omega}_t + \hat{\delta} E_t \hat{\Omega}_{t+1},$$

where $\omega_t\ \hat{\imath}_t^b - \hat{\imath}_t^d$ is the short-term *credit spread* and $\hat{\delta}$ is a coefficient satisfying $0 < \hat{\delta} < 1$. Thus the marginal-utility gap, $\hat{\Omega}_t$, is a forward-looking moving average of the expected path of the short-term credit spread. Alternatively, we can view $\hat{\Omega}_t$ itself as a credit spread, a positive multiple of the spread between two long-term yields,

$$r_t^\tau \equiv \left(1-\hat{\delta}\right)^{-1} \sum_{j=0}^{\infty} \hat{\delta}^j E_t \hat{\imath}_{t+j}^\tau$$

for $\tau \in \{b,d\}$. Hence the terms in (3) involving $\hat{\Omega}_t$ indicate that variations in credit spreads are relevant to aggregate demand. Credit spreads are also relevant to the relation between the path of the policy rate[11] and aggregate expenditure because of the identity

$$(5)\quad \hat{\imath}_t^{avg} = \hat{\imath}_t^d + \pi_b \hat{\omega}_t$$

connecting the policy rate to the interest rate that appears in (3). Under an assumption of Calvo-style staggered price adjustment, we similarly obtain an aggregate supply relation that is only slightly different from the "NK Phillips curve" of the representative-household model. Specifically, we obtain

$$(6)\quad \pi_t = \kappa\left(\hat{Y}_t - \hat{Y}_t^n\right) + \beta E_t \pi_{t+1} + u_t + \kappa_\Omega \hat{\Omega}_t - \kappa_\Xi \hat{\Xi}_t,$$

where $\hat{Y}_t^n$ (the "natural rate of output") is a composite exogenous disturbance that depends on technology, preferences, and government purchases; u_t (the "cost-push shock") is another composite exogenous disturbance that depends on variations in distorting taxes and in the degree of market power in labor or product markets; and the coefficients satisfy κ, $\kappa_\Xi > 0$ and, in the case that we regard as realistic, $\kappa_\Omega > 0$ as well. Here the first three terms on the right-hand side are identical to those of the standard "NK Phillips curve," subject to similar comments as above about the dependence of κ on a weighted average of the intertemporal elasticities of substitution of the two types and the dependence of $\hat{Y}_t^n$ on a weighted average of the preference shocks of the two types; the final two terms appear only as a result of credit frictions. We note in particular that increases in credit spreads shift *both* the aggregate-supply and aggregate-demand relations in our model.

In the presence of heterogeneity, household behavior results in one further structural equation that has no analog in the representative-household model. This is a law of motion for b_t, the per capita level of private borrowing, which depends on the fluctuations in the levels of expenditure of the two types and, hence, on the fluctuations in both marginal utilities λ_t^τ. Details of this additional relationship are provided in Cúrdia and Woodford (2009a). We also suppose that the government issues one-period riskless nominal debt, the real value of which at the end of period t is denoted b_t^g. We treat $\{b_t^g\}$ as an exogenous process; this is one of three independent fiscal disturbances that we allow for.[12] We suppose that government debt can be held either by saving households or by the central bank,[13] and in equilibrium we suppose that at least part of the public debt is always held by households. Since government debt is a perfect substitute for deposits with the intermediaries in our model, from the standpoint of saving households, in equilibrium the yield on government debt must always equal i_t^d, the competitive interest rate on deposits.

[10] See, for example, the reference by Alan Greenspan (1997) to the U.S. economy in the early 1990s as "trying to advance in the face of fifty-mile-an-hour headwinds," owing to "severe credit constraint." The point of the metaphor was that under such conditions, a given reduction in the federal funds rate stimulated less expenditure than it ordinarily would have.

[11] The identification of i_t^d with the policy rate is discussed below in Section 1.3.

[12] The other two disturbances are exogenous variations in government purchases, G_t, of the composite good and exogenous variations in a proportional sales tax rate.

[13] We could also allow intermediaries to hold government debt, but they will choose not to as long as $i_t^b > i_t^d$, as is always true in the equilibria that we consider.

1.2 Financial Intermediaries

We assume an intermediary sector made up of identical, perfectly competitive firms. Intermediaries take deposits on which they promise to pay a riskless nominal return, i_t^d, one-period later, and make one-period loans on which they demand a nominal interest rate i_t^b. An intermediary also chooses a quantity of reserves, M_t, to hold at the central bank, on which it will receive a nominal interest yield i_t^m. Each intermediary takes as given all three of these interest rates. We assume that arbitrage by intermediaries need not eliminate the spread between i_t^b and i_t^d for either of two reasons: (i) Resources are used in the process of loan origination or (ii) intermediaries may be unable to tell the difference between good borrowers (who will repay their loans the next period) and bad borrowers (who will be able to disappear without having to pay) and as a consequence may have to charge a higher interest rate to good and bad borrowers alike.

We suppose that origination of good loans in real quantity L_t requires an intermediary to also originate bad loans in quantity $\chi_t(L_t)$, where χ_t', $\chi_t'' \geq 0$, and the function $\chi_t(L)$ may shift from period to period for exogenous reasons. (While the intermediary is assumed to be unable to discriminate between good and bad loans, it is able to predict the fraction of loans that will be bad in the case of any given scale of its lending activity.) This scale of operations also requires the intermediary to consume real resources $\Xi_t^p(L_t; m_t)$ in the period in which the loans are originated, where $m_t \equiv M_t/P_t$, and $\Xi_t^p(L;m)$ is a convex function of its two arguments, with $\Xi_{Lt}^p \geq 0$, $\Xi_{mt}^p \leq 0$, $\Xi_{Lmt}^p \leq 0$. We further suppose that for any scale of operations, L, there exists a finite *satiation level* of reserve balances, $\bar{m}_t(L)$, defined as the lowest value of m for which $\Xi_{mt}^p(L;m) = 0$. (Our convexity and sign assumptions then imply that $\Xi_{mt}^p(L;m) = 0$ for all $m > \bar{m}_t(L)$.) We assume the existence of a finite satiation level of reserves for an equilibrium to be possible in which the policy rate is driven to zero, a situation of considerable practical relevance at present.

Given an intermediary's choice of its scale of lending operations, L_t, and reserve balances, m_t, to hold, we assume that it acquires real deposits, d_t, in the maximum quantity that it can repay (with interest at the competitive rate) from the anticipated returns on its assets (taking into account the anticipated losses on bad loans). Thus it chooses d_t such that

$$\left(1+i_t^d\right)d_t = \left(1+i_t^b\right)L_t + \left(1+i_t^m\right)m_t.$$

The deposits that it does not use to finance either loans or the acquisition of reserve balances,

$$d_t - m_t - L_t - \chi_t\left(L_t\right) - \Xi_t^p\left(L_t; m_t\right),$$

are distributed as earnings to its shareholders. The intermediary chooses L_t and m_t each period to maximize these earnings, given i_t^d, i_t^b, i_t^m. This implies that L_t and m_t must satisfy the first-order conditions:

$$(7) \quad \Xi_{Lt}^p\left(L_t; m_t\right) + \chi_{Lt}\left(L_t\right) = \omega_t \equiv \frac{i_t^b - i_t^d}{1+i_t^d},$$

$$(8) \quad -\Xi_{mt}^p\left(L_t; m_t\right) = \delta_t^m \equiv \frac{i_t^d - i_t^m}{1+i_t^d}.$$

Equation (7) can be viewed as determining the equilibrium credit spread, ω_t, as a function $\omega_t(L_t; m_t)$ of the aggregate volume of private credit and the real supply of reserves.[14] As indicated above, a positive credit spread exists in equilibrium to the extent that $\Xi_t^p(L;m)$, $\chi_t(L)$, or both are increasing in L. Equation (8) similarly indicates how the equilibrium differential δ_t^m between the interest paid on deposits and that paid on reserves at the central bank is determined by the same two aggregate quantities.

In addition to these two equilibrium conditions that determine the two interest rate spreads in the model, the absolute level of (real) interest rates must be such that the supply and demand for credit are equal. Market clearing in the credit market requires that

$$(9) \quad b_t = L_t + L_t^{cb},$$

[14] Note that in terms of this definition of the credit spread, ω_t, the previously defined deviation corresponds to $\hat{\omega}_t \equiv \log(1 + \omega_t/1 + \bar{\omega})$.

where L_t^{cb} represents real lending to the private sector by the central bank, as discussed next.

1.3 The Central Bank and Interest Rate Determination

In our model, the central bank's liabilities consist of the reserves, M_t, (which also constitute the monetary base) on which it pays interest at the rate i_t^m. These liabilities in turn fund the central bank's holdings of government debt and any lending by the central bank to type *b* households. We let L_t^{cb} denote the real quantity of lending by the central bank to the private sector; the central bank's holdings of government debt are then given by the residual $m_t - L_t^{cb}$. We can treat m_t (or M_t) and L_t^{cb} as the bank's choice variables, subject to the following constraints:

(10) $0 \leq L_t^{cb} \leq m_t.$

It is also necessary that the central bank's choices of these two variables also satisfy the bound

$$m_t < L_t^{cb} + b_t^g,$$

where b_t^g is the total outstanding real public debt, so that a positive quantity of public debt remains in the portfolios of households. In the calculations below, however, we assume that this last constraint is never binding. (We confirm this in our numerical examples.)

We assume that central bank extension of credit other than through open-market purchases of Treasury securities consumes real resources, just as in the case of private intermediaries, and represent this resource cost by a function $\Xi^{cb}(L_t^{cb})$, discussed further in Section 4, which is increasing and at least weakly convex, with $\Xi^{cb\prime}(0) > 0$.

The central bank has one further independent choice to make each period, which is the rate of interest i_t^m to pay on reserves. We assume that if the central bank lends to the private sector, it simply chooses the amount that it is willing to lend and auctions these funds, so that in equilibrium it charges the same interest rate i_t^b on its lending that private intermediaries do; this is therefore not an additional choice variable for the central bank. Similarly, the central bank receives the market-determined yield i_t^d on its holdings of government debt.

The interest rate i_t^d at which intermediaries are able to fund themselves is determined each period by the joint inequalities

(11) $m_t \geq m_t^d\left(L_t, \delta_t^m\right),$

(12) $\delta_t^m \geq 0,$

together with the "complementary slackness" condition that at least one of these—(11) and/or (12)—must hold with equality each period; here $m_t^d(L,\delta^m)$ is the demand for reserves defined by (8), defined to equal the satiation level $\bar{m}_t(L)$ in the case that $\delta^m = 0$. (Condition (11) may hold only as an inequality, as intermediaries will be willing to hold reserves beyond the satiation level as long as the opportunity cost, δ_t^m, is zero.) We identify the rate i_t^d at which intermediaries fund themselves with the central bank's *policy rate* (e.g., the federal funds rate in the case of the United States).

The central bank can influence the policy rate through two channels: its control of the supply of reserves and its control of the interest rate paid on them. By varying m_t, the central bank can change the equilibrium differential, δ_t^m, determined as the solution to (11) and (12). And by varying i_t^m, it can change the level of the policy rate, i_t^d, that corresponds to a given differential. Through appropriate adjustment on both margins, the central bank can control i_t^d and i_t^m separately (subject to the constraint that i_t^m cannot exceed i_t^d). We also assume that for institutional reasons, it is not possible for the central bank to pay a negative interest rate on reserves. (We may suppose that intermediaries have the option of holding currency, earning zero interest, as a substitute for reserves, and that the second argument of the resource cost function, $\Xi_t^p(b;m)$, is actually the sum of reserve balances at the central bank plus vault cash.) Hence the central bank's choice of these variables is subject to the constraints

(13) $0 \leq i_t^m \leq i_t^d.$

In our model, there are thus three independent dimensions along which central bank policy can be varied: the quantity of reserves, M_t, that are supplied; the interest rate i_t^m paid on those reserves; and the breakdown of central bank assets between government debt and lending L_t^{cb} to the private sector. Alternatively, we can specify these three independent dimensions as (i) *interest rate policy*, the central bank's choice of an operating target for the policy rate, i_t^d; (ii) *reserve-supply policy*, the choice of M_t, which in turn implies a unique rate of interest i_t^m that must be paid on reserves for the reserve-supply policy to be consistent with the bank's target for the policy rate[15]; and (iii) *credit policy*, the central bank's choice of the quantity of funds L_t^{cb} to lend to the private sector. We prefer this last identification of the three dimensions of policy because in this case our first dimension (interest rate policy) corresponds to the sole dimension of policy emphasized in many conventional analyses of optimal monetary policy; the first two are additional dimensions of policy introduced by our extension of the basic NK model.[16] Changes in central bank policy along each of these dimensions has consequences for the bank's cash flow, but we abstract from any constraint on the joint choice of the three variables associated with cash-flow concerns. (We assume that seignorage revenues are simply turned over to the Treasury, where their only effect is to change the size of lump-sum transfers to the households.)

Given that central bank policy can be independently varied along each of these three dimensions, we can independently discuss the criteria for policy to be optimal along each dimension. Below, we take up each of the three dimensions in turn.

[15] We might choose to call the second dimension "variation in the interest rate paid on reserves," which would correspond to something that the Board of Governors makes an explicit decision about under current U.S. institutional arrangements, as is also true at most other central banks. But describing the second dimension of policy as "reserve-supply policy" allows us to address the question of the value of "quantitative easing" under this heading as well.

[16] Goodfriend (2009) similarly describes central bank policy as involving three independent dimensions. These correspond to our first three dimensions, but he calls the first dimension (the quantity of reserves, or base money) "monetary policy." We believe that this does not correspond to standard usage of the term "monetary policy," since the traditional focus of Federal Open Market Committee (FOMC) deliberations about monetary policy has been the choice of an operating target for the policy rate, as is generally the case for central banks. Reis (2009) also distinguishes among the three dimensions of policy in terms similar to ours.

1.4 The Welfare Objective

In considering optimal policy, we take the objective of policy to be the maximization of average expected utility. Thus we can express the objective as maximization of

$$(14)\quad E_{t_0}\sum_{t=t_0}^{\infty}\beta^{t-t_0}U_t,$$

where the welfare contribution, U_t, each period weights the period utility of each of the two types by their respective population fractions at each point in time. As shown in Cúrdia and Woodford (2009a),[17] this can be written as

$$(15)\quad U_t = U\left(Y_t, \Omega_t, \Xi_t, \Delta_t; \xi_t\right).$$

Here Δ_t is an index of price dispersion in period t, taking its minimum possible value of 1 when the prices of all goods are identical; for any given total quantity Y_t of the composite good that must be produced, the total disutility of working indicated in (1) is greater the more dispersed are prices, as this implies a correspondingly less uniform (and hence less efficient) composition of output.

The total disutility of working is also a decreasing function of Ω_t, since a larger gap between the marginal utilities of the two types implies a less-efficient division of labor effort between the two types. The average utility from consumption is smaller, for given aggregate output Y_t, the larger is Ξ_t, since only resources $Y_t - G_t - \Xi_t$ are consumed by households. And the average utility from consumption is also decreasing in Ω_t, since a larger marginal-utility gap implies a less-efficient division of expenditure between the two types. Thus the derived utility $U(\cdot)$ is a concave function of Y_t that reaches an interior maximum for given values of the other arguments, and a monotonically decreasing function of Ω_t, Ξ_t, and Δ_t. The

[17] Cúrdia and Woodford (2009a) analyze a special case of the present model in which central bank lending and the role of central bank liabilities in reducing the transactions costs of intermediaries are abstracted from. However, the form of the welfare measure (15) depends only on the nature of the heterogeneity in our model, and the assumed existence of a credit spread and of resources consumed by the intermediary sector; the functions that determine how Ω_t and Ξ_t are endogenously determined are irrelevant for this calculation, and those are the only parts of the model that are generalized in this paper. Hence the form of the welfare objective in terms of these variables remains the same.

dependence of $U(\cdot)$ on Y_t and Δ_t is the same as in the representative-household model of Benigno and Woodford (2005), while the dependence on Ω_t and Ξ_t indicates new distortions resulting from the credit frictions in our model.

As in Benigno and Woodford, the assumption of Calvo-style price adjustment implies that the index of price dispersion evolves according to a law of motion of the form

$$\Delta_t = h\left(\Delta_{t-1}, \pi_t\right),$$

where for a given value of Δ_{t-1}, $h(\Delta_{t-1},\cdot)$ has an interior minimum at an inflation rate that is near zero when Δ_{t-1} is near 1. Thus for given paths of the variables $\{\Omega_t, \Xi_t\}$ welfare is maximized by trying (to the extent possible) to simultaneously keep aggregate output near the (time-varying) level that maximizes U and inflation near the (always low) level that minimizes price dispersion. Hence our model continues to justify concerns about output and inflation stabilization common to the NK literature. However, it also implies that welfare can be increased by reducing credit spreads and the real resources consumed in financial intermediation. These latter concerns make the effects of policy on the evolution of aggregate credit and on the supply of bank reserves also relevant to monetary policy deliberations. We now turn to the question of how each of the three dimensions of central bank policy can effect these several objectives.

2. OPTIMAL POLICY: THE SUPPLY OF RESERVES

We shall first consider optimal policy with regard to the supply of reserves, taking as given (for now) the way in which the central bank chooses its operating target for the policy rate, i_t^d and the state-contingent level of central bank lending to the private sector, L_t^{cb}. Under fairly weak assumptions, we obtain a very simple result: *Optimal policy requires that intermediaries be satiated in reserves*, that is, that $M_t/P_t \geq \bar{m}_t(L_t)$ at all times.

For levels of reserves below the satiation point, an increase in the supply of reserves has two effects relevant for welfare: The resource cost of financial intermediation, Ξ_t^p, is reduced (for a given level of lending by the intermediary sector), and the credit spread, ω_t, is reduced (again, for a given level of lending) as a consequence of (7). Each of these effects raises the value of the objective in (14); note that the reductions in credit spreads increase welfare because of their effect on the path of the marginal-utility gap, Ω_t, as a consequence of (4). Hence an increase in the supply of reserves is unambiguously desirable in any period in which they remain below the satiation level.[18] Once reserves are at or above the satiation level, however, further increases reduce neither the resource costs of intermediaries nor equilibrium credit spreads (as in this case, $\Xi_{mt}^p = \Xi_{Lmt}^p = 0$), so there would be no further improvement in welfare. Hence policy is optimal along this dimension if and only if $M_t/P_t \geq \bar{m}_t(L_t)$ at all times,[19] so that

$$(16)\quad \Xi_{mt}^p\left(L_t; m_t\right) = 0.$$

This is just another example in which the familiar Friedman rule for "the optimum quantity of money" (Friedman, 1969) applies. Note, however, that our result has no consequences for interest rate policy. While the Friedman rule is sometimes taken to imply a strong result about the optimal control of short-term nominal interest rates—namely, that the nominal interest rate should equal zero at all times—the efficiency condition (16), together with the equilibrium relation (8), implies only that the interest rate *differential*, δ_t^m, should equal zero at all times. With zero interest on reserves, this would also require that $i_t^d = 0$ at all times; but given that the central bank is free to set any level of interest on reserves consistent with (13), the efficiency condition (16) actually implies *no* restriction on either the average level or the degree of state-contingency of the central bank's target for the policy rate, i_t^d.

[18] The discussion here assumes that the upper bound in (10) is not a binding constraint. But if that constraint does bind, then an increase in the supply of reserves relaxes the constraint, and this too increases welfare, so that the conclusion in the text is unchanged.

[19] To be more precise, policy is optimal if and only if (16) is satisfied *and* the upper bound in (10) does not bind. Both conditions will be satisfied by any quantity of reserves above some finite level.

2.1 Is a Reserve-Supply Target Needed?

Our result about the importance of ensuring an adequate supply of reserves might suggest that the question of the correct target level of reserves at each point in time should receive the same degree of attention at meetings of the FOMC as the question of the correct operating target for the federal funds rate. But deliberations of that kind are not needed to ensure fulfillment of the optimality criterion (16); the efficiency condition can alternatively be stated (using (8)) as requiring that $i_t^d = i_t^m$ at all times. Reserves should be supplied to the point at which the policy rate falls to the level of the interest rate paid on reserves, or, in a formulation that is more to the point, *interest should be paid on reserves at the central bank's target for the policy rate*.

Given a rule for setting an operating target for i_t^d (discussed in the next section), i_t^m should be chosen each period in accordance with the simple rule

(17) $i_t^m = i_t^d$.

When the central bank implements its target for the policy rate through open-market operations, it will automatically have to adjust the supply of reserves to satisfy (16). But this does not require a central bank's monetary policy committee (the FOMC in the case of the United States) to deliberate about an appropriate target for reserves at each meeting; once the target for the policy rate is chosen (and the interest rate to be paid on reserves is determined by that, through condition (17)), the quantity of reserves that must be supplied to implement the target can be determined by the bank staff in charge of carrying out the necessary interventions (the Trading Desk at the New York Fed in the case of the United States), on the basis of a more frequent monitoring of market conditions than is possible for the monetary policy committee.

One obvious way to ensure that the efficiency condition (17) is satisfied is to adopt a routine practice of automatically paying interest on reserves at a rate that is tied to the current operating target for the policy rate. This is already the practice of many central banks outside the United States. At some of those banks, the fixed spread between the target for the policy rate and the rate paid on overnight balances at the central bank is quite small: for example, 25 basis points in the case of the Bank of Canada; in the case of New Zealand, the interest rate paid on overnight balances is the policy rate itself. There are possible arguments (relating to considerations not reflected in our simple model) why the optimal spread might be larger than zero, but it is likely in any event to be desirable to maintain a constant small spread rather than treat the question of the interest rate to be paid on reserves as a separate, discretionary policy decision to be made at each policy committee meeting. Apart from the efficiency gains modeled here, such a system should also help to facilitate the central bank's control of the policy rate (Goodfriend, 2002, and Woodford, 2003, Chap. 1, Sec. 3).

2.2 Is There a Role for "Quantitative Easing"?

While our analysis implies that it is desirable to ensure that the supply of reserves never falls below a certain lower bound, $\bar{m}_t(L_t)$ it also implies that there is no benefit from supplying reserves *beyond* that level. There is, however, one important exception to this assertion: It can be desirable to supply reserves beyond the satiation level if this is necessary to make the optimal quantity of central bank lending to the private sector, L_t^{cb}, consistent with (10). This qualification is important when considering the desirability of the massive expansion in the supply of reserves by the Fed since September 2008, as shown in Figure 2. The increase in reserves (shown in Figure 4) occurred only after the Fed expanded the various newly created liquidity and credit facilities beyond the scale that could be financed simply by reducing its holdings of Treasury securities (as had been its policy over the previous year).[20]

Some have argued, instead, that further expansion of the supply of reserves beyond the level

[20] Bernanke (2009) distinguishes between the Federal Reserve policy of "credit easing" and the type of "quantitative easing" practiced by the Bank of Japan earlier in the decade, essentially on this ground.

needed to bring the policy rate down to the level of the rate of interest paid on reserves is an important additional policy tool in its own right—one of particular value precisely when a central bank is no longer able to further reduce its operating target for the policy rate, owing to the zero lower bound (as at present in the United States and many other countries). It is sometimes proposed that when the zero lower bound is reached, it is desirable for a central bank's policy committee to shift from deliberations, about an interest rate target to a target for the supply of bank reserves, as under the Bank of Japan's policy of "quantitative easing" during the period between March 2001 and March 2006.

Our model provides no support for the view that such a policy should be effective in stimulating aggregate demand. Indeed, it is possible to state an *irrelevance proposition* for quantitative easing in the context of our model. Let the three dimensions of central bank policy be described by functions that specify the operating target for the policy rate, the supply of reserves, the interest rate to be paid on reserves, and the quantity of central bank credit as functions of macroeconomic conditions. For the sake of concreteness, we may suppose that each of these variables is to be determined by a Taylor-type rule,

$$
\begin{aligned}
i_t^d &= \phi^{id}\left(\pi_t, Y_t, L_t; \xi_t\right), \\
M_t/P_t &= \phi^m\left(\pi_t, Y_t, L_t; \xi_t\right), \\
i_t^m &= \phi^{im}\left(\pi_t, Y_t, L_t; \xi_t\right), \\
L_t^{cb} &= \phi^L\left(\pi_t, Y_t, L_t; \xi_t\right),
\end{aligned}
$$

where the functions are such that constraints in (10) through (13) are satisfied for all values of the arguments. (Here the vector of exogenous disturbances, ξ_t, on which the reaction functions may depend, includes the exogenous factors that shift the function $\Xi_t^p(L;m)$.) Then our result is that, given the three functions $\phi^{id}(\cdot)$, $\phi^{im}(\cdot)$, and $\phi^L(\cdot)$, the set of processes $\{\pi_t, Y_t, L_t, b_t, i_t^d, i_t^b, \Omega_t, \Delta_t\}$ that constitute possible rational expectations equilibria is *the same* independent of the choice of the function $\phi^m(\cdot)$ as long as the specification of $\phi^m(\cdot)$ is consistent with the other three functions (in the sense that (10) and (11) are necessarily satisfied and that (11) holds with equality in all cases where (12) is a strict inequality).[21]

Of course, the stipulation that $\phi^m(\cdot)$ be consistent with the other functions uniquely determines what the function must be for all values of the arguments for which the functions $i^d(\cdot)$ and $i^m(\cdot)$ imply that $\delta_t^m > 0$. However, the class of policies considered allows for an arbitrary degree of expansion of reserves beyond the satiation level in the region where those functions imply that $\delta_t^m = 0$, and in particular, for an arbitrary degree of quantitative easing when the zero bound is reached (i.e., when $i_t^d = i_t^m = 0$). The class of policies considered includes the popular proposal under which the quantity of excess reserves should depend on the degree to which a standard Taylor rule (unconstrained by the zero bound) would call for a negative policy rate. Our result implies that there should be no benefits from such policies.

Our result might seem to be contradicted by the analysis of Auerbach and Obstfeld (2005), in which an open market operation that expands the money supply is found to stimulate real activity even when the economy is at the zero bound at the time of the monetary expansion. But their thought experiment does not correspond to pure quantitative easing of the kind contemplated in the above proposition—because they specify monetary policy in terms of a path for the money supply and the policy change that they consider is one that *permanently* increases the money supply, so that it remains higher after the economy has exited from the "liquidity trap" in which the zero bound is temporarily binding. The contemplated policy change is therefore *not* consistent with an unchanged reaction function $\phi^{id}(\cdot)$ for the policy rate, and the effects of the intervention can be understood to be the consequences of the commitment to a different future interest rate policy.

Our result implies only that quantitative easing should be irrelevant under two conditions: when (i) an increase in reserves finances an increase in central bank holdings of Treasury securities, rather than an increase in central bank

[21] This result generalizes the irrelevance result for quantitative easing in Eggertsson and Woodford (2003) to a model with heterogeneity and credit frictions.

lending to the private sector, and (ii) policy implies no change in the way that people should expect future interest rate policy to be conducted.

Our model *does* allow for real effects of an increase in central bank lending, L_t^{cb}, financed by an increase in the supply of reserves, if private-sector financial intermediation is inefficient[22]; but the real effects of the increased central bank lending in that case are the same whether the lending is financed by an increase in the supply of reserves or by a reduction in central bank holdings of Treasury securities. Our model also allows for real effects of an announcement that interest rate policy in the future will be different, as when a central bank commits itself not to return immediately to its usual Taylor rule as soon as the zero bound ceases to bind, but promises instead to maintain policy accommodation for some time after it would become possible to comply with the Taylor rule (as discussed in the next section). But such a promise (if credible and correctly understood by the private sector) should increase output and prevent deflation to the same extent even if it implies no change in policy during the period when the zero lower bound binds.

While our definition of quantitative easing may seem narrow, the policy of the Bank of Japan during the period 2001-06 fits our definition fairly closely. The Bank of Japan's policy involved the adoption of a series of progressively higher quantitative targets for the supply of reserves. The aim of the policy was understood to be to increase the monetary base, rather than to allow the Bank of Japan to acquire any particular type of assets. The assets purchased were almost entirely Japanese government bonds, since credit allocation to malfunctioning markets was not a goal. There was no suggestion that the targets of policy after the end of the zero-interest-rate period would be any different from before. There was no commitment to maintain the increased quantity of base money in circulation permanently; and, indeed, once it was judged time to end the zero-interest-rate policy, the supply of reserves was rapidly contracted again (Figure 6).

Our theory suggests that expansion of the supply of reserves under such circumstances should have little effect on aggregate demand, and this seems to have been the case. For example, as is also shown in Figure 6, despite an increase in the monetary base of 60 percent during the first two years of the quantitative easing policy, and an eventual increase of nearly 75 percent, nominal GDP never increased at all (relative to its March 2001 level) during the entire five years of the policy.[23]

3. OPTIMAL POLICY: INTEREST RATE POLICY

We turn now to a second dimension of policy, the approach taken by the central bank in determining its operating target for the policy rate (the federal funds rate in the case of the Federal Reserve). In this section, we take for granted that reserve-supply policy is being conducted in the way recommended in the previous section, that is, that the rate of interest on reserves will satisfy (17) at all times. In this case, we can replace the function $\Xi_t^p(L_t; m_t)$ with

$$\bar{\Xi}_t^p\left(L_t\right) \equiv \Xi_t^p\left(L_t; \bar{m}_t\left(L_t\right)\right)$$

and the function $\omega_t(L_t; m_t)$, defined by the left-hand side of (7), with

$$\bar{\omega}_t\left(L_t\right) \equiv \omega_t\left(L_t; \bar{m}_t\left(L_t\right)\right),$$

since there will be satiation in reserves at all times.[24] Using these functions to specify the

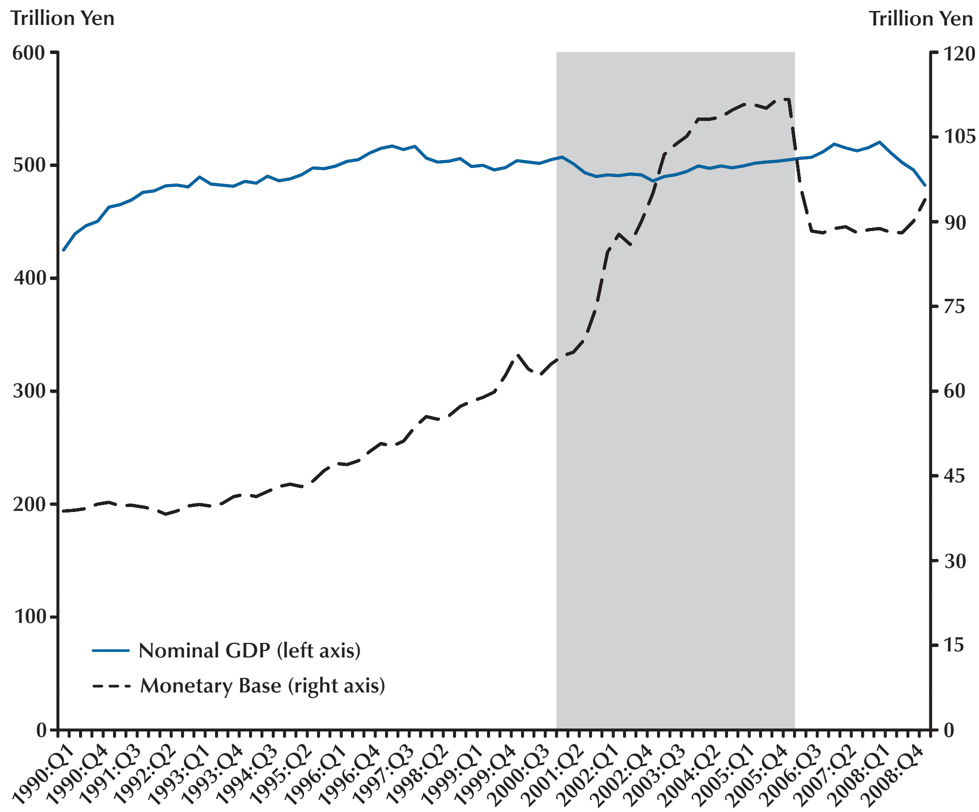
[22] This result differs from that obtained in Eggertsson and Woodford (2003), where changes in the composition of the assets on the central bank's balance sheet are *also* shown to be irrelevant. That stronger result depends on the assumption of a representative household (as in Eggertsson and Woodford) or, alternatively, frictionless financial intermediation.

[23] As indicated in Figure 6, over the first two years of the quantitative-easing policy, nominal GDP fell by more than 4 percent, despite extremely rapid growth of base money. While nominal GDP recovered thereafter, it remained below its 2001:Q1 level over the entire period until 2006:Q4, three quarters after the official end of quantitative easing, by which time the monetary base had been reduced again by more than 20 percent. Moreover, even if the growth of nominal GDP after 2003:Q1 is regarded as a delayed effect of the growth in the monetary base two years earlier, this delayed nominal GDP growth was quite modest relative to the size of the expansion in base money.

[24] Even if at some times m_t exceeds $\bar{m}_t(L_t)$, this will not affect the values of Ξ_t^p or ω_t.

Figure 6

The Monetary Base and Nominal GDP for Japan 1990-2009 (seasonally adjusted)



NOTE: The shaded region shows the period of "quantitative easing," from March 2001 through March 2006.
SOURCE: International Monetary Fund International Financial Statistics and Bank of Japan.

equilibrium evolution of Ξ_t^p and ω_t as functions of the evolution of aggregate private credit, we can then write the equilibrium conditions of the model without any reference to the quantity of reserves or to the interest rate paid on reserves. We shall also take as given the state-contingent evolution of central bank lending $\{L_t^{cb}\}$, and ask how the central bank's target for the policy rate should be adjusted in response to shocks to the economy. In this case the problem considered is of the form considered in Cúrdia and Woodford (2009a).

As in a representative-household model with no financial frictions, a consideration of optimal interest rate policy requires taking into account the desired evolution of aggregate output and of inflation (which affects the objective (14) because of the consequences of inflation for the evolution of the price dispersion index, Δ_t), given the trade-off between variations in these two variables implied by the aggregate-supply relation. While our model implies that, in the presence of credit frictions, interest rate policy also has consequences for the evolution of Ξ_t and Ω_t (which are also arguments of (15)), owing to its effects on the volume of lending by the intermediary sector, the most important effects are the effects on the paths of output and inflation. The way in which the paths of output and inflation matter for welfare are essentially the same as in a model without financial frictions, and the nature of the aggregate-supply tradeoff indicated by (6) remains the same as well, with credit frictions appearing mainly as a source of additional shift terms (like the "cost-push shocks" emphasized in treatments such as those of Clarida, Gali, and Gertler, 1999). Hence some of the important conclusions of the standard literature continue to apply, at least approximately, even in an environment where credit frictions are nontrivial and time varying.

3.1 The Robustness of Flexible Inflation (or Price-Level) Targeting

Benigno and Woodford (2005) show that in the representative-household version of our model, optimal interest rate policy can be characterized by the requirement that interest rates be adjusted so that a certain *target criterion* is satisfied each period.[25] To a log-linear approximation, the optimal target criterion can be expressed as

$$(18)\quad \pi_t + \phi\left(x_t - x_{t-1}\right) = 0,$$

regardless of the degree of steady-state distortions due to market power or distorting taxes, where $x_t \equiv \hat{Y}_t - \hat{Y}_t^*$, $\hat{Y}_t^*$ is a function of the exogenous disturbances to preferences, technology, fiscal policy, and markups,[26] and ϕ is a positive coefficient. This can be viewed as a form of "flexible inflation targeting" in the sense of Svensson (1997): The acceptable near-term inflation projection should be adjusted by an amount proportional to the projected change in the output gap. (Farther in the future, there will never be continuing forecastable changes in the output gap; so the criterion will always require that the projected path of inflation a few years in the future will equal an unchanging long-run target value, here equal to zero.)

[25] For further discussion of targeting regimes as an approach to the conduct of monetary policy, see Svensson (1997 and 2005), Svensson and Woodford (2005), or Woodford (2007).

[26] In the case that the steady-state level of output under flexible prices (or with zero inflation) is efficient, $\hat{Y}_t^*$ corresponds to variations in the efficient level of output. When the steady-state level of output under flexible prices is not efficient, the two concepts differ somewhat; for the more general definition of $\hat{Y}_t^*$, and discussion of its relation to the efficient level of output and to the flexible-price equilibrium level of output, see Woodford (2009, section 2).

The optimal target criterion in the representative-household model can alternatively be expressed in the form

$$(19)\quad \tilde{p}_t \equiv p_t + \phi x_t = p^*,$$

where p_t is the log of the general price index at time t. (Note that (18) simply states that the first difference of $\tilde{p}_t$ should be zero each period, so that $\tilde{p}_t$ must never be allowed to change.) This is an output gap–adjusted price-level target, or the commitment to a rule of the form in (19), which is an example of what Hall (1984) calls an "elastic price standard." If the target criterion can be fulfilled precisely each period, the two target criteria are equivalent; but if it is not always possible for the central bank to satisfy the target criterion (as when the zero lower bound is reached, discussed below), the two commitments are no longer equivalent. In this case, there are actually advantages to the price-level formulation, as we discuss below.

Cúrdia and Woodford (2009a) show that in a special limiting case, the target criterion (18) or alternatively, (19)—continues to be necessary and sufficient for the optimality of interest rate policy, even in the model with heterogeneity and credit frictions. This is the special case in which steady-state distortions (including the steady-state credit spread $\bar{\omega}$) are negligible, though we allow for shocks that temporarily increase credit spreads relative to the steady-state level. Real resources used in financial intermediation are negligible (so that the shocks that increase credit spreads are purely due to an increase in the perceived fraction of bad loans), and the time-varying fraction of bad loans is independent of intermediaries' scale of operations. In this case, there are no variations in Ξ_t and the fluctuations in Ω_t are essentially exogenous, so that the welfare-relevant effects of interest rate policy relate only to its effects on output and inflation, as in a model without credit frictions; and the additional terms in the aggregate-supply tradeoff (6) are purely exogenous disturbance terms, so that the derivation of the optimal target criterion proceeds as in the representative-household model.

More generally, the target criterion (18) will not correspond precisely to optimal policy; but our numerical investigations of calibrated models suggest that it can easily continue to provide a reasonably good approximation to the optimal Ramsey policy, making the prescription of "flexible inflation targeting" still a useful practical rule of thumb. Figures 7 through 10 illustrate this, for one illustrative calibration of our model, now allowing both Ξ_t^p and ω_t to vary endogenously with the volume of private lending.[27] Each figure plots the impulse responses (under a log-linear approximation to the model dynamics) of several of the endogenous variables to a particular type of exogenous disturbance, under each of four different possible specifications of monetary policy: (i) a simple "Taylor rule" using the coefficients proposed by Taylor (1993); (ii) a "strict inflation-targeting" regime, under which interest rate policy is used to ensure that inflation never deviates from its target level (zero) in response to any disturbance; (iii) a "flexible inflation-targeting" regime, under which interest rate policy ensures that (18) holds each period; and (iv) a fully optimal policy (the solution to the Ramsey policy problem).

In each of the cases shown (as well as for a large number of other types of disturbances that we have considered), the "flexible inflation-targeting" regime remains a good approximation to the fully optimal policy, even if it is no longer precisely the optimal policy. Both types of inflation-targeting regimes are closer to the optimal policy than is the Taylor rule, which mechanically responds to observed variations in real activity without taking account of the types of disturbances responsible for those variations.[28] (The Taylor rule tightens policy too much in response to increases in output resulting from productivity growth or increased government purchases, while it does not tighten enough in the case of the wage-markup shock, which causes output to fall even as inflation increases.) But especially in the case of the wage-markup shock and the shock to government purchases, the flexible inflation target provides a better approximation to optimal policy than would a strict inflation target.

The target criterion (18) continues to provide a good approximation to optimal policy in the case of a "purely financial" disturbance as well, even though such disturbances are not allowed for in the analysis of Benigno and Woodford (2005). Figure 10 shows the impulse responses to an exogenous increase in the function $\chi_t(L)$, corresponding to an increase in the fraction of loans expected to be bad loans, that then gradually shifts back to its steady-state value. Such a shock temporarily shifts up the value of $\bar{\omega}_t(L)$ for any value of L and so represents a contraction of the loan supply for reasons internal to the financial sector. In equilibrium, such a disturbance results both in a contraction of private lending (and hence in equilibrium borrowing b_t, as shown in the bottom-left panel) and in an increase in the equilibrium credit spread, ω_t (as shown in the middle-right panel). If the central bank follows the Taylor rule, such a shock results in both an output contraction and deflation, but an optimal policy would allow little of either to occur.[29] Again, the flexible

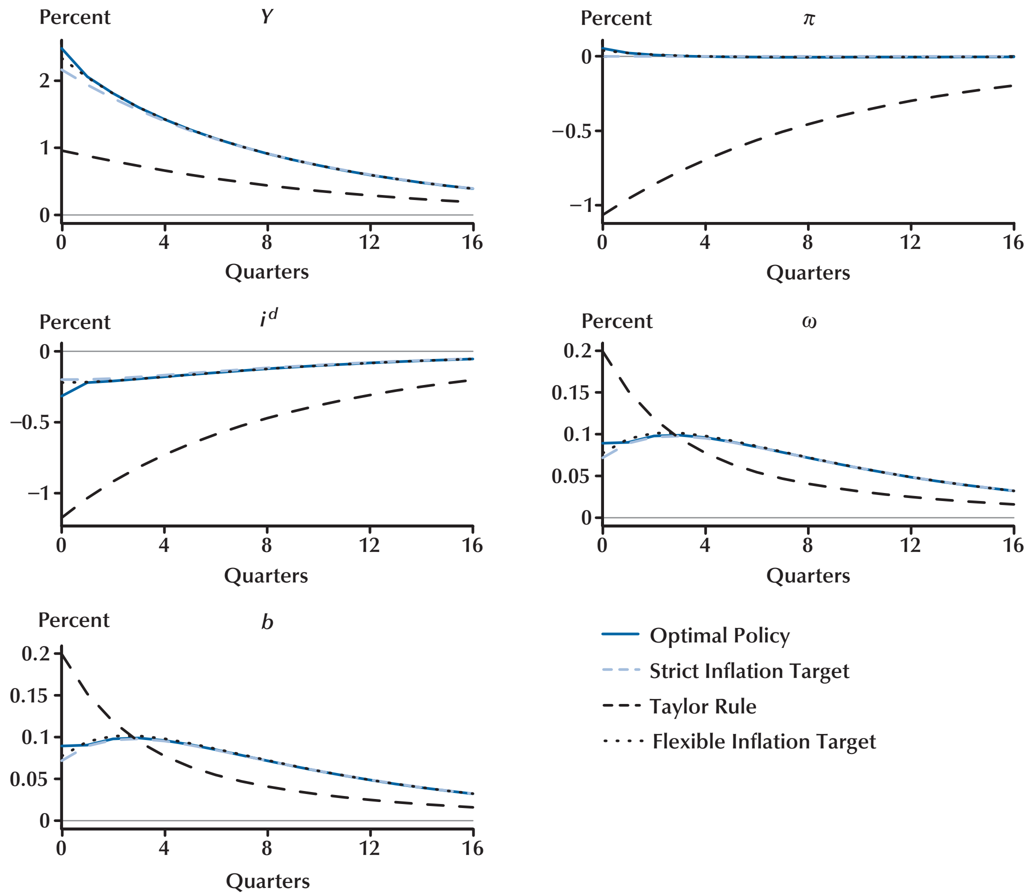
[27] The calibration is discussed further in Cúrdia and Woodford (2009a). The model parameters that are shared with the representative-household version of the model are calibrated as in Woodford (2003, Chap. 6), on the basis of the empirical estimates of Rotemberg and Woodford (1997). The degree of heterogeneity of the consumption preferences of the two types is as shown in Figure 5, while the disutility of labor is the same for the two types, except for a multiplicative factor chosen so that in steady state the two types work the same amount. The steady-state credit spread is calibrated to equal 2 percent per annum, as in Mehra, Piguillem, and Prescott (2008), and is attributed entirely to the marginal resource cost of private financial intermediation, to make the endogeneity of Ξ_t as great as possible given the average size of the spread. A highly convex function $\Xi^p(L)$ is also assumed in the numerical results presented here, to make the endogeneity of the credit spread as great as possible. If we assume a less convex function for $\Xi^p(L)$ or that a smaller fraction of the steady-state credit spread is due to real resource costs, then the special case in which equation (18) is optimal is an even better approximation than in the case shown in the figures.

[28] Here we assume a rule in which the intercept term representing the equilibrium real funds rate is a constant, and the output gap is defined as output relative to a deterministic trend, as in Taylor (1993). A more sophisticated variant, in which the intercept varies with variations in the "natural rate of interest," and the output gap is defined relative to variations in the "natural rate of output" (defined as in equation (6)), provides a better approximation to optimal policy, but still less close an approximation than that provided by the flexible inflation-targeting rule. The responses to exogenous disturbances under the more sophisticated form of Taylor rule are discussed in Cúrdia and Woodford (2009b).

[29] Interestingly, the optimal policy does not involve a much larger cut in the policy rate than occurs under the Taylor rule. The difference is that under the Taylor rule, the central bank is unwilling to cut the policy *except* to the extent that this can be justified by a fall in inflation or output, and so in equilibrium those must occur; under the optimal policy, the central bank is willing to cut the policy rate without requiring inflation or output to decline, and in equilibrium they do not.

Figure 7

Impulse Responses to a 1 Percent Increase in Total-Factor Productivity, Under Four Alternative Monetary Policies



SOURCE: Cúrdia and Woodford (2009a).

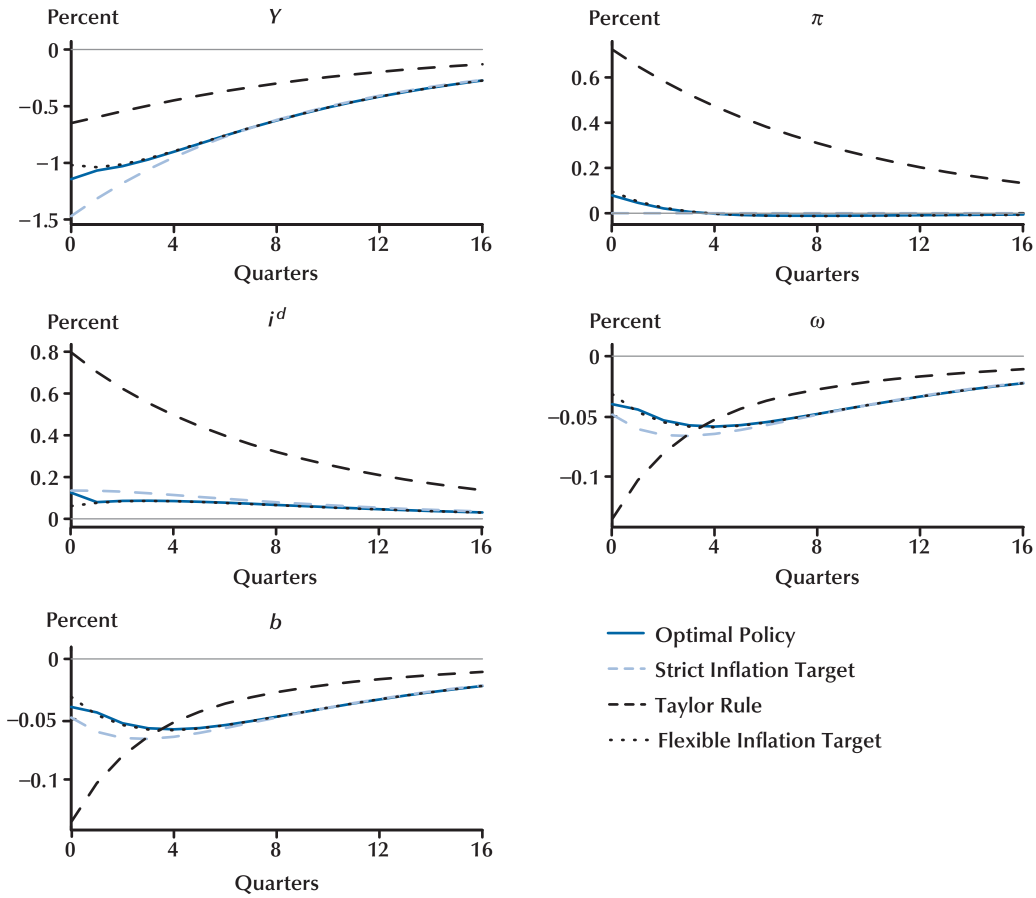
inflation-targeting regime provides a reasonable approximation to what would happen under an optimal policy commitment. (We obtain a very similar figure in the case in which the disturbance is instead an exogenous increase in the marginal resource cost of private financial intermediation.)

These results provide an answer to one of the questions posed in the introduction: Does keeping track of the projected paths of inflation and output alone provide a sufficient basis for judgments about whether monetary policy (by which interest rate policy is here intended) remains on track, even during times of financial turmoil? Our results suggest that, while the target criterion (18) involving only the projected paths of inflation and the output gap is not complex enough to constitute a fully optimal policy in our extended model, ensuring that (18) holds at all times would in fact ensure that policy is not too different from a fully optimal policy commitment—not only in an environment in which financial intermediation is imperfect, but even when the main disturbances to the economy originate in the financial sector and imply large increases in the size of credit spreads.

It is important to note, however, that our results do *not* imply that there is no need for a

Figure 8

Impulse Responses to a 1 Percent Increase in the Wage Markup, Under Four Alternative Monetary Policies



SOURCE: Cúrdia and Woodford (2009a).

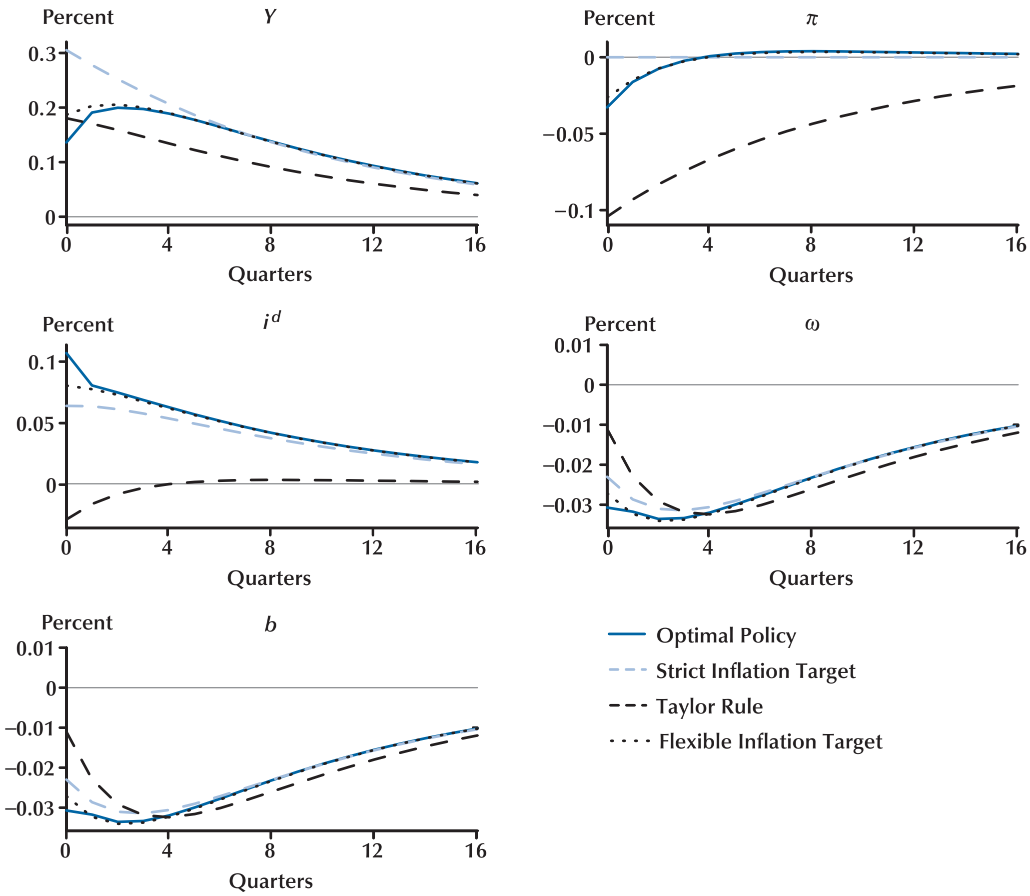
central bank to monitor or respond to financial conditions. Under the targeting regime recommended here, it is necessary to keep track of the various exogenous disturbances affecting the economy, to correctly forecast the evolution of inflation and output under alternative paths for the policy rate—and this includes keeping track of financial disturbances, when these are important. The simple Taylor rule, which does not require the central bank to use *information* about any variables other than inflation and real GDP, would *not* be an adequate guide to policy.

3.2 A Spread-Adjusted Taylor Rule?

Might a Taylor rule instead be a sufficient basis for setting interest rate policy if the standard Taylor rule is augmented, as proposed by Taylor (2008), by an adjustment for observed variations in a credit spread, such as one of the LIBOR-OIS spreads shown in Figure 1? For the kind of disturbance considered in Figure 10, this type of adjustment would allow the policy rate to be cut by more than a full percentage point even in the absence of any decline in inflation or output—which is exactly what is necessary to the allow

Figure 9

Impulse Responses to a 1 Percent Increase in G_t Equal to 1 Percent of Steady-State Output, Under Four Alternative Monetary Policies



SOURCE: Cúrdia and Woodford (2009a).

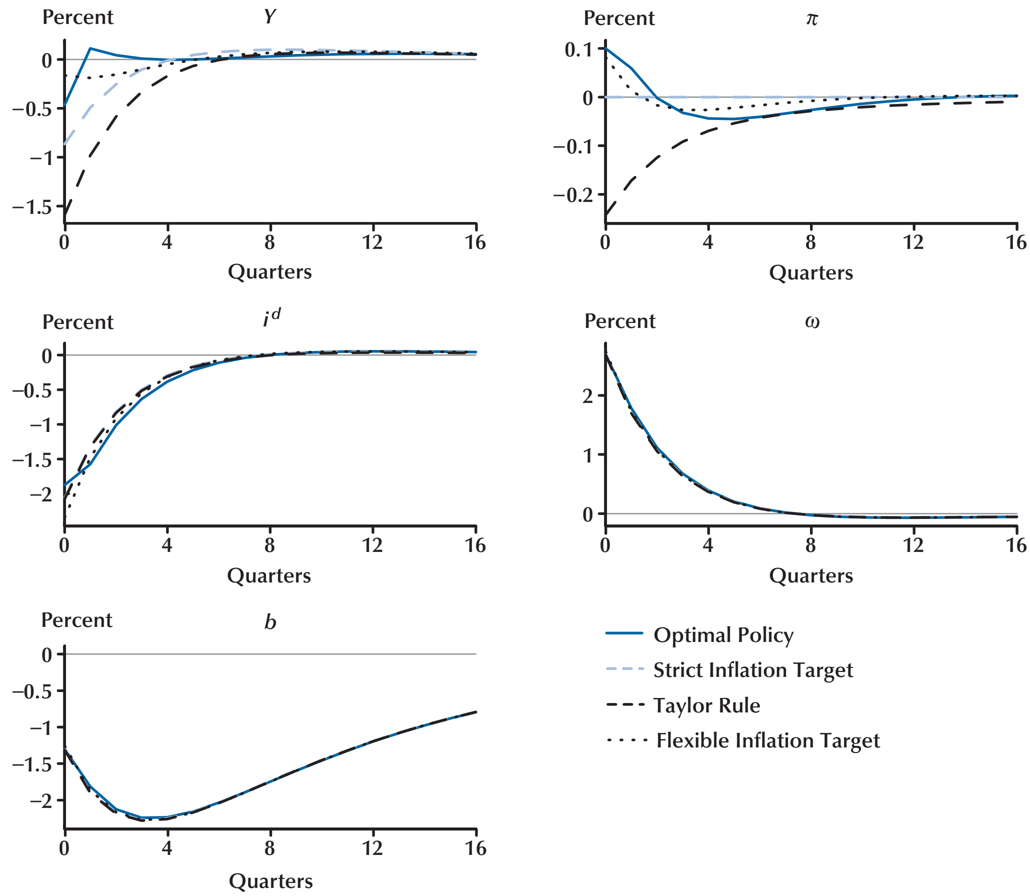
the kind of equilibrium responses associated with the optimal policy commitment.

Cúrdia and Woodford (2009b) consider modified Taylor rules of this kind in the context of the same calibrated structural model used in Figures 7 through 10. While they find that the type of spread adjustment proposed by Taylor (2008) would be beneficial under some circumstances—such as the type of disturbance considered in Figure 10—the desirable degree of adjustment (and even sometimes the sign of the adjustment) of the policy rate in response to a change in credit spreads is not independent of the nature of the disturbance that causes spreads to change. Even in the case of "purely financial" disturbances, like the kind considered in Figure 10, the optimal degree of response to changes in the credit spread depends on the degree of anticipated persistence of the disturbance.

In fact, the targeting regime that we propose above automatically involves a spread adjustment of the general type proposed by Taylor (2008). Given that a change in the credit spread (and in the anticipated future path of credit spreads, which determines the marginal-utility gap, Ω_t, because of (4)) affects aggregate demand for any

Figure 10

Impulse Responses to a Shift in the Function $\chi_t(L)$ that Triples the Size of $\bar{\omega}_t(L)$ for Each Value of L, Under Four Alternative Monetary Policies



SOURCE: Cúrdia and Woodford (2009a).

given anticipated path of the policy rate—both because of the difference between i_t^{avg} and the policy rate indicated in (5) and because of the $\hat{\Omega}_t$ terms in (3)—the consequences of a given path of the policy rate for the inflation and output projections will be different when the path of credit spreads changes, and so the path for the policy rate required to produce projections that conform to the target criterion will be different. Since larger credit spreads (now and in the future) reduce aggregate demand leading to lower inflation, the policy rate will generally need to be reduced to offset this effect.

Moreover, we believe that the targeting approach represents a conceptually superior way of introducing these considerations into decisions about interest rate policy. The Taylor (2008) proposal requires that one specify which particular measure of credit spreads will be taken into account in the modified reaction function. (Taylor has proposed one very specific spread—the LIBOR-OIS spread.) But in fact central banks monitor many different credit spreads; and while in our highly stylized model there is only a single credit spread, a more empirically realistic model would have to include several (as indeed the

FRB/U.S. model already does). Under our proposed targeting regime, *each* of these would be relevant to setting interest rate policy: Variations in each of the different spreads would be taken into account to the extent that they enter the equations of the model used to project the paths of inflation and output. Furthermore, under the targeting approach, the adjustment of the policy rate would not have to be a mechanical (and purely contemporaneous) function of the change in the credit spread; instead, one would automatically respond differently depending on the nature of the disturbance and would respond also to changes in the expected future path of spreads as well as to the current spread.

3.3 Policy When the Zero Lower Bound Is Reached

In the discussion above (and in the simulations in Figures 7 through 10), it is assumed that the zero lower bound on the policy rate is never reached, and our theoretical model implies that it should not be reached, in the case of *small enough* shocks. But it is theoretically possible for it to bind in the case of large-enough shocks of certain types, and recent events in the United States and elsewhere have shown that one cannot presume that the constraint will never bind in practice. (As a practical matter, it seems that it is most likely to bind following severe disruptions of the financial sector, as in the case of the Great Depression, in Japan during the 1990s, and at present.)

When the zero bound is a binding constraint, it may not be possible for the central bank to use interest rate policy to ensure fulfillment of the target criterion (19) in all periods. Does this affect the validity of our recommendation of this policy? Although it may not be possible to fulfill the target criterion at all times, that does not in itself imply that it is not desirable to adjust interest rate policy to fulfill the criterion when it *can* be satisfied. Also, nothing here implies that, when policymakers deliberate interest rate policy, they should forgo the question of whether there exists an interest rate path that would satisfy the target criterion.

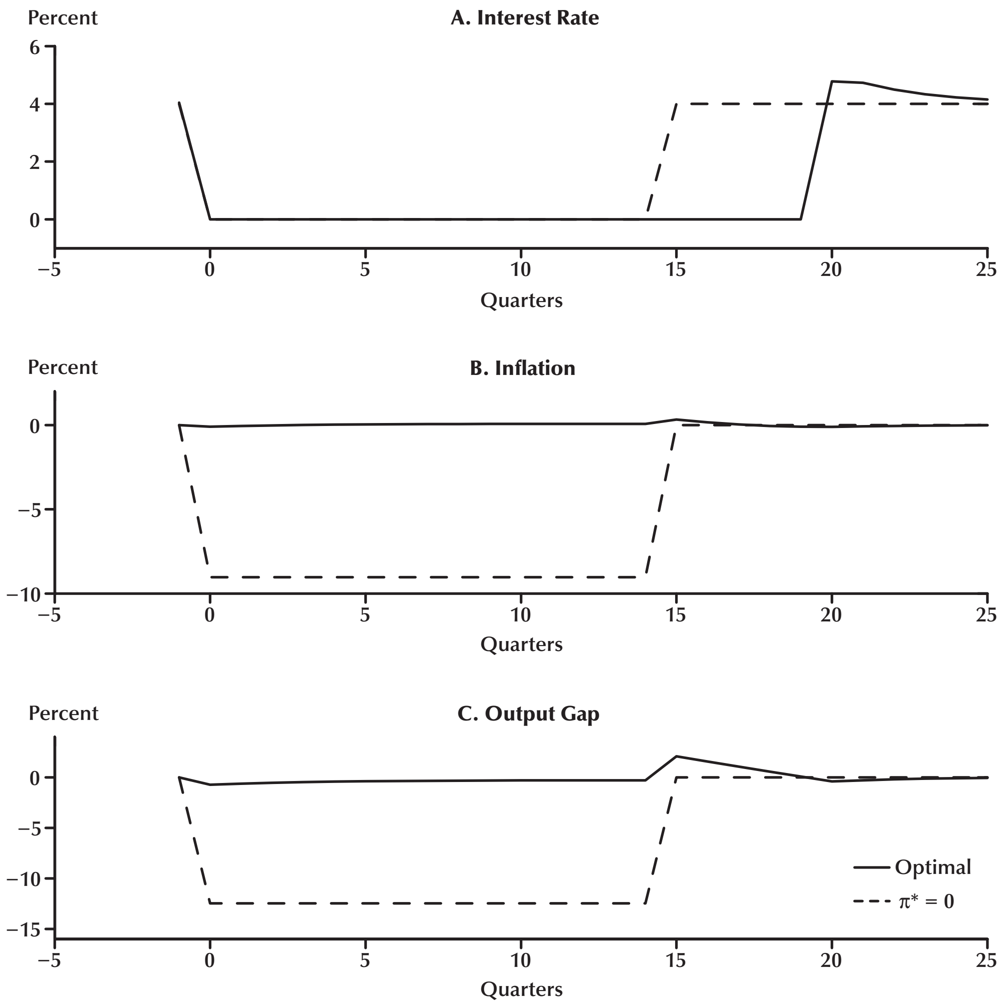
But the fact that the lower bound is sometimes a binding constraint also has consequences for the appropriate policy target even under certain circumstances when the zero lower bound would *not* prevent one from achieving the target criterion (18). The reason is that the severity of the distortions during the period when the lower bound is binding should depend on the way in which policy is expected to be conducted *after* the constraint ceases to bind. Hence, the policy that a central bank should commit to follow in such a period should be chosen with a view to the consequences of the anticipation of that policy during the period when the zero bound binds.

Eggertsson and Woodford (2003) analyze this issue in a model that is equivalent to a special case of the model considered here. Let us again consider the special case (mentioned in Section 3.1) in which there are no steady-state distortions, no resources are used in financial intermediation, and the fraction of bad loans is independent of the scale of lending. Because in this case both the credit spread and the marginal-utility gap evolve exogenously, a second-order Taylor series approximation to the objective function (14), expanding around the optimal (zero-inflation) steady state, is exactly the same quadratic function of inflation and the output gap as in the case of a representative-household model (the case considered by Eggertsson and Woodford). The "intertemporal IS relation" (3) and the aggregate-supply relation (6) are also identical to those of the representative-household model, except for the presence of additional additive disturbance terms involving $\hat{\omega}_t$ and $\hat{\Omega}_t$.

The optimal policy problem—which can be stated as the choice of processes for inflation, output, and the policy rate consistent with (3), (6), and (13) each period to maximize the welfare measure written in terms of output and inflation—is of the same form as the one analyzed by Eggertsson and Woodford (2003), except with additional possible interpretations of the exogenous disturbance terms. In particular, the extension of the model to incorporate credit frictions provides a more empirically realistic interpretation of the disturbance hypothesized by Eggertsson and Woodford (2003), which makes the real policy

Figure 11

Equilibrium Responses of the Policy Rate, Inflation, and the Output Gap, Under Two Alternative Monetary Policies



NOTE: The figure represents equilibrium responses when the expected probability of loan default exogenously increases beginning in quarter zero and ending in quarter 15.

SOURCE: Eggertsson and Woodford (2003).

rate needed to maintain a constant zero output gap temporarily negative. Rather than postulate a sudden, temporary disappearance of real spending opportunities or a temporary reduction in the rate of time preference, we can instead attribute the situation to a temporary increase in credit spreads as a result of disruption of the financial sector.

Eggertsson and Woodford (2003) show that it can be a serious mistake for a central bank to be expected to return immediately to the pursuit of its normal policy target as soon as the zero bound no longer prevents it from hitting that target. For example, Figure 11 (reproduced from their paper) compares the dynamic paths of the policy rate, the inflation rate, and aggregate output under two alternative monetary policies in the case of a real disturbance (here interpreted as an exogenous increase in the probability that loans are bad, requiring intermediaries to increase the credit spread by several percentage points) that begins in period zero and lasts for 15 quarters, before real fundamentals permanently return to their original ("normal") state.

In this case, if the financial disturbance were never to occur, optimal policy would involve maintaining a zero inflation rate, as this would also imply a zero output gap in every period. After the disturbance dissipates, one of the feasible policies is an immediate return to this zero-inflation steady state (under the parameterization assumed in the figure, this involves a nominal interest rate of 4 percent), and this is optimal from the point of view of welfare in all periods after the financial disturbance dissipates. It is not, however, possible to maintain the zero-inflation steady state at all times, because during the financial disturbance this would require the policy rate to equal –2 percent, which would violate the zero lower bound.

One of the policies considered in Figure 10 (dashed lines) is strict (forward-looking) inflation targeting: The central bank uses interest rate policy to maintain a zero inflation rate whenever it is not prevented by the zero lower bound on the policy rate. When undershooting the inflation target cannot be avoided, the policy rate is maintained at the lower bound. The other policy (solid lines) is the optimal Ramsey policy, when the zero lower bound is included among the constraints on the set of possible equilibria. The forward-looking inflation-targeting policy is clearly much worse, as it involves both a much more severe output contraction and much more severe deflation during the period when the zero bound constrains policy.

The problem with the forward-looking inflation-targeting policy is that because the central bank simply targets zero inflation from the time that it again becomes possible to do so, all of the deflation that occurs while the zero bound binds is fully accommodated by the subsequent policy: The central bank continues to maintain the price level at whatever level it has fallen to. This results in expected deflation during the entire period of the financial disturbance, for deflation will continue as long as the financial disruption continues, while no inflation will be allowed even if the disturbance dissipates; this expected deflation makes the zero bound on nominal interest rates a higher lower bound on the *real* policy rate, making the contraction and deflation worse, giving people reason to expect more deflation as long as the disruption continues, and so on in a vicious circle.

The outcome would be even worse if the central bank were to seek to achieve the target criterion (18) each period as soon as it becomes possible to do so. This is because, once credit spreads contract again, this policy would require the central bank to target *negative* inflation and/or a negative output gap (even though zero inflation and a zero output gap would now be achievable), simply because there had been a large negative output gap in the recent past (when the zero bound was a binding constraint); but the expectation of such policy would make the output contraction while the zero bound constrained policy even more severe (justifying even tighter policy immediately following the "exit" from the "liquidity trap," and so on).

Under the optimal policy, there is instead a commitment to maintain accommodative conditions for a brief interval, even though the reduction in credit spreads means that this level for the policy rate is now expansionary, leading to a mild boom and temporary inflation above the long-run target level (of zero). The expectation that this will occur during the "exit" from the trap results in much less contraction of economic activity and much less deflation, because it makes the perceived real rate of interest lower at all times while the policy rate is at zero (given that there is in each period some probability that credit spreads will shrink again in the next period, allowing mild inflation to occur). This expectation results in less deflation and higher real activity while the lower bound binds; and the expectation that continuation of the financial stress will have less drastic consequences is itself a substantial factor in making those consequences much less drastic—in a "virtuous circle" that exactly reverses the logic of our analysis above.

While our analysis implies that it is desirable for people to be able to expect that the "exit" from the trap will involve mild inflation, it does *not* follow that the possibility of occasionally hitting the zero lower bound on the policy rate is a reason to aim for a substantial positive rate of inflation at all times (as proposed by Summers, 1991) simply to ensure that a zero nominal interest rate will always mean a sufficiently negative value of the real policy rate. To the extent that a history-dependent inflation target of the kind called for in Eggertsson and Woodford (2003) can be made credible and understood by the public, it suffices that the central bank be committed to bringing about a *temporarily* higher rate of inflation only on the particular occasions when the zero lower bound has bound in the recent past, and not all of the time.[30]

This analysis implies that a commitment to maintain policy accommodation can play an important role in mitigating the effects of the zero lower bound on interest rates. One might reasonably ask for what length of time it is sensible to commit to keep rates low, and in particular whether it is really prudent to make any lengthy commitment when it is hard for a central bank to be certain that recovery may not come much sooner than anticipated. The answer is that the best way to formulate such a commitment is not in terms of a *period of time* that can be identified with certainty in advance, but rather in terms of *targets that must be met* for the removal of policy accommodation to be appropriate.

In fact, Eggertsson and Woodford (2003) show that in the representative-household model (and hence similarly in the special case described above), optimal policy can be precisely described, regardless of the nature of the exogenous disturbances,[31] by a target criterion involving only the path of the output gap–adjusted price level defined in (18). Under the optimal rule, the central bank has a target each period for $\tilde{p}_t$ that depends only on the economy's history through period t–1 and must use interest rate policy to achieve the target, if this is possible without violation of the zero lower bound; if the target is undershot even with a zero policy rate, the policy rate is at any rate reduced to zero—and the target for $\tilde{p}_{t-1}$ is increased in proportion to the degree of undershooting. In periods when the zero bound does not bind, the target for the gap-adjusted price level is not adjusted, and the target criterion is the same as the one discussed in Section 3.1.

Actually, the adjustments of the target are not of great importance, even when the zero bound does bind: Eggertsson and Woodford (2003) show that almost all of the improvement in stabilization achievable under the optimal policy commitment can be obtained by simply committing to a target criterion of the form in (19) with a constant target p^*. The crucial feature of the optimal policy is that the target for $\tilde{p}_t$ must not be allowed to *fall* as a result of having undershot the target in past periods. Hence one of the approximate characterizations of optimal policy proposed in Section 3.1 continues to provide a good approximation to optimal policy even when the zero lower bound sometimes binds: It is simply important that the commitment be to the *level* form of the target criterion (19) rather than to the *growth rate* form (18).

4. OPTIMAL POLICY: CREDIT POLICY

We turn now to the final of our three independent dimensions of central bank policy, namely, adjustment of the composition of the asset side of the central bank's balance sheet, taking as given the overall size of the balance sheet (deter-

[30] Eggertsson and Woodford (2003) compare the welfare levels associated with alternative constant inflation targets and find that the existence of an occasionally binding zero lower bound does indeed make the optimal inflation target higher than it would otherwise be, if one must choose from among this very restrictive class of policies. But they show that even the best policy in that class involves much larger average distortions than a price-level targeting policy, even though a price-level targeting policy implies a long-run average inflation rate of zero.

[31] Their analysis allows for both exogenous variations in the "natural rate of interest" (which means an additive exogenous term in the intertemporal IS relation) and in the "cost-push" term (which means an additive exogenous term in the Phillips-curve tradeoff), evolving according to arbitrary stochastic processes. Since the effects of the financial frictions in (3) and (6) are to add additional terms involving $\hat{\Omega}_t$ that can be viewed as a combination of these two types of shifts, the optimal target criterion derived by Eggertsson and Woodford (2003) continues to apply—under the special assumptions stated above—even in the presence of time-varying credit frictions.

mined by the reserve-supply decision discussed in Section 2). According to the traditional doctrine of "Treasuries only," the central bank should *not* vary the composition of its balance sheet as a policy tool. Instead, it should avoid both balance-sheet risk and the danger of politicization by holding only (essentially riskless) Treasury securities at all times, while varying the size of its balance sheet to achieve its stabilization goals for the aggregate economy.[32]

Apart from these prudential concerns, if private financial markets can be relied on to allocate capital efficiently, it is hard to argue that there would be any substantial value to allowing the central bank this additional dimension of policy. Eggertsson and Woodford (2003) present a formal irrelevance proposition in the context of a representative-household general-equilibrium model. In their model, the assets purchased by the central bank have no consequences for the equilibrium evolution of output, inflation, or asset prices—and this is true regardless of whether the central bank purchases long-term or short-term assets, nominal or real assets, riskless or risky assets, and so on. In addition, even in a model with heterogeneity of the kind considered here, the composition of the central bank's balance sheet would be irrelevant if we were to assume frictionless private financial intermediation, since private intermediaries would be willing to adjust their portfolios to perfectly offset any changes in the portfolio of the central bank.

This irrelevance result does not hold, however, in the presence of credit frictions of the kind assumed in Section 1; so we can also consider the optimal use of this additional dimension of policy if we are willing to suppose that the prudential arguments against the central bank's involvement in the allocation of credit should not be determinative, at least in the case of sufficiently severe financial disruptions. In our model, an increase in L_t^{cb} can improve welfare on two grounds: For a given volume of private borrowing, b_t an increase in L_t^{cb} allows the volume of private lending, L_t, to fall, which should reduce both the resources Ξ_t^p consumed by the intermediary sector and the equilibrium credit spread, ω_t (due to equilibrium (7)). Under plausible conditions, our model implies both a positive shadow value $\varphi_{\Xi,t}$ of reductions in Ξ_t (the Lagrange multiplier associated with the resource constraint (2)) and a positive shadow value $\varphi_{\omega,t}$ of reductions in ω_t (the Lagrange multiplier associated with the constraint (4)); hence an increase in L_t^{cb} should be desirable on both grounds.

In the absence of any assumed cost of central bank credit policy, one can easily obtain the result that it is always optimal for the central bank to lend an amount sufficient to allow an equilibrium with $L_t = 0$; that is, the central bank should substitute for private credit markets altogether. Of course, we do not regard this as a realistic conclusion. As a simple way of introducing into our calculations the fact that the central bank is unlikely to have a comparative advantage at the activity of credit allocation under normal circumstances, we assume that central bank lending consumes real resources in a quantity $\Xi^{cb}(L_t^{cb})$, by analogy with our assumption that real resources, Ξ_t^p, are consumed by private intermediaries. The function $\Xi^{cb}(L)$ is assumed to be increasing and at least weakly convex; in particular, we assume that $\Xi^{cb\prime}(0) > 0$ so that there is a positive marginal resource cost of this activity, even when the central bank starts from a balance sheet made up entirely of Treasury securities.

4.1 When Is Active Credit Policy Justified?

The first-order conditions for optimal choice of L_t^{cb} then become

$$\text{(20)}\quad \begin{aligned}&\varphi_{\Xi,t}\left[\Xi_t^{p\prime}\left(b_t - L_t^{cb}\right) - \Xi^{cb\prime}\left(L_t^{cb}\right)\right]\\ &+\varphi_{\omega,t}\left[\Xi_t^{p\prime\prime}\left(b_t - L_t^{cb}\right) + \chi_t^{\prime\prime}\left(b_t - L_t^{cb}\right)\right] \le 0,\end{aligned}$$

$$\text{(21)}\quad L_t^{cb} \ge 0,$$

together with the complementary slackness condition that at least one of conditions (20) or (21) must hold with equality in each period. (Here, the first expression in square brackets in (20) is the partial derivative of Ξ_t with respect to L_t^{cb}, hold-

[32] See Goodfriend (2009) for a discussion of this view and a warning about the dangers of departing from it.

ing constant the value of total borrowing, b_t; the second expression in square brackets is the partial derivative of ω_t with respect to L_t^{cb} under the same assumption.)

A "Treasuries only" policy is optimal in the event of a corner solution, in which (20) is an inequality, as will be the case if $\Xi^{cb\prime}(0)$ is large enough. In our view, it is probably most reasonable to calibrate the model so that this is true in steady state. Then not only will the optimal policy involve "Treasuries only" in the steady state, but (assuming that the inequality is strict at the steady state) this will continue to be true in the case of any stochastic disturbances that are small enough. However, it will remain possible for the optimal policy to require $L_t^{cb} > 0$ in the case of certain large-enough disturbances. This is especially likely to be true in the case of large-enough disruptions of the financial sector of a type that increase the marginal resource cost of private intermediation (the value of $\bar{\Xi}^{p\prime}$) and/or the degree to which increases in private credit require a larger credit spread (the value of $\bar{\varpi}'$).

However, not all "purely financial" disturbances—by which we mean exogenous shifts in the functions $\bar{\Xi}_t^p(L)$ or $\chi_t(L)$ of a type that increase the equilibrium credit spread $\bar{\varpi}_t(L)$ for a given volume of private credit—are equally likely to justify an active central bank credit policy on the grounds just mentioned.[33] To illustrate this, let us consider four different possible purely financial disturbances, each of which will be assumed to increase the value of $\bar{\varpi}_t(\bar{L})$ by the same number of percentage points. Here, by an *additive* shock, we mean one that translates the schedule $\bar{\varpi}_t(L)$ vertically by a constant amount; a *multiplicative* shock will instead multiply the entire schedule $\bar{\varpi}_t(L)$ by some constant factor greater than 1. We shall also distinguish between disturbances that change the function $\bar{\Xi}_t(L)$ ("Ξ shocks") and disturbances that change the function $\chi_t(L)$ ("χ shocks"). Thus a "multiplicative χ shock" is a change in the function $\chi_t(L)$; as a consequence, of which the schedule $\bar{\varpi}_t(L)$ is multiplied by a factor greater than 1 for all values of L, and so on.

With the model calibrated as in the numerical exercises in Figures 7 through 10, Figure 12 plots the dynamic response of the sum of the three positive terms on the left-hand side of (20) to each of these four types of purely financial disturbances. In these simulations, both interest rate policy and reserve-supply policy are assumed to be optimal, as discussed in Sections 2 and 3. We assume in each case that there is no central bank lending to the private sector in the equilibrium being computed, but we ask (in the equilibrium computed under this assumption) what the *smallest* value of $\Xi^{cb\prime}(0)$ is at each point in time, for which this would be consistent with the first-order condition (21). (Thus an increase in the quantity plotted means that the marginal benefit of central bank credit policy is increased, even if in our calculations no central bank lending actually occurs.) We divide the sum of the three terms by the value of $\varphi_{\Xi,t}$, so that the quantity plotted is precisely the threshold value of $\Xi^{cb\prime}(0)$, expressed in terms of an interest rate spread. (Since it is an interest rate spread, we multiply by 4 so that the quantity on the vertical axis of the figure is in units of percentage points per annum.) In the figure, each of the four disturbances is of a size that increases the value of $\bar{\varpi}_t(\bar{L})$ by 4 percentage points per annum (i.e., from 2.0 percent to 6.0 percent).

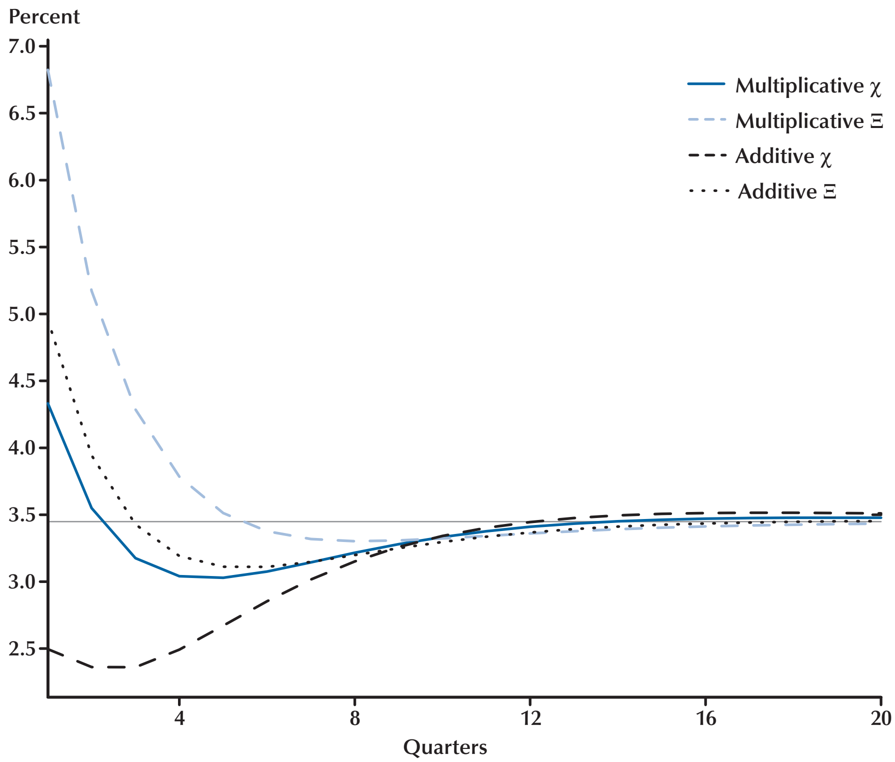
In the absence of any disturbances, the steady-state value of this quantity is a little less than 3.5 percentage points per annum. This means that a marginal resource cost of central bank loan origination of 3.5 percent or higher will suffice to justify our proposal above—that in the steady state the optimal quantity of central bank credit is zero.[34] Let us suppose that $\Xi^{cb\prime}(0)$ is equal to 4.0 percent. Then in the absence of shocks, a corner solution with Treasuries only is optimal. However, either a "multiplicative Ξ shock" or an "additive Ξ shock" of the size assumed would

[33] Our result here is quite different from that in Section 3, where the consequence of a "purely financial" disturbance for optimal interest rate policy, taking as given the path of central bank lending to the private sector, depends (to a first approximation) only on the size of the shift in $\bar{\varpi}_t(\bar{L})$, which is why we do not bother to show the optimal responses to more than one type of purely financial disturbance.

[34] Note that this quantity is well above the marginal resource cost of private lending in the steady state, which we have calibrated at 2.0 percent per annum because our baseline calibration implies a relatively inelastic private supply of credit: $\bar{\varpi}_t(L)$ is steeply increasing with L.

Figure 12

Response of the Critical Threshold Value of $\Xi^{cb\prime}(0)$ for a Corner Solution, Under Four "Purely Financial" Disturbances



NOTE: For each disturbance, $\varpi_t(\bar{L})$ increases by 4 percentage points.

cause condition (21) to be violated in the case of a corner solution; hence optimal policy would require a positive quantity of central bank lending. (In the case of the "multiplicative Ξ shock," this would be true even if $\Xi^{cb\prime}(0)$ were equal to 5.0 percentage points.)

On the other hand, even in the case of the "multiplicative Ξ shock," the threshold required to justify a corner solution is only above 4 percent in the quarter of the shock and the quarter immediately following it—despite the fact that in our numerical experiment the disturbance is assumed to have an autocorrelation coefficient of 0.9, so that the shift in the $\varpi_t(L)$ schedule is still 65 percent of its initial magnitude a year later. This suggests that, even in the case of those disturbances for which the welfare benefits of central bank credit policy are greatest, departure from the corner solution is likely to be justified only for a relatively brief period of time.

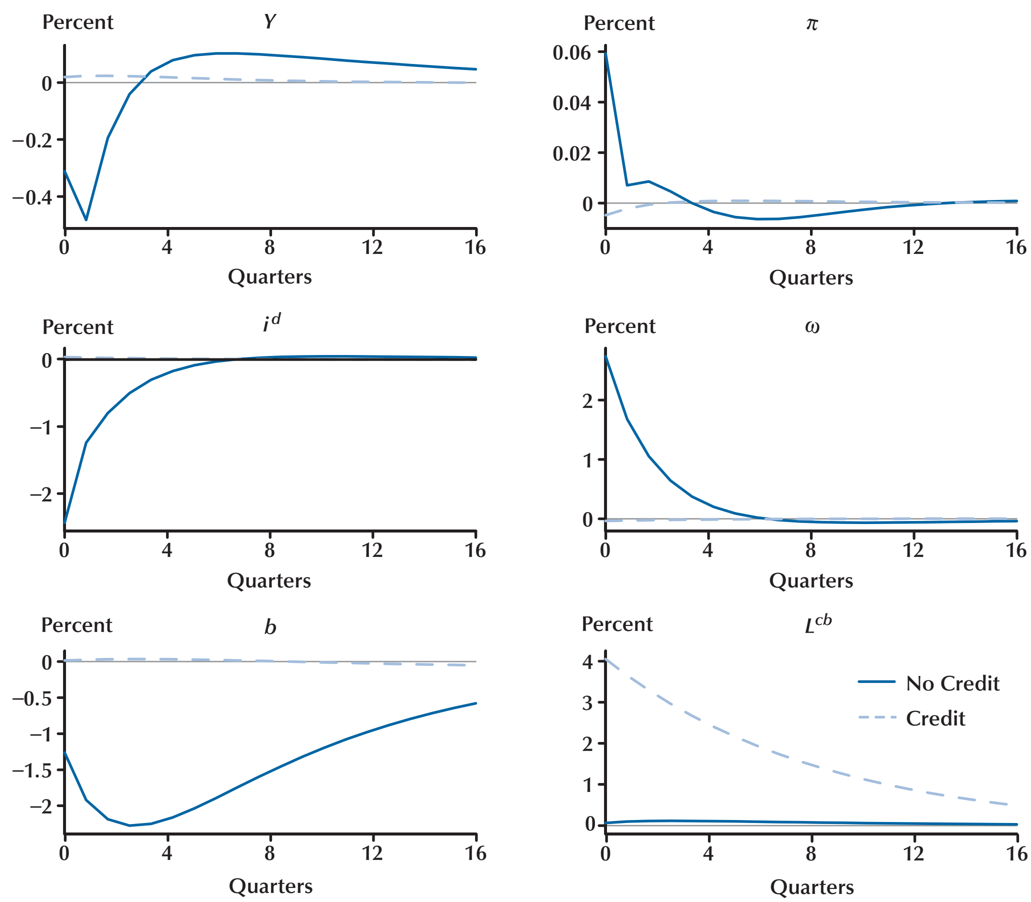
4.2 An Example with Active Credit Policy

As an example of how optimal credit policy can, under some circumstances, substantially alter the economy's response to a financial disruption, Figure 13 considers the optimal response to a "multiplicative Ξ shock," under a calibration in which $\Xi^{cb\prime}(0)$ is assumed to be low enough so that even in the steady state a corner solution is not optimal.[35] (While this is not the case that we regard as most realistic, it simplifies the calcula-

[35] This alternative calibration is chosen to imply that in the steady state, only 5 percent of total credit, b_t, is supplied by the central bank.

Figure 13

Impulse Responses to a Shift in $\Xi_t(L)$ that Triples the Size of $\bar{\omega}_t(L)$ for Each Value of L, Under Optimal Interest Rate Policy and Two Alternative Assumptions About Credit Policy



tions reported in Figure 13, since it implies that constraint (21) never binds. We leave for future work analysis of the more interesting case, in which (21) binds in some periods and not in others.) The figure plots the impulse responses under two alternative assumptions about policy: With credit, central bank policy is optimal along all three dimensions (and L_t^{cb} varies over time); with no credit, L_t^{cb} is constrained to equal the steady-state value $\bar{L}^{cb}$ at all times,[36] while interest-rate policy and reserve-supply policy are optimal.

[36] We impose the constraint that L_t^{cb} must equal $\bar{L}^{cb}$, rather than zero, in the no-credit case, so that the steady state is the same under both policies.

In addition to the responses of the five variables plotted in Figures 7 through 10, Figure 13 also plots the response of an additional variable, $\hat{L}_t^{cb}$, indicating the deviation of central bank credit from its steady-state value, expressed as a fraction of total steady-state credit, $\bar{b}$ (in percentage points).

Under an optimal use of credit policy, central bank lending to the private-sector increases substantially in response to the financial disturbance (central bank lending increases from 5 percent of total credit to a little over 9 percent). As a result, the large increase in the credit spread that would otherwise occur as a result of the shock is essentially prevented from occurring (so that the credit spread remains close to its steady-state level of 2.0 percent per annum). As a further consequence, it is not necessary under this policy to cut the policy rate sharply, as would otherwise be required by an optimal interest rate policy. The substantial contraction of credit that would otherwise occur (an eventual contraction of aggregate credit by more than 2 percent a year after the shock) is largely avoided, and the modest effects on output and inflation that would occur even under an optimal interest rate policy in the absence of an active credit policy are also largely avoided.

This example indicates that, under at least some circumstances, our model would support a fairly aggressive use of active credit policy for stabilization purposes. We must caution, however, that these results are quite dependent upon assumptions about the nature of the financial disturbance. It is equally possible to conclude that central bank credit should be *contracted* (assuming that it would be positive to begin with) in response to a disturbance that increases credit spreads. If the only form of purely financial disturbance is an "additive χ disturbance," and we assume that $\Xi^{cb}(L^{cb})$ is a linear function, then none of the functions $\bar{\Xi}^{p\prime}(L)$, $\bar{\Xi}^{p\prime\prime}(L)$, or $\chi'(L)$ is time varying and $\Xi^{cb\prime}$ is a constant. In this case, the requirement that (20) hold with equality determines the volume of private credit, L_t, as a time-invariant function of $\varphi_{\omega,t}/\varphi_{\Xi,t}$. In the case of a disturbance that increases the credit spread, the resulting decline in credit demand, b_t, means that, for credit supply L_t to be stabilized, L_t^{cb} would have to contract; so unless $\varphi_{\omega,t}/\varphi_{\Xi,t}$ changes to such an extent that the value of L_t consistent with (20) falls as much as b_t does,[37] it is optimal for L_t^{cb} to contract (as Figure 12 would also suggest). In a case of this kind, active credit policy would actually cause credit to contract by more (and credit spreads to increase by more) than they would if the supply of central bank credit did not respond to the shock.

[37] Our numerical experiments indicate that this can easily fail to be the case.

4.3 Segmented Credit Markets

In the simple model expounded above, there is a single credit market and single borrowing rate, i_t^b, charged for loans in this market. Our discussion of central bank credit policy has correspondingly simply referred to the optimal quantity of central bank lending to the private sector overall, as if the allocation of this credit is not an issue. In reality, of course, there are many distinct credit markets and many different parties to which the central bank might consider lending. Moreover, since there is only a potential case to be made for central bank credit policy when private financial markets are severely impaired, it does not make sense to assume efficient allocation of credit among different classes of borrowers by the private sector, so that only the total credit extended by the central bank would matter. Our simple discussion here has sought merely to clarify the connection that exists, in principle, between decisions about credit policy and the other dimensions of credit policy. An analysis of credit policy that could actually be used as a basis for credit policy decisions would instead need to allow for multiple credit markets, with imperfect arbitrage between them.

We do not here attempt an extension of our model in that direction. (A simple extension would be to allow for multiple types of "type *b*" households, each only able to borrow in a particular market with its own borrowing rate and market-specific frictions for the intermediaries lending in each of these markets.) We shall simply note that in such an extension there would be a distinct first-order condition, analogous to conditions (20) and (21), for each of the segmented credit markets. There would be no reason to assume that the question of whether active credit policy is justified should have a single answer at a given point in time: Lending might be justified in one or two specific markets while the corner solution remained optimal in the other markets.

The conditions that should be appealed to in order to justify central bank lending are more microeconomic than macroeconomic: They relate to the severity of the distortions that have arisen in particular markets and to the costs of intervention in those particular markets, rather than to aggregate conditions. Thus the main determinants of whether central bank credit policy is justified—when it is justifiable to initiate active policy and when it would be correct to phase out such programs—should not be questions such as whether the zero lower bound on interest rate policy binds or whether the central bank continues to undershoot the level of real GDP that it would like to attain. While aggregate conditions will be one factor that affects the shadow value of marginal reductions in the size of credit spreads (represented by the multiplier $\varphi_{\omega,t}$ in (20)), the value of this multiplier will likely be different for different markets and the main determinants of variations in it are likely to be market specific. This will apply even more to the other variables that enter into the first-order condition (20).

Hence it would be a mistake to think of credit policy as a substitute for interest rate policy, an alternative tool that can be used to achieve the same goals and that should be used to achieve the central bank's target criterion for inflation and the output gap when interest rate policy alone is unable to. Such a concept would be dangerous for two reasons. On the one hand, it would direct attention away from the most relevant costs and benefits when thinking about the appropriate scale, timing, and allocation of active credit policy. And on the other hand, it could also allow the central bank to avoid recognition of the extent to which the correct target criterion for interest rate policy needs to be modified as a result of the zero lower bound—in particular, to avoid the challenge of shaping expectations about interest rate policy after the lower bound ceases to bind, on the ground that credit policy (or "quantitative easing") should allow the bank's usual target criterion to be achieved continuously, without any need for signaling about unconventional future interest rate policy as compensation for past target misses.

CONCLUSIONS

We have shown that a canonical New Keynesian model of the monetary transmission mechanism can be extended in a fairly simple way to allow analysis of additional dimensions of central bank policy that have been at center stage during the recent global financial crisis—variations in the size and composition of the central bank balance sheet and in the interest rate paid on reserves—alongside the traditional monetary policy issue of the choice of an operating target for the federal funds rate (or some similar overnight inter-bank rate elsewhere). We have also considered the consequences for monetary policy analysis both of nonzero credit spreads all of the time and of financial disruptions that greatly increase the size of those spreads for a period of time; we have also considered the consequences of the fact the zero lower bound for short-term nominal interest rates is sometimes a binding constraint on interest rate policy.

One of our most important conclusions is that these issues can be addressed in a framework that represents a straightforward extension of the kind of model often used for monetary policy analysis in the past. This allows both the considerations emphasized in the traditional literature and the more novel considerations brought to the fore by recent events to be taken into account, within a single coherent framework. This integration is particularly important, in our view, for clear thinking about the way in which the transition from the current emergency policy regime to a more customary policy framework should be handled as financial conditions normalize. Because of the importance of expectations regarding future policy in determining market outcomes now, we believe that clarity about "exit strategy" is important for the success of policy even during periods of severe disruption of financial markets.

Another important implication of our model is that interest rate policy should continue to be a central focus of monetary policy deliberations, despite the existence of the other dimensions of policy discussed here, and despite the existence of time-varying credit frictions that complicate the relationship between the central bank's policy rate and financial conditions more broadly. While welfare can also be affected by reserve-supply policy, we argue that this dimension of policy should be determined by a simple principle that does not require any discretionary adjustments in light of changing economic conditions: Intermediaries should be satiated in reserves at all times, by maintaining an interest rate on reserves at or close to the current target for the policy rate.

And while welfare can similarly be affected by central bank credit policy, to the extent that nontrivial credit frictions exist, we nonetheless believe that under normal circumstances a corner solution ("Treasuries only") is likely to represent the optimal composition of the central bank balance sheet. Decisions about active credit policy then will be necessary only under relatively unusual circumstances, and it will be desirable to phase out special credit programs relatively rapidly after the disturbances that have justified their introduction. We thus do not anticipate that it should be necessary to routinely make state-contingent adjustments of central bank policy along multiple dimensions, even if recent events suggest that it is desirable for central banks to have the power to act along additional dimensions under sufficiently exigent circumstances.

Finally, our results suggest that the traditional emphasis in interest rate policy deliberations on the consequences of monetary policy for the projected evolution of inflation and aggregate real activity is not mistaken, even taking into account the consequences for the monetary transmission mechanism of time-varying credit frictions. At least in the context of the simple model of credit frictions proposed here, optimal interest rate policy can be characterized to a reasonable degree of approximation by a target criterion that involves the paths of inflation and of an appropriately defined output gap, but no other endogenous target variables. This does not mean that central banks should remain indifferent toward changes in financial conditions; to the contrary, credit spreads (and perhaps other measures of financial market distortions as well) should be closely monitored and taken into account in judging the forward path of interest rate policy necessary for conformity with the target criterion. However, financial variables need not be taken themselves as *targets* of monetary policy.

The main respect in which the appropriate target criterion for interest rate policy should be modified to take account of the possibility of financial disruptions is by aiming at a target path for the price level (ideally, for an output gap–adjusted price level), rather than for a target rate of inflation looking forward, as a forward-looking inflation target accommodates a permanent decline in the price level after a period of one-sided target misses due to a binding zero lower bound on interest rates. Our analysis implies that a credible commitment to the right kind of "exit strategy" should substantially improve the ability of monetary policy to deal with the unusual challenges posed by a binding zero lower bound during a deep financial crisis; and, to the extent that this is true, the development of an integrated framework for policy deliberations, suitable both for crisis periods and for more normal times, is a matter of considerable urgency for the world's central banks.

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New Monetarist Economics: Methods

Stephen Williamson and Randall Wright

This essay articulates the principles and practices of New Monetarism, the authors' label for a recent body of work on money, banking, payments, and asset markets. They first discuss methodological issues distinguishing their approach from others: New Monetarism has something in common with Old Monetarism, but there are also important differences; it has little in common with Keynesianism. They describe the principles of these schools and contrast them with their approach. To show how it works in practice, they build a benchmark New Monetarist model and use it to study several issues, including the cost of inflation, liquidity, and asset trading. They also develop a new model of banking. (JEL E0, E1, E4, E5)

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1. INTRODUCTION

The purpose of this essay is to articulate the principles and practices of a school of thought we call *New Monetarist Economics*. It is a companion piece to Williamson and Wright (forthcoming), which provides more of a survey of the models used in this literature and focuses on technical issues to the neglect of methodology or history of thought. Although we do present some technical material in order to show how the approach works in practice, here we also want to discuss in more detail what we think defines New Monetarism.[1] Although there is by now a large body of research in the area, perhaps our labeling of it merits explanation. We call ourselves New Monetarists because we find much that is appealing in Old Monetarist economics, epitomized by the writings of Milton Friedman and his followers, although we also disagree with some of their ideas in important ways. We have little in common with Old or New Keynesians, in part because of the way they approach monetary economics and the microfoundations of macroeconomics and in part because of their nearly exclusive focus on nominal rigidities as the key distortion shaping policy. Below we describe in more detail what we see as the defining principles of these various schools and try to differentiate our approach.

[1] The other paper is forthcoming as a chapter for the new *Handbook of Monetary Economics*, edited by Benjamin Friedman and Michael Woodford, and early versions included much of the discussion contained here. But to keep the chapter focused, on the advice of the editors, we separated the material into two papers. There is unavoidably some overlap in the presentations, since the same benchmark model is developed in both, but the applications are different, and there remains almost no discussion of how our approach compares to alternative schools of thought in the *Handbook* chapter. In this essay, we try explain what we think our methods are, not just how our models work.

Stephen Williamson is a professor of economics at Washington University in St. Louis, a visiting scholar at the Federal Reserve Bank of Richmond, and a research fellow at the Federal Reserve Bank of St. Louis. Randall Wright is a professor of economics at the University of Wisconsin–Madison, and a research associate at the Federal Reserve Bank of Minneapolis. The authors thank many friends and colleagues for useful discussions and comments, including Neil Wallace, Fernando Alvarez, Robert Lucas, Guillaume Rocheteau, and Lucy Liu. They thank the National Science Foundation for financial support. Wright also thanks for support the Ray Zemon Chair in Liquid Assets at the Wisconsin Business School.

One reason to do so is the following: We think that it was a healthy state of affairs when, even in the halcyon days of Old Keynesianism, there was a dissenting view presented by Old Monetarists. At the very least, this dissenting view could be interpreted as a voice of caution to those who thought that macro and monetary economics back in the day were solved problems—which obviously looks premature with the benefit of hindsight.[2] The claim that people thought the problems were solved is well documented by the sentiments of Solow as quoted by Leijonhufvud (1968), when he said,

> I think that most economists would feel that short-run macroeconomic theory is pretty well in hand...The basic outlines of the dominant theory have not changed in years. All that is left is the trivial job of filling in the empty boxes, and that will not take more than 50 years of concentrated effort at a maximum.

At least prior to recent events, many people seemed to be of the opinion that there was a New Keynesian consensus, similarly sanguine as in the 1960s. We feel that it would be healthier if currently more people recognized that there is an alternative to New Keynesianism. We dub our alternative New Monetarism.

Evidence that people have an impression of consensus, at least among more policy-oriented economists, about the idea that New Keynesianism is the most useful approach to analyzing macroeconomic phenomena and guiding central bank policy can be found in many places (see, e.g., Goodfriend, 2007). We find this somewhat surprising, mainly because we encounter much sympathy for the view that there are fundamental flaws in the New Keynesian framework. It must then be the case that those of us who think New Keynesianism is not the only game in town, or who think that the approach has some deep issues that need to be discussed, are not speaking with enough force and clarity. In part, this essay is an attempt to rectify this state of affairs and foster more healthy debate. The interaction we envision between New Monetarists and New Keynesians is in some ways similar to the debates in the 1960s and 1970s, but it is in other ways different, of course, since much of the method and language has changed in economics since then. To bring the dialog to the twenty-first century, we need to describe what New Monetarists are doing and why we are doing it.

New Monetarism encompasses a body of research on monetary theory and policy, banking, financial intermediation, payments, and asset markets, developed over the past few decades. In monetary economics, this includes the seminal work using overlapping generations models by Lucas (1972) and some of the contributors to the Kareken and Wallace (1980) volume, although antecedents exist, including, of course, Samuelson (1958). More recently, much monetary theory has adopted the search and matching approach, an early example of which is Kiyotaki and Wright (1989), although there are also antecedents for this, including Jones (1976) and Diamond (1984). In the economics of banking, intermediation, and payments, which builds on advances in information theory that occurred mainly in the 1970s, we have in mind papers such as Diamond and Dybvig (1983), Diamond (1984), Williamson (1986 and 1987a), Bernanke and Gertler (1989), and Freeman (1996). On asset markets and finance we have in mind recent work such as Duffie, Gârleanu, and Pederson (2005) or Lagos and Rocheteau (2009). Much of this research is abstract and theoretical, but attention has turned more recently to empirical and policy issues.[3]

To explain what unifies this work, we begin in Section 1 by saying what New Monetarism is *not*, describing what we see as the defining characteristics of other schools. Then we lay out a set of principles that guide our approach. By way of preview, we think New Monetarists agree more or less with the following:

Principle 1. Microfoundations matter, and productive analyses of macro and monetary economics,

[2] Rather than go through the details, we refer to Lucas (1980a) for a discussion of how the paradigm of the 1960s was disrupted by the confluence of events and technical developments in the 1970s, leading to the rise of the rational expectations, or New Classical, approach to macroeconomics.

[3] The examples cited here are meant only to give a broad impression of the kind of research we have in mind. More examples and references are found below.

including policy discussions, require adherence to sound and internally consistent economic theory.

Principle 2. Money matters, and in the quest to understand monetary phenomena and monetary policy, it is decidedly better to use models that are explicit about the frictions that give rise to a role for money in the first place; as Wallace (1998) puts it, *money should not be a primitive in monetary economics*.

Principle 3. Financial intermediation matters—e.g., while bank liabilities and currency sometimes perform similar roles as media of exchange, for many issues treating them as identical can lead one astray.

Principle 4. In modeling frictions, like those that give rise to a role for money or financial intermediaries, one has to have an eye for the appropriate level of abstraction and tractability—e.g., the fact that in some overlapping generations models people live two periods, or that in some search models people meet purely at random, may make them unrealistic but it does not make them irrelevant.

Principle 5. No single model should be an all-purpose vehicle for dealing with every question in monetary economics, but it is still desirable to have a framework, or a class of models making use of similar assumptions and technical devices, that can be applied to a variety of issues.

That these principles are not all universally accepted is to us only too clear. Consider Principle 2 (money matters). This is violated by the many currently popular models used for monetary policy analysis that either have no money—or banks or related institutions—or, if they do, they slip it in by assuming cash-in-advance constraints or by putting money in utility or production functions or even putting government bonds and commercial bank reserves in utility or production functions.[4] Also, while some of these principles may be accepted in principle by most economists, it is a matter of degree. Consider Principle 4 (appropriate abstraction). We all learn, or at least teach, that useful economic models are not necessarily realistic, but one still hears rather harsh critiques of both overlapping generations and search models of money based primarily on their lack of realism.[5] Also, we don't want Principle 1 (microfoundations matter) to sound like a platitude, even if everyone, of course, wants sound and consistent economic theory—or at least they pay lip service to this—as we believe New Monetarists take it more seriously. Not to pick too much on any one example, for now, but consider the so-called fiscal theory of the price level. New Keynesians seem to find this quite interesting despite the fact that it typically relies on descriptions of what happens out of equilibrium, in models that have nothing to say except about what happens in equilibrium. This is something that would bother a New Monetarist a lot.[6]

A more obvious illustration of New Monetarists worrying relatively more about the soundness and consistency of economic theories may be the reliance of the entire Keynesian edifice on a foundation of sticky prices, which are not what we would call microfounded, even when—especially when—appeal is made to Calvo (1983) pricing or Mankiw (1985) menu costs. This may not be the place to go too far into a discussion of the merits or demerits of imposing nominal rigidities, and given the readiness of many economists to adopt stickiness with neither trepidation nor apology, we can't imagine changing anyone's mind easily. But in Williamson and Wright (forthcoming) we offer as food for thought two New Monetarist models that speak to the issue. In one, we blatantly impose price stickiness to yield a version of our framework that looks in many ways like what one sees in Woodford (2003) or Clarida, Gali, and Gertler (1999). This is intended to show that, even if one cannot live without nominal

[4] See Krishnamurthy and Vissing-Jorgensen (2009) and Curdia and Woodford (2009) for recent examples of T-Bills or bank reserves showing up in utility or production functions. We are not here arguing that taking such shortcuts isn't time-honored (see Tobin 1958) or that it is never useful. The claim is that this is not what a New Monetarist would do on a good day.

[5] See Tobin (1980) and Howitt (2005) for negative takes on overlapping generations and search models, based on the unrealistic assumptions of two-period–lived agents and random matching, respectively.

[6] Bassetto (2002) is a notable exception because he does not use classical equilibrium theory to discuss what happens out of equilibrium.

rigidity, this does not mean one cannot be serious about money, banking, and related institutions. The other model uses search theory to get nominal rigidities to emerge endogenously, as an outcome rather than an assumption. This model is consistent not just with the broad observation that many prices appear to be sticky, but also the detailed micro evidence discussed by Klenow and Malin (forthcoming) and references therein. Yet it delivers policy prescriptions very different from those of New Keynesians: Money is neutral. We return to some of these issues below, but the point here is that sticky prices do not logically constitute evidence of nonneutralities or support for Keynesian policy.[7]

The rest of the paper is organized as follows. In Section 2 we go into detail concerning what we think New Monetarism is and how it compares with other approaches. In Section 3, in the spirit of Principle 5 above, we lay out a very tractable New Monetarist benchmark model based on Lagos and Wright (2005). We try to explain what lies behind the assumptions and we give some of its basic properties—money is neutral but not superneutral, the Friedman rule is optimal but may not give the first best, and so on. In Section 4 we discuss a few extensions of the baseline model that can be found in the literature. Then we show how these models can be used in novel ways to address issues pertaining to asset markets, banking, and monetary policy. In Section 5 we construct a model with money and equity shares and discuss its implications for asset pricing, asset trading, and liquidity premia, including how these depend on monetary policy. This model is extended in Section 6 to include banking, in order to show how financial intermediation can improve welfare and to derive some new results concerning the effect of monetary policy on interest rates. This illustrates one way in which New Monetarism departs from Old Monetarism: Friedman's proposal for 100 percent reserve requirements is a bad idea, according to this model, because it eliminates the welfare gains from intermediation, exemplifying Principle 3 above. We conclude in Section 7.

We think that the examples presented here and in Williamson and Wright (forthcoming) illustrate the usefulness of the New Monetarist approach. As we hope readers will appreciate, the models used in different applications all build on a consistent set of economic principles. This is true of the simplest setups used to formalize the role of currency in the exchange process, and of the extensions to incorporate banking, credit arrangements, payment systems, and asset markets. We think this is not only interesting in terms of theory, but there are also lessons to be learned for understanding the current economic situation and shaping future policy. To the extent that the recent crisis has at its roots problems related to banking, to mortgage and other credit arrangements, or to information problems in asset markets, one cannot hope to address the issues without theories that take seriously the exchange process. Studying this process is exactly what New Monetarist economics is about. Although New Keynesians have had some admirable success, perhaps especially in convincing policymakers to listen to them, we are not convinced that all economic problems are caused by nominal rigidities. And despite the views of reactionaries such as Krugman (2009), we cannot believe the answer to every interesting question hangs on the Old Keynesian cross. We think our approach provides a relevant alternative for academics and policymakers, and what follows is an attempt to elaborate on this position.

2. PERSPECTIVES ON MONETARY ECONOMICS

To explain the basic precepts underlying New Monetarism, we find it helps to first summarize some popular alternative schools of thought. This will allow us to highlight what is different about our approach to understanding monetary phenomena and guiding monetary policy.

[7] The model we are referring to is based on Head et al. (2010), which is related to, but also quite different from Caplin and Spulber (1987). To be clear, the New Monetarist position is not that monetary nonneutralities can never arise, and indeed we provide examples where they do (based, e.g., on incomplete information), nor is it our position that policy is irrelevant, as in some examples from New Classical macro (e.g., Sargent and Wallace, 1975, 1976). The point is rather that, despite what one hears from pundits such as Ball and Mankiw (1994), as a matter of logic, nominal rigidities in theory do not mean Keynesians are right in practice.

2.1 Keynesianism

We begin with a discussion of Keynesian economics, ostensibly to describe what it is, but, we have to admit, also partially to critique it. Of course, it all began with Keynes's (1936) *General Theory*. His ideas were soon popularized in Hicks's (1937) IS-LM model, which became enshrined in the undergraduate curriculum and was integrated into the so-called Neoclassical Synthesis of the 1960s. New Keynesian economics, as surveyed in Clarida, Gali, and Gertler (1999) or Woodford (2003), makes use of more sophisticated tools than Old Keynesian economists had at their disposal, but much of the language and many of the ideas are essentially the same. New Keynesianism is typically marketed as a synthesis that can be boiled down to an IS relationship, a Phillips curve, and a policy rule determining the nominal interest rate, the output gap, and the inflation rate. It is possible to derive a model featuring these equations from slightly more primitive ingredients, including preferences, but often practitioners do not bother with these details. If one were being pedantic one could find this problematic, since reduced-form relations from one model need not hold once one changes the environment, but we don't want to dwell on self-evident points.

A more serious concern is that all New Keynesian models have weak foundations for the ingredient at the very core of the theory: Prices (or sometimes wages) must be set in nominal terms, even in nonmonetary versions, mind you, and these prices are sticky in the sense that they cannot be changed, except at times specified rather arbitrarily, or at a cost. We already discussed some issues related to nominal rigidities in the Introduction, and rather than repeat that material here, we mention a few other points. First, as everyone including any card-carrying Keynesian is well aware, the key implications of the theory would be completely overturned if nominal prices could be indexed to observables, say if a seller announces "my price in dollars is p and it increases one-for-one with aggregate P." Such a scheme does not seem especially complicated or costly—to miss this trick, one has to be not merely rationally inattentive but a veritable slug. Having said that, we are all for the idea that information processing may be costly, consistent with the "sticky information" approach suggested by Mankiw and Reis (2002), even if we find the label sticky information, to mix metaphors, pandering to the choir. We are not sure, however, that when all is said and done the most relevant manifestation of information-processing costs will be that Keynes turned out to be right.

Another issue is this: Economists take many ingredients as given, including preferences, endowments, and technology. Why not treat other things the same way and take sticky prices, or, more generally, incomplete contracts or incomplete markets, as given? One answer is it depends on the question. But from this perspective, taking nominal rigidities as given is delicate when they are the essential component of the theory and the main driver of its policy prescriptions. Another answer is one that we think we heard suggested by Neil Wallace (he may disavow it). Economists have others to study preferences, endowments, and technology—including psychologists, resource specialists, and engineers—and they can at least potentially inform us about those elements of the world. We might hope to get away with deferring to others, in saying we take those things as given, since they are not our area of expertise. But the pricing mechanism, including nominal stickiness and more generally incomplete markets and contracts, is exactly the thing we ought to be studying. Almost by definition, there is no one *but* economists to chime in on these elements. When we take them as given we are surely shirking.[8]

Another point is that we object to calling sticky prices a "friction," and this is only partly semantic. We think of frictions as features of the environment that make it difficult for agents in the

[8] A different but related idea is that, if we are going to allow menu costs to muck up the process of changing prices, we ought to take seriously the costs of changing everything, and we don't mean merely tacking on ad hoc costs of adjustment in capital, inventories, and employment. If this is not obvious, consider the following. At some level we might all agree that search theory is a type of adjustment-cost theory, yet one can still claim that for many purposes it is more fruitful to use explicit search-based models of the labor market than otherwise frictionless models with some parametric cost-of-adjustment specification. As always, this will depend on the issue at hand, and perhaps also on taste or faith, but in our opinion what we learn from the successes (and the failures!) of search-based models of labor markets speaks for itself.

model to achieve desirable outcomes. Examples include private information or limited commitment, which may make it difficult to get agents to tell the truth or keep their promises; spatial or temporal separation, which can make it hard for agents to get together in the first place; and problems like imperfect monitoring, incomplete record keeping, and so on. These are, to repeat, frictions in the *environment*. By contrast, price stickiness is, if anything, a friction in the *mechanism*. It interferes directly with the way agents behave, as opposed to letting them interact as they like subject to constraints imposed by endowments, technology, preferences, and frictions in the environment as mentioned above. A serious, and not just semantic, reason to distinguish between frictions in the environment and the mechanism is that agents, in both our world and our models, should be allowed to be creative and resilient when it comes to seeking out gains from trade.

What we mean is this: In some environments, competitive equilibrium and alternative solution concepts, like the core, generate the same outcomes, so it does not matter which we use. However, once we make prices or wages sticky, say using Calvo (1983) pricing or Mankiw (1985) costs, these mechanisms are generally not equivalent. In a world where market prices are sticky, agents may well choose endogenously to adopt an alternative trading mechanism that delivers superior outcomes. One early version of this notion was the suggestion by Barro (1977) that sticky wages may be nothing more than a facade. An earlier version is Coase's (1937) theory of firm formation. In all these cases, the big idea is that when the price mechanism is doing a relatively poor job, agents will abandon it and start interacting via alternative institutions. An implication we find unattractive (although we understand that this is what some people like the most) in sticky-price theory is that agents in the model are not doing as well as they could: Gains from trade are being left on the table when exchanges are forced at the wrong relative prices. The modelers who use this approach are only allowing agents to do the best they can from a very narrow perspective, taking institutions as given, as if microfoundations means it is enough to let agents solve any old constrained maximization problem.

This is in sharp contrast to some economic theory, the purest of which we take to be the mechanism design approach, where, by construction, agents do as well as they can subject to constraints imposed by the environment and incentive conditions. There can be frictions, including private information or limited commitment, of course, that make doing as well as one can fairly bad. It would be a rookie mistake to think that the practitioners of mechanism design believe we live in a Panglossian world, as Buiter (1980) once said of New Classical macroeconomists. The world could be better with fewer constraints (and, indeed, sometimes it would be better with more constraints). We find it appealing that mechanism design attributes creativity and resiliency to the agents in models. We also find it interesting that economists often proceed as though agents can figure out how to interact optimally in the presence of moral hazard, adverse selection, and other recalcitrant situations, and yet at other times they proceed as if these agents can't get their heads around the comparatively minor inconvenience of a tardy Calvo fairy.

We do not want to push the whole mechanism design approach too hard here, and since we do not have the space, anyway, we refer to Wallace (forthcoming), which is another *Handbook of Monetary Economics* chapter, and is dedicated to the topic.[9] We do want to mention Townsend (1988), however, who put it this way:

> The competitive markets hypothesis has been viewed primarily as a postulate to help make the mapping from environments to outcomes more precise...In the end though it should be emphasized that market structure should be endogenous to the class of general equilibrium models at hand. That is, the theory should explain why markets sometimes exist and sometimes do not, so that economic organisation falls out in the solution to the mechanism design problem. (pp. 22-23)

Nominal rigidities, like incomplete markets or contracts, more generally, might conceivably

[9] We do think there are some subtle unresolved issues, like whether a given bargaining protocol should be considered part of the environment or a particular imposed mechanism (see Hu, Kennan, and Wallace, 2009).

emerge endogenously out of some environments, but we think it would be better if they were an outcome and not an assumption, especially since in Keynesian economics *everything* hinges on such rigidities. The Introduction discussed a case where sticky prices emerged endogenously that did *not* support the Keynesian position.[10]

But we digress. And we are perhaps being too negative. Despite the above concerns, which may sound like nit picking to many people, New Keynesianism has met with considerable success, obviously. It is also sometimes argued that it is consistent with, or has absorbed, the major revolutionary ideas developed in macroeconomics over the past few decades, including the Lucas critique and real business cycle theory, though this is somewhat less obvious. If we take Woodford (2003) as representing the state of the art, the main tenets of the approach are the following:

(1) The key friction that gives rise to short-run nonneutralities of money, and the primary concern of central bank policy, is sticky prices. Because some prices are not fully flexible, inflation or deflation induces relative price distortions, and this has consequences for welfare. There can be other distortions, such as monopolistic as opposed to perfect competition, or non-lump-sum taxes, in some applications, but nominal rigidities are clearly the essence of the approach.

(2) The frictions that we encounter in relatively deep monetary economics, or even not-so-deep monetary economics, like cash-in-advance models, are at best of second-order importance. In monetary theory these frictions include explicit descriptions of specialization that make direct exchange difficult, and information problems that make credit difficult, giving rise to a fundamental role for media of exchange and to different implications for policy.

(3) There is a short-run Phillips curve trade-off between inflation and output (if not inflation and unemployment, since these theories typically do not have detailed descriptions of the labor market, with exceptions like Gertler and Trigari, 2009). We can induce a short-run increase in output with an increase in inflation.

(4) The central bank is viewed as being able to set a short-term nominal interest rate, and the policy problem is presented as the choice over alternative rules for how this should be done in response to current economic conditions.

We also think it is fair to say that New Keynesians tend to be supportive of current practice by central banks. Elements of the modeling approach in Woodford (2003) are specifically designed to match standard operating procedures, and he appears to find little in the behavior of central banks that he does not like. The feeling seems to be mutual, which may be what people envisage when they conclude that there is a consensus. Interest in New Keynesianism has been intense in recent years, especially in policy circles, and as we said above, some economists (again, see Goodfriend, 2007) profess that it constitutes the default approach to analyzing and evaluating monetary policy.

2.2 Monetarism

Old Monetarist ideas are represented in the writings of Friedman (1960, 1968, and 1969) and Friedman and Schwartz (1963). In the 1960s and 1970s, the approach was viewed as an alternative to Keynesianism, with different implications for how policy should be conducted. Friedman put much weight on empirical analysis and the approach was often grounded only informally in theory—even if some of his work, such as the theory of the consumption function in Friedman (1957), is concerned with what we would call

[10] Relatedly, speaking more directly about money and banking, a position advocated in Williamson (1987b), is that what makes financial intermediation potentially worth studying are its special functions, such as diversification, information processing, and asset transformation. We cannot expect to generate these special activities or derive many useful implications if our approach does not build on the economic features that cause financial intermediaries to arise in the first place. This is another call for making one's assumptions explicit and generating market structure, including everything from intermediation to nominal contracting, endogenously.

microfoundations. Although there are few professed monetarists in the profession these days, the school has had an important role in shaping macroeconomics and the practice of central banking.[11]

The central canons of Old Monetarism include the following:

(1) Sticky prices, while possibly important in generating short-run nonneutralities, are unimportant for monetary policy.

(2) Inflation, and inflation uncertainty, generate significant welfare losses.

(3) The quantity theory of money is an essential building block. There exists a demand function for money which is an empirically stable function of a few variables.

(4) There may exist a short-run Phillips curve trade-off, but the central bank should not attempt to exploit it. There is no long-run Phillips curve trade-off (although Friedman tempered this position between 1968 and 1977 when he seemed to perceive the possibility of an upward-sloping long-run Phillips curve).

(5) Monetary policy is viewed as a process of determining the supply of money in circulation, and an optimal monetary policy involves minimizing the variability in the growth rate of some monetary aggregate.

(6) Money is any object that is used as a medium of exchange, and whether these objects are private or government liabilities is irrelevant for the analysis of monetary theory and policy.

We think it is also apparent that Friedman and his followers tended to be critical of contemporary central bank practices, and this tradition was carried on through such institutions as the Federal Reserve Bank of St. Louis and the Shadow Open Market Committee. One lasting influence of monetarism is the notion that low inflation should be a primary goal of policy, which is also a principle stressed by New Keynesian economists. However, the policy prescription in Friedman (1968) that central banks should adhere to strict targets for the growth of monetary aggregates is typically regarded as a practical failure. Old Monetarism tended to emphasize the long run over the short run: Money can be nonneutral in the short run, but exploitation of this by the central bank only makes matters worse (in part due to infamous long and variable lags). Policy should focus on long-run inflation. We also think it is fair to suggest that monetarists tended to favor relatively simple models, as compared to the Keynesian macroeconometric tradition.

Some but definitely not all of these ideas carry over to New Monetarism. Before moving to that, we mention that there are many other facets to the policy prescriptions, methodological ideas, and philosophical positions taken by Friedman and his epigones, any one of which may or may not fit with the thinking of any particular New Monetarist. In some sense Friedman's undeniable faith in free markets, for example, resembles the approach a mechanism design specialist might take, but in another sense it is the polar extreme, given the latter puts much weight on private information and other incentive problems. We do not want to get into all of these issues, but there is one position advocated by Friedman that we think is noteworthy, in the current climate, concerning fiscal rather than monetary policy. Friedman was clear when he argued that spending and tax proposals should be evaluated based on microeconomic costs and benefits, not on their potential impact on the macroeconomy. In stark contraposition, virtually all the popular and academic discussion of the recent stimulus package seems to focus on the size of multipliers, which to us seems misguided. But let us return to monetary economics, which is probably our (comparative) advantage.

[11] In the early 1980s a standard textbook put it this way: "As a result of all of this work quantity theorists and monetarists are no longer *a despised sect* among economists. While they are probably a minority, they are a powerful minority. Moreover, many of the points made by monetarists have been accepted, at least in attenuated form, into the mainstream Keynesian model. But even so, as will become apparent as we proceed, the quantity theory and the Keynesian theory have quite different policy implications" (Mayer, Duesenberry, and Aliber, 1981, emphasis added).

2.3 New Monetarism

Although dating such things precisely can be subtle, we would suggest that the foundations for New Monetarism can be traced to a conference on *Models of Monetary Economies* at the Federal Reserve Bank of Minneapolis in the late 1970s, with the proceedings and some post-conference contributions published in Kareken and Wallace (1980). Important antecedents are Samuelson (1958), which is a legitimate model of money in general equilibrium, and Lucas (1972), which sparked the rational expectations revolution and the move toward incorporating rigorous theory in macroeconomics. The Kareken and Wallace volume contains a diverse body of work with a common goal of moving the profession toward a deeper understanding of the role of money and the proper conduct of monetary policy, and spurred much research using overlapping generations and related models, including the one in Townsend (1980).[12]

Much of this work was conducted by Wallace and his collaborators during the 1980s. Some findings from that research are the following:

(1) Because Old Monetarists neglect key elements of economic theory, their prescriptions for policy can go dramatically wrong (Sargent and Wallace, 1982).

(2) The fiscal policy regime is critical for the effects of monetary policy (Sargent and Wallace, 1981, and Wallace, 1981).

(3) Monetary economics can make good use of received theory in other fields, like finance and public economics (Bryant and Wallace, 1979 and 1984).

A key principle, laid out first in the introduction to Kareken and Wallace (1980) and elaborated in Wallace (1998), is that progress can be made in monetary theory and policy analysis only by modeling monetary arrangements explicitly. In line with the arguments of Lucas (1976), to conduct a policy experiment in an economic model, it must be invariant to the experiment under consideration. One interpretation is the following: If we are considering experiments involving the operating characteristics of the economy under different monetary policy rules, we need a model in which economic agents hold money not because it enters utility or production functions, in a reduced-form fashion, but because money ameliorates some fundamental frictions in the exchange process. This is our last, best, and only hope for invariance, and it is why we are so interested in trying to carefully model frictions, instead of simply assuming some particular channel by which money matters. Of course, the suggestion that monetary economists need to look frictions in the face goes way back to Hicks (1935).[13]

There are various ways to try to conceptualize the notion of frictions. Just as Old Monetarists tended to favor simplicity, so do we. One reason for the preference for simple models is that, relative to Keynesian economics, there may be more of a focus on long-run issues such as the cost of steady state inflation, instead of business cycles. This is mainly because the long run is taken to be more important from a welfare perspective, but as a by-product, it often allows one to employ simpler models. It is also relevant to point out that tractability is especially important in monetary economics, where questions of existence, uniqueness versus multiplicity, and dynamics are big issues that can more easily and more naturally be addressed using analytic rather than numerical methods. With all due respect to computational economics, which has made brilliant advances in recent years, we believe that there are still some important questions to which the answer is not a number.

Overlapping generations models can be simple, although one can also complicate them as much as one likes, but much research in monetary theory following Kiyotaki and Wright (1989) instead uses matching models, building more on

[12] In addition to much impressive modeling and formal analysis, the Kareken-Wallace volume also contains in some of the discussions and post-conference contributions a great deal of fascinating debate on methodology and philosophy of the sort that we would like to see resurface, related to our comments in the Introduction about healthy economic science.

[13] Notice that, in line with the previous discussion, we are talking about frictions in the exchange process, as opposed to frictions in the price-setting process, like nominal rigidities, where money does not help (in fact, it is really the cause of the problem).

ideas in search and game theory than general equilibrium theory.[14] Matching models are very tractable for many applications, although a key insight that eventually arose from this research program is that spatial separation per se is not the critical friction making money essential, where here we are using the term in a technical sense usually attributed to Hahn (1973): Money is essential when the set of allocations that can be supported (satisfying resource and incentive conditions) with money is bigger or better than without money. As pointed out by Kocherlakota (1998), and emphasized by Wallace (2001), with credit due to earlier work by Ostroy (see Ostroy and Starr, 1990) and Townsend (1987 and 1989), money is essential when it overcomes a double coincidence of wants problem combined with limited commitment and imperfect record keeping. Perfect record keeping, what Kocherlakota calls perfect memory, implies that efficient allocations can be supported through insurance and credit arrangements, or various other arrangements, in a large class of environments including those used by search theorists without the use of money.

It needs to be emphasized that random bilateral matching among a large number of agents can be a convenient way to generate a double coincidence problem and to motivate incomplete record keeping, but it is not otherwise important to the approach. Corbae, Temzelides, and Wright (2003) and Julien, Kennes, and King (2008), e.g., redo much of the early monetary search theory using directed rather than random matching, and although some of the results change, in interesting ways, the essence of the theory emerges unscathed. Moreover, although it is good, perhaps essential, for monetary economists to understand what may or may not make currency essential in the exchange process, New Monetarists are interested in a host of other issues, institutions, and phenomena. Developments in intermediation and payment theories over the last 25 years are critical to our understanding of credit and banking arrangements, and one significant difference between Old and New Monetarists is how they think about the role of financial intermediaries and their interactions with central banks, as we discuss more formally in Section 6.

The 1980s saw important developments in the field, spurred by earlier progress in information theory. One influential contribution is Diamond and Dybvig (1983), which we now understand to be a useful approach to studying banking as liquidity transformation and insurance (although whether it can produce anything resembling a bank run depends on auxiliary assumptions, as discussed, e.g., by Ennis and Keister, 2009a,b). Other work involved well-diversified intermediaries economizing on monitoring costs, including Diamond (1984) and Williamson (1986), in models where financial intermediation is an endogenous phenomenon. The resulting intermediaries are well-diversified, process information in some manner, and transform assets in terms of liquidity, maturity, or other characteristics. The theory has also been useful in helping us understand the potential for instability in the banking and financial system (Ennis and Keister, 2009a,b) and how the structure of intermediation and financial contracting can propagate aggregate shocks (Williamson, 1987a, and Bernanke and Gertler, 1989).

A relatively new sub-branch of the area examines the economics of payments. This involves the study of payment and clearing systems, particularly among financial institutions, such as Fedwire in the United States, where central banks can play an important role (see Freeman, 1996, for an early contribution and Nosal and Rocheteau, 2009, for a recent survey). The key insights from this literature are related to the role played by outside money and central bank credit in the clearing and settlement of debt, and the potential for systemic risk as a result of intraday credit. Even while payment systems are working well, work in this field is important, because the cost of failure is potentially great given the amount of money processed through such systems each day. New Monetarist economics not only has something to

[14] Other papers in this literature will be discussed below, although a more comprehensive survey is to be found in Williamson and Wright (2010). See Ostroy and Starr (1990) for a survey of earlier attempts at building microfoundations for money using general equilibrium theory. Overlapping generations models are discussed and surveyed in various places, including Wallace (1980) and Brock (1990).

say about these issues, it is basically the only approach that could. How can one hope to understand payments and settlement without modeling the exchange process?

In an even newer research area, people have recently been using models consistent with our approach to study asset markets, including Duffie, Gârleanu, and Pederson (2005 and 2007), Vayanos and Weill (2008), and Lagos and Rocheteau (2009). This may come as a surprise to some people—it initially did to us—who might think financial markets are as close to a frictionless ideal as there is, but it turns out to be one of the most natural applications of search and bargaining theory. As Duffie, Gârleanu, and Pederson (2007) put it,

> many assets, such as mortgage-backed securities, corporate bonds, government bonds, U.S. federal funds, emerging-market debt, bank loans, swaps and many other derivatives, private equity, and real estate, are traded in over-the-counter (OTC) markets. Traders in these markets search for counterparties, incurring opportunity or other costs. When counterparties meet, their bilateral relationship is strategic; prices are set through a bargaining process that reflects each investor's alternatives to immediate trade.

This branch of finance uses formal models very close to those presented below (see Williamson and Wright, forthcoming, for more discussion).

In terms of how we go about it, to reiterate what was said in the introduction, New Monetarists more or less try to abide by the following principles:

(1) Useful analysis in macro and monetary economics, including policy analysis, requires sound micro economic theory, which involves using what we know from general equilibrium, search, and game theory.

(2) Especially important is a clear and internally consistent description of the exchange process and the means by which money and related institutions help facilitate that process, implying that the theory must be built on environments with explicit frictions.

(3) Rigorous models of financial intermediation are important for monetary theory and policy: Credit, banking, and payment systems matter.

(4) Other things being equal relatively simple models are preferred. While this is true in most of economics, it is especially important in monetary theory, because existence, uniqueness versus multiplicity, and dynamics are big issues that are not easy to study numerically. This makes it crucial to come up with assumptions that deliver tractability without sacrificing too much along other dimensions.

(5) While no one theory can answer all questions, in monetary economics, there are important characteristics that we feel any good model should have. In addition to tractability, this includes the right amount of abstraction, and internal consistency (which means there are not too many institutions, like incomplete markets, nominal contracting, and so on, that are taken as primitives). It would be useful to have a benchmark model with these properties that is also flexible enough to address a variety of questions.

Taking the above as our desiderata, we now present a baseline New Monetarist model and show how it can be used to study several substantive issues. Since we go into detail concerning the technical aspects of related models in Williamson and Wright (forthcoming), here we provide only a cursory discussion of those before getting to the structure that we actually put to use.

3. A BENCHMARK FRAMEWORK

3.1 Background

The simplest setup consistent with the spirit of New Monetarist Economics is a version of first-generation monetary search theory along the lines of Kiyotaki and Wright (1993), which is a stripped-down version of Kiyotaki and Wright (1989 and 1991). In such a model, agents meet bilaterally and at random, which makes barter difficult due to a double-coincidence problem generated by specialization. Also, these models have limited commitment and imperfect memory, which makes credit arrangements difficult. Money is then essential in the sense that (the set of) equilibrium outcomes can be better with money than without it. We think this is a good starting point for monetary economics, since money is playing a bona fide role in facilitating exchange. Moreover, frictions like those in the models, or at least informal descriptions thereof, have long been thought to be important for understanding the role of money, by such luminaries as Jevons (1875), Menger (1892), and Wicksell (1967), among others. The goal of the early search-based literature is to formalize these ideas, to see which are valid under what assumptions, and to develop new insights.

These first-generation models make some strong assumptions, however, including the indivisibility of money and goods. This allows one to focus on describing the pattern of trade without having to determine the terms of trade, but does not otherwise seem especially desirable. Even with such assumptions in place, we think the theory captures something salient about money. One can look at Williamson and Wright (forthcoming) for a summary of results from these rudimentary models, but we can at least mention here the following. Equilibria exist where an intrinsically useless asset, fiat currency, is valued. These equilibria can have good welfare properties relative to pure barter, even if they typically do not achieve first best. They are tenuous in the sense that there coexist nonmonetary equilibria, although monetary equilibria are also robust in that they can survive even if we endow currency with some undesirable properties by giving it, say, a storage or transaction cost, or if we tax it. Money encourages specialization in the models, as has been understood since Adam Smith, but has not been previously easy to formalize. One can also use the model to analyze commodity money, international currency, some issues related to banking, and so on (see our companion paper, Williamson and Wright (forthcoming) for references).

Beginning the next generation of papers in this literature, Shi (1995) and Trejos and Wright (1995) endogenize prices by retaining the assumption that money is indivisible but allowing divisible goods and having agents bargain. Results stemming from these models illustrate additional properties of fiat and commodity money systems, and one can use the framework to study many substantive issues. Compared to the previous work, a new insight from these second-generation models is that the equilibrium price level is typically not efficient: Under natural assumptions, it can be shown that one does not get enough for one's money. Many other results and applications are available, and again, one can look at Williamson and Wright (forthcoming) for more discussion and references. But clearly, while this is an improvement over models where prices are not determined endogenously, and while research using the framework has proved productive, the maintained indivisibility of money makes the model ill suited for much empirical and policy analysis as it is usually conceived by practitioners.

When one admits divisible money, however, one has to keep track of the distribution of money across agents as a state variable, and this gets complicated, even using numerical methods.[15] Still, Molico (2006) computes equilibria in his divisible-money model, and uses it to discuss the effects of inflation generated by transfers from the monetary authority. See also Chiu and Molico (2008 and 2010) and Dressler (2009 and 2010). Since we are interested in analytic results, we do not pursue the computational approach here. Instead we focus on models that allow us to avoid having to track distributions, and to this end there are two main routes.[16] The first, originating with Shi (1997), gets a degenerate distribution from the assumption of large households (a natural exten-

[15] The problem is in dealing with the distribution of money, and wealth, more broadly defined, in multiple-asset models. Heterogeneous-agent, incomplete-markets, macro models of the sort analyzed by Huggett (1993) or Krusell and Smith (1998) also have an endogenous distribution as a state variable, but the agents in those models do not care about this distribution per se—they only care about prices. Of course prices depend on the distribution, but one can typically characterize accurately prices as functions of a small number of moments. In a search model, agents care about the distribution of money directly, since they are trading with each other and not merely against their budget equations.

[16] Alternative approaches include Camera and Corbae (1999), Zhu (2003 and 2005), and a body of work emanating from the model introduced by Green and Zhou (1998), citations to which can be found in Jean, Stanislav, and Wright (2010).

sion for random-matching models of the worker-shopper pair discussed in the cash-in-advance literature since Lucas, 1980b). Thus, each decisionmaking unit consists of many members, who search randomly, but at the end of each trading round they return to the homestead where they share any money they bring back. Loosely speaking, by the law of large numbers, large families start each new trading round with the same amount of money. See Shi (2006) for a discussion and survey of this approach.

We take another route, following Lagos and Wright (2005), where alternating centralized and decentralized markets take the place of families. This allows us to address a variety of issues in addition to rendering distributions tractable. And it helps reduce the gap between monetary theory with some claim to microfoundations and mainstream macro as, while money is essential in the decentralized markets, having some centralized markets allows us to add elements that are hard to integrate into pure search models, such as standard capital and labor markets, fiscal policy. For what it's worth, we also believe the framework provides a realistic way to think about economic activity. In actual economies some activity is relatively centralized—it is fairly easy to trade, credit is available, we take prices as given, etc.—which is arguably well approximated by the apotheosis of a competitive market. But there is also much activity that is decentralized—it is not so easy to find a partner, it can be hard to get credit, etc.—as in search theory. For all these reasons we like the approach.

3.2 The Environment

The population consists of a continuum of infinitely lived agents with unit mass, each of whom has discount factor β. We divide each period in discrete time into two subperiods. In one, agents interact in a decentralized market, or DM, where there is pairwise random matching with α denoting the arrival rate (the probability of a match). Conditional on meeting someone, due to specialization (see Williamson and Wright, forthcoming, for more discussion), each agent has probability σ of being able to produce something the other agent wants to consume but not vice versa, and the same probability σ of wanting to consume what the other one can produce but not vice versa. Each of these two types of meetings involves a single coincidence of wants. Purely for simplicity, and without loss of generality, we assume no double-coincidence meetings, so that with probability $1 - 2\sigma$ there is no opportunity for trade in a meeting. Also, there is no record keeping in the DM, in the sense that the agents cannot observe actions in meetings other than their own, and have no knowledge of the histories of their would-be trading partners in any given meeting.

In the other subperiod, agents interact in a frictionless centralized market, or CM, as in standard general equilibrium theory. In the CM there is also limited record keeping, in the sense that agents only observe prices, which is all they need to respect their budget constraints. In particular they do not observe the actions of other individuals directly, only market outcomes (prices), which makes it difficult to use game-theoretic triggers that might otherwise render money inessential (Aliprantis, Camera, and Puzzello, 2006 and 2007, and Araujo et al., 2010). Some applications do allow partial record keeping, so that, for example, bonds can be traded across two meetings of the CM, although usually this is not crucial. Sometimes the setup is described by saying the DM convenes during the day and the CM at night, or vice versa, but this is not important for anything except perhaps mnemonics, to keep track of the timing. One can also proceed differently, without changing basic results, say as in Williamson (2007), where both markets are always open and agents randomly transit between them.[17]

There is one consumption good x in the DM and another X in the CM, although it is easy to have x come in many varieties, or to interpret X

[17] For some issues it is also interesting to have more than one round of trade in the DM between meetings of the CM, as in Berentsen, Camera, and Waller (2005) or Ennis (2009), or more than one period of CM trade between meetings of the DM, as in Telyukova and Wright (2008). Chiu and Molico (2006) allow agents to transit between markets whenever they like, at a cost, embedding what looks like the model of Baumol (1952) and Tobin (1956) into general equilibrium, where money is essential, but that requires numerical methods.

as a vector. For now x and X are produced one-for-one using labor h and H, so the real wage in the CM is $w = 1$. Preferences in any period encompassing one DM and CM are described by a standard utility function $\mathcal{U}(x, h, X, H)$. What is important for tractability, if not for the theory, in general, is quasilinearity: $\mathcal{U}$ should be linear in either X or H.[18] For now, we assume $\mathcal{U}$ is linear in H, and in fact we also make it separable,

$$\mathcal{U} = u(x) - c(h) + U(X) - H.$$

Assume $u' > 0$, $u'' < 0$, $u'(0) = \infty$, $c' > 0$, $c'' \geq 0$, $c'(0) = u(0) = c(0) = 0$, $U' > 0$, and $U'' \leq 0$. Also, denote the efficient quantities by x^* and X^*, where $u'(x^*) = c'(x^*)$ and $U'(X^*) = 1$ (we leave it as an exercise to verify these are efficient).

If we shut down the CM then this environment, including the random matching specification, technology, and preferences, is identical to that used by Molico (2006) in the model discussed above. And since the Molico (2006) model collapses to the one in Shi (1995) or Trejos and Wright (1995) when we make money indivisible, and to the one in Kiyotaki and Wright (1993) when we additionally make goods indivisible, these ostensibly different environments are actually special cases of one framework. As we discuss in Williamson and Wright (forthcoming), this is good not because we want one all-purpose vehicle for every issue in monetary economics, but because we want to avoid the impression that New Monetarist economics consists of a huge set of mutually inconsistent models. The same fundamental building blocks are used in the models discussed above, in the extensions presented below, in our companion paper, and in many other places in the literature, even if some applications sometimes make certain special assumptions.

Let $V_t(m)$ and $W_t(m)$ denote, respectively, the value function at date t for an agent holding money balances m at the beginning of the DM and the CM. Then we have

$$W_t(m) = \max_{X,H,\hat{m}} \left\{ U(X) - H + \beta V_{t+1}(\hat{m}) \right\}$$
$$\text{st } X = H + \phi_t(m - \hat{m}) + T,$$

where ϕ_t is the CM value of money, or the inverse of the nominal price level $p_t = 1/\phi_t$, and T is a lump-sum transfer, as discussed below. Assuming an interior solution (see Lagos and Wright, 2005), we can eliminate H and write

$$\begin{aligned} W_t(m) &= \varphi_t m + T + \max_X \left\{ U(X) - X \right\} \\ &+ \max_{\hat{m}} \left\{ -\varphi_t \hat{m} + \beta V_{t+1}(\hat{m}) \right\}. \end{aligned} \tag{1}$$

From this it is immediate that $W_t(m)$ is linear with slope ϕ_t; $X = X^*$; and $\hat{m}$ is independent of wealth $\phi_t m + T$. This last result implies a degenerate distribution across agents leaving the CM: They all choose $\hat{m} = M$ regardless of the m they brought in.[19]

In a sense, one can think of the CM as a settlement subperiod, where agents reset their liquidity positions. Quasilinearity implies they all rebalance to the same $\hat{m}$, leading to a representative agent in the DM. Without this feature the analysis is more complicated. It can also be more interesting, for some applications, but we want a tractable benchmark. By analogy, while models with heterogeneous agents and incomplete markets in macro generally are interesting, it is nice to have the basic neoclassical growth theory, with complete markets and homogeneous agents, as the textbook case. Since serious monetary theory with complete markets and homogeneity is a non-starter, we present this model as our benchmark, but one is free to relax our assumptions and use computational methods (analogous, perhaps, to the way some people compute large-scale overlapping generations models while others prove theorems in simpler versions).

To see one manifestation of this tractability, compared to many other models, consider an individual contemplating bringing m dollars into the DM. Since we just established everyone else in the DM has M, it does not matter who the agent

[18] To be clear, one can proceed with general preferences, but this requires numerical methods; with quasilinearity, we can derive many results analytically. Actually, one can use general utility and still be achieve tractability if we assume indivisible labor, since then agents act as if utility is quasilinear (see Rocheteau et al., 2008).

[19] This is obvious at least if V_t is strictly concave, which is the case under some conditions (given below), but as shown in Wright (2010), it is true generically even if V_t is not strictly concave.

under consideration meets, except insofar as it can determine whether he is a buyer or seller (all sellers look the same to a buyer and vice versa). Hence,

(2)
$$V_t(m) = W_t(m) + \alpha\sigma\left\{u\left[x_t(m,M)\right] - \phi_t d_t(m,M)\right\}$$
$$+\alpha\sigma\left\{-c\left[x_t(M,m)\right] + \phi_t d_t(M,m)\right\},$$

where $x_t(m,M)$ is the quantity of goods and $d_t(m,M)$ the dollars traded at t in a single-coincidence meeting where the buyer has m and the seller has M (which, if you are following along, explains why the arguments are reversed in the second and third terms). Note that we used the earlier result $W_t'(m) = \phi_t$ to simplify this.

The next step is to determine $x_t(\cdot)$ and $d_t(\cdot)$, and for now we use the generalized Nash bargaining solution (but see Section 4.1). Letting the bargaining power of the buyer be given by θ and the threat points by continuation values, $x_t(m,M)$ and $d_t(m,M)$ solve

$$\max_{x,d}\left[u(x) - \varphi_t d\right]^{\theta}\left[-c(x) + \varphi_t d\right]^{1-\theta} \text{ st } d \le m.$$

Again we used $W_t' = \phi_t$, which makes this bargaining problem nice and easy. First note that in any equilibrium the constraint $d \le m$ must bind (see Lagos and Wright, 2005). Then inserting $d = m$, taking the first-order condition (FOC) with respect to x, and rearranging, we get $\phi_t m = g(x)$ where

$$(3) \quad g(x) \equiv \frac{\theta c(x)u'(x) + (1-\theta)u(x)c'(x)}{\theta u'(x) + (1-\theta)c'(x)}.$$

This expression may look nasty, but $g(\cdot)$ is quite well behaved, and it simplifies a lot in some special cases; for example, $\theta = 1$ implies $g(x) = c(x)$, in which case real balances paid to the producer $\phi_t m$ exactly compensate him for his cost. In any case, $\partial x/\partial m = \phi_t/g'(x) > 0$.

We have shown that for any $(m,\tilde{m})$, in equilibrium $d_t(m,\tilde{m}) = m$ and $x_t(m,\tilde{m})$ depend on m but not $\tilde{m}$. We can now differentiate (2) to obtain

$$(4) \quad V_t'(m) = (1-\alpha\sigma)\varphi_t + \alpha\sigma\varphi_t u'(x_t)/g'(x_t),$$

where on the right-hand side $x_t = x_t(m)$. The marginal benefit of money in the DM is the marginal value of carrying it into the CM, which is ϕ_t, with probability $1 - \alpha\sigma$, plus the marginal value of spending it, which is $u'(x)\partial x/\partial m$, with probability $\alpha\sigma$. Updating this one period and combining it with the FOC from the CM, $\phi_t = \beta V_{t+1}'(\hat{m})$, we arrive at

$$(5) \quad \varphi_t = \beta\varphi_{t+1}\left[1 + \ell(x_{t+1})\right],$$

where we define

$$(6) \quad \ell(x) \equiv \alpha\sigma\left[\frac{u'(x)}{g'(x)} - 1\right].$$

The expression in (6) is the *liquidity premium*, giving the marginal value of spending a dollar, as opposed to carrying it forward, times the probability $\alpha\sigma$ one spends it.

Assume for now that the lump-sum transfer T is financed by printing currency, or, if negative, by retiring currency. Then the amount of currency in the CM at t is the amount brought in by private agents M_t, plus the transfer $\mu_t M_t$, where μ_t is the rate of increase in the money stock. Market clearing implies $\hat{m}_t = (1 + \mu)M_t = M_{t+1}$ is brought out of the CM and into the DM at t+1. Thus, the bargaining solution tells us $\phi_{t+t}M_{t+1} = g(x_{t+1})$for all t, and inserting this into (5) we arrive at

$$(7) \quad \frac{g(x_t)}{M_t} = \beta\frac{g(x_{t+1})}{M_{t+1}}\left[1 + \ell(x_{t+1})\right].$$

For a given path of M_t, equilibrium can be defined as a list including paths for $V_t(\cdot)$, $W_t(\cdot)$, $x_t(\cdot)$, and so on, satisfying the relevant conditions. But (7) reduces all of this to a simple difference equation determining a path for x_t. Here we focus on stationary equilibria, where x_t and hence $\phi_t M_t$ are constant, which makes sense as long as μ_t is constant (nonstationary equilibria, including sunspot, cyclic, and chaotic equilibria, are discussed in Lagos and Wright, 2003). In a stationary equilibrium, (7) simplifies nicely to $1 + \mu = \beta[1 + \ell(x)]$.[20]

[20] One has to also consider the consolidated government budget constraint, say $G + T = (\mu - 1)\phi M$, where G is government CM consumption. But notice that it does not actually matter for (7) whether changes in M are offset by changing T or G—individuals would prefer lower taxes, other things equal, but this does not affect their decisions about real balances or consumption in the model. Therefore, we do not have to give new money away as a transfer, but can instead have the government spend it, for the purpose of describing the most interesting variables in equilibrium.

3.3 Result

Having defined monetary equilibrium, we proceed to discuss some of its properties. To facilitate comparison to the literature, imagine that we can use standard methods to price real and nominal bonds between any two meetings of the CM, assuming these bonds are illiquid—they cannot be traded in the DM.[21] Then the real and nominal interest rates r and i satisfy $1 + r = 1/\beta$ and $1 + i = (1 + \mu)(1 + r)$, the latter being of course the standard Fisher equation. Then we can rewrite the condition $1 + \mu = \beta[1 + \ell(x)]$ for stationary equilibrium derived above as

$$\ell(x) = i. \tag{8}$$

Intuitively, (8) equates the marginal benefit of liquidity to its cost, given by the nominal interest rate i. In what follows we assume $i > 0$, although we do consider the limit $i \to 0$ (it is not possible to have $i < 0$ in equilibrium).

For simplicity let us assume $\ell'(x) < 0$, in which case there is a unique stationary monetary equilibrium and it is given by the $x > 0$ that solves (8). It is not true that we can show $\ell'(x) < 0$ under the usual concavity and monotonicity assumptions, but there are conditions that work. One such condition is $\theta \approx 1$; another is that $c(x)$ is linear and $u(x)$ displays decreasing absolute risk aversion. Note also that the same conditions that make $\ell'(x) < 0$ make $V(m)$ strictly concave. In any case, this is not especially important, since the argument in Wright (2010) shows that there generically exists a unique stationary monetary equilibrium even if $\ell(x)$ is not monotone.

In terms of welfare and policy implications, the first observation is that it is equivalent for policymakers to target either the money growth or inflation rate, since both equal $\mu - 1$; or they can target the nominal rate i, which is tied to μ through the Fisher equation. Second, it is clear that the initial stock of money M_0 is irrelevant for the real allocation (money is neutral), but the same is not true for the growth rate μ (money is not superneutral). These properties are shared by many theories, of course. Next, it is easy to see that $\partial x/\partial i < 0$, intuitively, because i is a tax on DM activity. Since CM output $X = X^*$ is independent of i in this basic setup, total output is also decreasing in i. However, it is important to point out that X is not generally independent of i if we allow nonseparable utility (see Williamson and Wright, forthcoming).

One can also show that x is increasing in bargaining power θ, that $x < x^*$ for all $i > 0$, and in fact, $x = x^*$ iff $i = 0$ and $\theta = 1$. The condition $i = 0$ is the Friedman rule, which is standard, while $\theta = 1$ is a version of the Hosios (1990) condition describing how to split the surplus in a socially efficient fashion in bilateral trade, which does not show up in reduced-form monetary theory. To understand it, note that in general there is a holdup problem in money demand analogous to the usual problem with ex ante investments and ex post negotiations. Thus, agents make an investment when they acquire cash in the CM, which pays off in single-coincidence meetings since it allows them to trade. But if $\theta < 1$, producers capture some of the gains from trade, leading agents to initially underinvest in $\hat{m}$. The Hosios condition tells us that investment is efficient when the payoff to the investor is commensurate with his contribution to the total surplus, which in this case means $\theta = 1$, since it is the money of the buyer (and not that of the seller) that allows the pair to trade.

There is reason to think that this is important in terms of quantitative and policy analysis, and not merely a technical detail. To make the case, first consider the typical quantitative exercise using something like a cash-in-advance model, without other explicit frictions, where one asks about the welfare cost of fully anticipated inflation. If as usual we measure this cost by asking agents what fraction of consumption they would be willing give up to go from, say, 10 percent inflation to the Friedman rule, the answer is generally very low. There are many such studies, but we can summarize the typical result by saying that consumers would be willing to give up around 1/2 of 1 percent, or perhaps slightly more, but not above 1 percent, of their consumption

[21] Do not get confused: We are not introducing tangible objects called bonds here; we are considering a thought experiment where we ask agents what return they would require to move one unit of either X or m from the CM at t to the CM at t+1.

(see Cooley and Hansen, 1989, or Lucas, 2000, for representative examples, or Craig and Rocheteau, 2008, for a survey). This has led many economists to conclude that the inflation tax distortion is not large, and may be one reason that New Keynesians focus virtually all their attention on sticky-price distortions.

Given the apparent aversion to inflation of many politicians, as well as regular people, one may wonder, why are the numbers generated by those models so small? The answer is straightforward. In standard cash-in-advance and other reduced-form models, at the Friedman rule we get the first best. Hence, by the envelope theorem, the derivative of welfare with respect to i is 0 at the Friedman rule, and a small inflation matters little. This is consistent with what one finds in our benchmark model when we set $\theta = 1$. But if $\theta < 1$, then the envelope theorem does not apply, since while $i = 0$ is still optimal it is a corner solution, given $i < 0$ is not feasible. Hence, the derivative of welfare is not 0 at $i = 0$, and a small deviation from $i = 0$ has a first-order effect. The exact magnitude of the effect of course depends on parameter values, but in calibrated versions of the model it can be considerably bigger than what one finds in the reduced-form literature. These results lead New Monetarists to rethink the previously conventional wisdom that anticipated inflation does not matter much.

One should look at the individual studies for details, but we can sketch the method. Assume $U(X) = \log(X)$, $u(x) = Ax^{1-a}/(1-a)$, and $c(x) = x$. Then calibrate the parameters as follows. First set $\beta = 1/(1 + r)$, where r is some average real interest rate in the data. In terms of arrival rates, we can at best identify $\alpha\sigma$, so normalize $\alpha = 1$. In fact, it is not that easy to identify $\alpha\sigma$, so for simplicity set σ to its maximum value of $\sigma = 1/2$, although this is actually not very important for the results. We need to set bargaining power θ, as discussed below. Then, as in virtually all other quantitative monetary models, we set the remaining parameters A and a to match the so-called money demand observations. By these observations we mean the empirical relationship between i and the inverse of velocity, M/PY, which is traditionally interpreted as money demand by imagining agents setting real balances proportional to income, with a factor of proportionality that depends on the opportunity cost i.

Here, with $U(X) = \log(X)$, real CM output is $X^* = 1$ (a normalization), and so nominal CM output is $PX = 1/\phi$. Nominal DM output is $\alpha\sigma M$, since in every single-coincidence meeting M dollars change hands. Hence, total nominal output is $PY = 1/\phi + \alpha\sigma M$. Using $\phi M = g(x)$, we get

$$(9)\quad \frac{M}{PY} = \frac{g(x)}{1+\alpha\sigma g(x)},$$

and since x is decreasing in i, so is M/PY. This is the money-demand curve implied by theory. Given θ, $g(x)$ depends on preferences, and we can pick the parameters a and A of $u(x)$, by various methods, to fit (9) to the data (assuming, for simplicity, say, that each observation corresponds to a stationary equilibrium of the model, although one can also do something more sophisticated). To implement this one has to choose an empirical measure of M, which is typically $M1$.[22]

This is all fairly straightforward, the only nonstandard parameter in quantifying the model being θ, which does not show up in theories with price taking. A natural target for calibrating θ is the markup, price over marginal cost, since it seems intuitive that this should convey information about bargaining power. One can compute the average markup implied by the model and set θ so that this matches the data. In terms of which data, we think the evidence discussed by Faig and Jerez (2005) from the Annual Retail Trade Survey, describing markups across various types of retailers, is most relevant. According to these data, at the low end, in warehouse clubs, superstores, automotive dealers, and gas stations, markups range between 1.17 and 1.21; and at the high end, in specialty foods, clothing, footware, and furniture, they range between 1.42 and 1.44. Aruoba, Waller, and Wright (2009) target 1.3, at the midpoint of these data. Lagos and Wright

[22] Which measure of M one uses does make a difference (as it would in any model of money, with or without microfoundations). One might think a more natural measure would be M0 based on a narrow interpretation of the theory, but this is probably taking the model too literally for empirical work (see, e.g., Lucas, 2000). More research is needed to better match theory and data on this dimension.

(2005) earlier used 1.1, consistent with other macro applications (e.g., Basu and Fernald, 1997). However, in this range, the exact value of θ does not matter too much.

It is now routine to compute the cost of inflation. It is hard to summarize the final answer with one number, since the results can depend on factors such as the sample period, frequency (monthly, quarterly, or annual), whether one includes complications like capital or fiscal policy, and so on. However, it is safe to say that Lagos and Wright (2005) can get agents to willingly give up 5 percent of consumption to eliminate a 10 percent inflation, which is an order of magnitude bigger than previous findings. In a model with capital and taxation, Aruoba, Waller, and Wright (2009) get closer to 3 percent when they target a markup of 1.3, which is still quite large. There are many recent studies using variants of New Monetarist models that have come up with similar numbers (again, see Craig and Rocheteau, 2008). Two points to take away from this are the following: First, the intertemporal distortion induced by inflation may be more costly than many economists used to think. Second, getting into the details of monetary theory is not only a matter of striving for logical consistency or elegance; it can also make a big difference for quantitative and policy analysis.

Which distortions are most important? Although there is more work to be done on this question, state-of-the-art research by Aruoba and Schorfheide (2010) attempts to answer it by estimating a model integrating New Keynesian and New Monetarist features (and they provide references to related work). They compare the importance of the sticky-price friction, which implies 0 inflation is optimal, and the intertemporal inflation distortion on which we have been focusing, which recommends the Friedman rule. They consider four scenarios, having to do with whether they try to fit the short- or long-run money-demand elasticity, and on whether the terms of trade are determined in the DM according to Nash bargaining or Walrasian pricing (see Section 4.1). In the version with bargaining designed to match the short-run elasticity, despite a reasonably-sized sticky-price distortion, the Friedman rule turns out to be optimal after all. The other three versions yield optimal inflation rates of –1.5 percent, –1 percent, and –0.75 percent. Even considering parameter uncertainty, they never find optimal inflation close to 0. They conclude that the two distortions are about equally important. Again, more work needs to be done, but in light of these findings, we see no compelling evidence supporting the New Keynesian assertion that one may with impunity ignore intertemporal inflation distortions, or monetary distortions, or money, more generally.

4. EXTENSIONS

In this section, we discuss some extensions in the literature to the benchmark New Monetarist model, before moving to new results.

4.1 Alternative Mechanisms

In the previous section we determined the terms of trade between buyers and sellers in the DM using the Nash bargaining solution. This seems reasonable in a bilateral matching context and is actually fairly general, at least in the sense that as we vary bargaining power θ between 0 and 1, we trace out the pairwise core (the set of bilaterally efficient trades). But alternative solution concepts can and have been used. Rocheteau and Wright (2005), among many others since, consider Walrasian price taking, as well as price posting with directed search, in the benchmark model. Aruoba, Rocheteau, and Waller (2007) consider bargaining solutions other than Nash. Galenianos and Kircher (2008) and Dutu, Julien, and King (2009), in versions with some multilateral meetings, use auctions. Ennis (2008), Dong and Jiang (2009), and Sanches and Williamson (2010a) study pricing with private information. Hu, Kennan, and Wallace (2009) use pure mechanism design. Head et al. (2010) use price posting with random search.

While these may all be appropriate for particular applications, in the interests of space, here we present just one: Walrasian pricing. This can be motivated by interpreting agents as meeting in large groups in the DM, rather than bilaterally, and assuming that whether one is a buyer or seller is determined by preference and technology shocks rather than random matching. It might help to think about labor search models, like Mortensen and Pissarides (1994), which uses bargaining, and Lucas and Prescott (1974), which uses price taking. A standard interpretation of the latter is that workers and firms meet on islands representing local labor markets, but on each island there are enough workers and firms that it makes sense to take wages parametrically. The same is true in monetary models: Specialization and anonymity can lead to an essential role for money independent of whether agents meet in small or large groups.

Let γ be the probability of being a buyer in any given DM subperiod, and also the probability of being a seller, so that we have the same measure of each, although this is easy to relax.[23] Assume for now that whether an agent ends up a buyer or seller in the DM is realized *after* the CM closes. Hence, agents are homogeneous ex ante, and they all choose the same $\hat{m}$ (we consider ex ante heterogeneity below). Leaving off t subscripts when there is little risk of confusion, the CM problem is the same as above, but in the DM

$$V(m) = \gamma V^b(m) + \gamma V^s(m) + (1-2\gamma)W(m),$$

where $V^b(\cdot)$ and $V^s(\cdot)$ are the payoffs to ending up a buyer or a seller ex post. These payoffs are given by

$$V^b(m) = \max\left\{u(x) + W(m - \tilde{p}x)\right\} \text{ st } \tilde{p}x \le m$$
$$V^s(m) = \max\left\{-c(x) + W(m + \tilde{p}x)\right\},$$

where $\tilde{p}$ is the DM nominal price of x (which in general differs from the CM price $p = 1/\phi$). The buyer's constraint always binds, $\tilde{p}x = m$, exactly as in the bargaining model. Then, market clearing in the DM and optimization imply that, to use Walrasian pricing, simply replace $g(x)$ with $c(x)$ and $\alpha\sigma$ with γ. In particular, the same simple condition $\ell(x) = i$ in (8) determines the unique stationary monetary equilibrium, as long as in the formula for $\ell(x) = \alpha\sigma[u'(x)/g'(x) - 1]$ we replace $\alpha\sigma$ with γ and $g'(x)$ with $c'(x)$. The results are otherwise qualitatively the same. However, there can be very interesting *quantitative* differences between the Nash and Walrasian versions of the model (see Aruoba, Waller, and Wright, 2009, or Aruoba and Schorfheide, 2010, for a case in point). Also, notice that here we made two changes to the baseline model: We generate the double coincidence problem via preference and technology shocks, instead of random bilateral matching; and we swapped Nash bargaining for Walrasian pricing. One could of course use preference and technology shocks instead of matching and stick with bargaining, or one could impose price taking with bilateral matching, although this seems less reasonable.

4.2 Ex Ante Heterogeneity

Here we present a simple extension of the benchmark model to illustrate another application and to make some methodological points. As above, preference and technology shocks rather than matching generate the DM double coincidence problem, but now agents know the realization of these shocks *before* they choose $\hat{m}$ in the CM. In fact, in our quasilinear specification, it is equivalent to assume there are two permanently distinct types: buyers, who may consume but never produce in the DM; and sellers, who may produce but never consume in the DM.[24] We can allow buyers and sellers to have different CM utility functions, say $U^b(X) - H$ and $U^s(X) - \upsilon H$.[25] Denote the measures of buyers and sellers by n_b and n_s. If we normalize $n_s = 1$, then by varying

[23] We assume here that one can never be both a buyer and seller in the same subperiod, but this is also easy to relax, just like it is easy to allow some double-coincidence meetings in the matching model.

[24] In case it is not obvious that it is equivalent to have permanently different types or types determined every period, it follows from the fact that agents exit each CM with a clean slate, rebalancing their money balances appropriately to wipe out previous histories. Notice also that it makes sense to have some agents who are permanently sellers in the DM only when the CM is operative—otherwise, say in Molico's model, what would they do with their money? Similarly it makes sense to have some agents who are permanently buyers in the DM only when the CM is operative—otherwise, where would they get their money?

[25] A case used in some applications is $U^b(X) = 0$, $U^s(X) = X$, and $\upsilon = 0$, which means buyers consume only in the DM and produce only in the CM, while sellers do just the opposite. Notice that $\upsilon = 0$ implies we need $U^s(X)$ to be linear if we want quasilinearity. In some applications, sellers are interpreted as firms operating in the DM, paying dividends to their owner in the CM (e.g., Berentsen, Menzio, and Wright, 2010).

n_b we allow variation in market tightness in the DM, given by $\tau = n_b/n_s$.

We now have to write separate value functions for buyers and sellers in the CM. Again, leaving off the t subscripts, after eliminating H, these can be written

$$W^b(m) = \varphi m + T + U^b\left(X^b\right) - X^b + \max_{\hat{m}}\left\{-\varphi\hat{m} + \beta V^b(\hat{m})\right\} \quad (10)$$

$$W^s(m) = \varphi m + T + U^s\left(X^s\right) - \nu X^s + \beta V^s(0), \quad (11)$$

where we use two results that should be obvious: Buyers and sellers respectively choose X^b and X^s, where $U^j(X^j) \leq 1$ with equality if $X^j > 0$; and only buyers ever choose $\hat{m} > 0$, so that $\hat{m} = 0$ for sellers. Hence we no longer have a degenerate distribution of money balances in the DM, but this does not complicate the analysis. Indeed, it is perhaps worth emphasizing that what makes the framework easy to use is not degeneracy, per se, but history independence. It is the fact that the distribution of money in the DM is degenerate conditional on agent type that begets tractability.

In the DM,

$$V^b(\hat{m}) = -k_b + W^b(\hat{m}) + \alpha_b\sigma\left\{u\left[x(\hat{m})\right] - \varphi\hat{m}\right\} \quad (12)$$

$$V^s(0) = -k_s + W^s(0) + \alpha_s\sigma\left\{-c\left[x(\bar{m})\right] + \varphi\bar{m}\right\}, \quad (13)$$

where we use Nash bargaining, implying the result $d = \hat{m}$ and $x = x(\hat{m})$, with $\hat{m}$ being the money the buyer chooses, while sellers take it as given that buyers have $\bar{m}$ (they are equal in equilibrium). Additionally, for buyers and sellers, respectively, we add flow search costs k_b and k_s and distinguish the arrival rates as α_b and α_s, which can now be endogenous. Notice that even though we use the same notation, $V^b(\cdot)$ and $V^s(\cdot)$ are different here than in Section 4.1, where agents were homogeneous ex ante (when they choose $\hat{m}$). Manipulating the buyer's FOC $\phi = \beta V'(\hat{m})$, following the same steps as in the benchmark model, we get the analogous equilibrium condition

$$i = \ell^b(x) \equiv \alpha_b\sigma\left[\frac{u'(x)}{g'(x)} - 1\right]. \quad (14)$$

This extension of the benchmark model is often adopted in applications, where it may be more natural, or easier. Here we can use it to expound on a venerable issue: the effect of inflation on the time it takes people to spend their money. Conventional wisdom has it that higher inflation makes people spend money faster—like a hot potato they want to get rid of sooner rather than later —and this is one channel via which inflation increases velocity.[26] Search-based theory seems ideal for studying this phenomenon. Li (1994 and 1995) introduced endogenous search effort into a first-generation model, and proxied for inflation with taxation, since it is hard to have inflation with indivisible money. He shows that increasing his inflation-like tax makes buyers search harder and spend money faster, increasing velocity. Moreover, some inflation is good for welfare, because there is too little search under laissez faire, because agents do not internalize the effect of their search effort on others' expected payoffs.

Lagos and Rocheteau (2005) show, however, that the main result is an artifact of indivisibilities. They introduce search intensity into the standard New Monetarist framework, which allows them to model inflation directly, and more importantly to determine prices endogenously. They then prove that inflation reduces buyers' search effort, the opposite of Li's (1994, 1995) finding. Intui-

[26] Of Keynes's many beautiful passages, we like this one: "The public discover that it is the holders of notes who suffer taxation [from inflation]...and they begin to change their habits and to economize in their holding of notes. They can do this in various ways...[T]hey can reduce the amount of till-money and pocket-money that they keep and the average length of time for which they keep it, even at the cost of great personal inconvenience...By these means they can get along and do their business with an amount of notes having an aggregate real value substantially less than before. In Moscow the unwillingness to hold money except for the shortest possible time reached at one period a fantastic intensity. If a grocer sold a pound of cheese, he ran off with the rubles as fast as his legs could carry him to the Central Market to replenish his stocks by changing them into cheese again, lest they lost their value before he got there; thus justifying the prevision of economists in naming the phenomenon velocity of circulation! In Vienna, during the period of collapse...[it] became a seasonable witticism to allege that a prudent man at a cafe ordering a bock of beer should order a second bock at the same time, even at the expense of drinking it tepid, lest the price should rise meanwhile" (Keynes, 1924, p. 51).

We like it not only because it involves beer and cheese, consistent with our Wisconsin connections, but also because Keynes was able to anticipate the usefulness of our benchmark specification where agents periodically visit the Central(ized) Market.

tively, people cannot *avoid* the inflation tax by spending money more quickly, buyers can only *pass it on* to sellers, who are not inclined to absorb it for free. When prices can adjust, inflation reduces x and hence the trading surplus, which reduces the return to DM activity. Thus, agents invest less in this activity, which means search effort goes down, and they end up spending money more slowly. Li's ostensibly plausible finding fails when prices are endogenous—somewhat reminiscent of Gresham's law, that bad money drives out good money, which also holds when prices are fixed but not necessarily when they are flexible (see Friedman and Schwartz, 1963, for a discussion and Burdett, Trejos, and Wright, 2001, for a theoretical analysis). We would not claim this is a puzzle in any serious sense, but several people have worked on trying to resurrect the result that inflation makes people spend money faster in various extensions of the benchmark model, including Ennis (2009) and Nosal (2010).

One resolution is proposed by Lagos and Rocheteau (2005) themselves, who can get search effort to increase with inflation when they replace bargaining by price posting, although their result is not very robust—it only holds for some parameter values, and in particular for low inflation rates. Here we take a different tack, following Liu, Wang, and Wright (2010). We start with a very simple matching technology, which assumes that, as in Li (1995), sellers wait passively, while buyers actively search by directly choosing α_b at flow cost $k_b = k(\alpha_b)$. Simplicity comes from the fact that with this technology search effort by other buyers does not affect the arrival rate of an individual buyer, although it does affect the arrival rate of sellers (see Liu, Wang, and Wright, 2010, for details, but note that this is only used to ease the presentation). Taking the FOC with respect to α_b in (12) and using the bargaining solution $\phi m = g(x)$, we have

$$(15)\quad k'(\alpha_b) = \sigma\left[u(x) - g(x)\right].$$

Equilibrium is a quantity x and an arrival rate α_b solving (14) – (15). It is not hard to show, as in Liu, Wang, and Wright (2010), that in equilibrium x and α_b both fall with i.

This is our simplified version of the Lagos and Rocheteau (2005) result that inflation makes buyers spend their money less quickly, because it reduces the expected gain from a meeting, $\sigma[u(x) - g(x)]$. As we said, one can try to overturn this by changing the pricing mechanism, but instead we change the notion of search intensity: Rather than the intensive margin (effort), we consider the extensive margin (participation). That is, we introduce a free entry decision by buyers, similar to the decision of firms in the textbook labor search model in Pissarides (2000) (for other applications, one may alternatively consider entry by sellers or allowing agents to choose whether to be buyers or sellers in the DM). For this demonstration, we use a general constant returns to scale matching technology. Thus, the number of DM meetings $n = n(n_b, n_s)$ depends on the measures of buyers n_b and sellers n_s in the market, and $\alpha_b = n(n_b, n_s)/n_b = n(\tau,1)$, where $\tau = n_b/n_b$. We make the usual assumptions on $n(\cdot)$.[27]

We now set $k_b = 0$, but assume buyers must pay a fixed cost k to enter the DM, while sellers get in for free. Hence, all sellers participate and $n_s = 1$, while n_b is endogenous. Assuming some but not all buyers participate, they must be indifferent about going to the DM, which as a matter of algebra can be shown to imply

$$(16)\quad k + ig(x) = \alpha_b \sigma\left[u(x) - g(x)\right].$$

This equates the total cost of participating in the DM, the entry cost k plus the real cost of carrying cash $i\phi\hat{m} = ig(x)$, to the expected benefit. A monetary equilibrium in this model is a non-zero solution (x,α_b) to (14) and (16), from which we can easily get the rest of the endogenous variables, including the measure of participating buyers n_b, which is a decreasing function of α_b. One can verify, as in Liu, Wang, and Wright (2010), that there is a unique equilibrium, with x decreasing and α_b increasing with i.

Thus we unambiguously get the hot potato effect $\partial\alpha_b/\partial i > 0$ that was elusive, at least with

[27] It is twice continuously differentiable, strictly increasing, and strictly concave. Also, $n(n_b,n_s) \le \min(n_b,n_s)$, $n(0,n_s) = n(n_b,0) = 0$, $\lim_{\tau\to\infty} \alpha_b = 0$, and $\lim_{\tau\to\infty} \alpha_b = 1$.

bargaining, when search intensity was modeled on the intensive margin. The intuition is crystal clear: An increase in inflation has to lead to buyers spending their money faster, because this is the only way to keep them indifferent about participating! It works by having n_b go down, naturally, when i increases. Moreover, this implies velocity unambiguously increases with i. In terms of welfare, it can be shown that (as in the benchmark model), the Friedman rule $i = 0$ plus the Hosios condition $\theta = 1$ are necessary and sufficient for $x = x^*$ But this does not in general imply efficiency in terms of entry, because of so-called search externalities: With a general matching function, participation by buyers increases the arrival rate for sellers and decreases it for other buyers. There is a separate Hosios condition for efficient participation, which as in a standard Pissarides (2000) model equates θ to the elasticity of the matching function with respect to n_b. But this conflicts in general with the condition $\theta = 1$ required for $x = x^*$. Further analyzing efficiency and policy interventions in this class of models is an important area of investigation (see, e.g., Berentsen and Waller, 2009).

There are at least two reasons to be interested in these issues. One is normative: Ongoing research is studying whether there is, apropos the previous paragraph, too little or too much search or entry under laissez faire, and what policy can do about it. The other is positive: The effect of inflation on the speed with which people spend money is one channel through which it affects velocity, which is related to money demand. This is interesting for many reasons, including, as we saw in Section 3, the fact that it helps calibrate the model and measure the cost of inflation. We also think this subsection makes the following methodological point. We are arguing generally for better foundations for monetary economics. Although it is not the only possible way to proceed, it is sometimes convenient and informative to use search-and-bargaining theory. We have often heard it said that everything that can be done with search and bargaining can also be done using a money-in-the-utility-function or cash-in-advance model. Therefore, as the argument goes, we do not need search and bargaining. This application is a manifest counterexample: The interesting issues are all about search and bargaining.[28]

4.3 Other Extensions

Williamson and Wright (forthcoming) provide more details and references, but it would not hurt here to briefly summarize a few existing applications and generalizations of the benchmark model. As already mentioned, various alternative pricing mechanisms have been considered. People have included neoclassical capital and labor markets, and versions that nest standard real business cycle theory as a special case. Others have studied labor markets and the Phillips curve, using either Rogerson (1988) or Mortensen and Pissarides (1994) models of unemployment. People have included unanticipated inflation and signal extraction problems to quantify the importance of monetary uncertainty, while others have introduced private information to study recognizability and the counterfeiting of money or other assets. Others have analyzed optimal fiscal and monetary policy. Some people have introduced banking in various ways, while others have studied technology transfer and economic growth. Still others have studied the interaction between money and bonds, details of monetary policy implementation, the use of credit cards, and various issues in finance. There are many other applications and extensions of the benchmark model, both theoretical and empirical. In the rest of this essay we will present some examples related to asset markets and to intermediation.

5. ASSET PRICING AND LIQUIDITY

New Monetarist models provide insights into the exchange process and allow us to be explicit about the frictions that provide a role for money. Another advantage is that they allow us to consider a rich array of assets, credit arrangements, and intermediary structures. In this section we construct a version with two assets: money and

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[28] Berentsen, Menzio, and Wright (2010) provide a different argument pertaining to search-and-bargaining models and reduced-form models delivering different results, both qualitatively and quantitatively.

equity shares.[29] We use the setup with ex ante heterogeneity developed in Section 4.2, with no entry costs, so that all buyers and sellers participate in the DM, and here we normalize $n_b = 1$. Again, in the DM, buyers always want to consume but cannot produce, while sellers are always able to produce but do not want to consume. As before, we can give buyers and sellers different CM utility $U^b(X) - H$ and $U^s(X) - A^sH$. Also, to reduce notation we set $c(x) = x$, and buyers in the DM now make take-it-or-leave-it offers $\theta = 1$. Also, to make the discussion of welfare below more interesting, we assume it can be costly to maintain the stock of currency: It uses up $\omega\phi M$ units of the CM good X to maintain a real currency supply of ϕM where M is the stock of currency before the transfer from the government occurs in the CM. This can be interpreted as the cost of replacing worn-out notes, or thwarting counterfeiters, perhaps, and is financed through lump-sum taxes in the CM.

As is standard, following Lucas (1978), there is a productive asset in this economy that one can think of as a tree in fixed supply, normalized to 1, that yields a dividend y in fruit in units of the numeraire each period in the CM. Agents can trade equity shares in the tree in the CM at price ψ. Ownership of a shares entitles a shareholder to receive ay units of X in the CM. In the DM, for simplicity, each buyer is matched with a seller with probability 1. As in the benchmark model, there is no record keeping, so credit is unavailable. Also, because we want to have both money and equity used in transactions, even when money is dominated in rate of return, we give shares a disadvantage in terms of *recognizability*. Thus buyers in the DM can costlessly produce fake shares, which are illegitimate claims to dividends in the CM, perhaps because they are counterfeit—bad claims to good trees—or because they are lemons—good claims to bad trees (see Lester, Postlewaite, and Wright, 2009 and 2010; Rocheteau, 2009; and Li and Rocheteau, 2010, for more on this).

To capture the extent of the recognizability problem, following Williamson and Wright (1994), in a fraction η of DM meetings the seller has no technology for discriminating between phony and genuine shares, so they do not accept them (if they did they would only receive fakes). We call these meetings *nonmonitored*. In these meetings, money, which can always be recognized, is the only object accepted in trade. In the remaining fraction $1 - \eta$ of DM meetings, sellers can differentiate between genuine and phony shares, so equity as well as currency are potentially acceptable. We call these meetings monitored, with one idea being that the seller can keep a record of who gave him any particular asset, so that when he gets to the next frictionless CM, where phony and genuine shares can always be distinguished, he could report and we could punish severely anyone who passed a fake. This is not the only interpretation, however, another one being that the seller in a monitored meeting has a technology to verify an asset's authenticity.

The timing is such that buyers do not know whether they will be in a monitored or nonmonitored meeting in the DM until after the CM closes. Therefore, the problem for a buyer coming into the CM with a portfolio (m,a) of currency and shares is given, after eliminating H, by

$$W^b(m,a) = U^b(X^b) - X^b + \varphi m + (\psi + y)a + T + \max_{\hat{m},\hat{a}} \left\{ -\varphi\hat{m} - \psi\hat{a} + \beta V^b(\hat{m},\hat{a}) \right\}, \tag{17}$$

where X^b satisfies $\partial U^b(X^b)/\partial X^b \leq 1$ with equality if $X^b > 0$.[30] In any case, $\partial W^b/\partial m = \phi$ and $\partial W^b/\partial a = \psi + y$. We do not actually need to consider the seller's problem beyond noting that, as long as we assume sellers' preferences are quasilinear, their CM value function will also satisfy $\partial W^s/\partial m = \phi$ and $\partial W^s/\partial a = \psi + y$. Given this, in nonmonitored and monitored DM meetings the bargaining solutions with $\theta = 1$ and $c(x) = x$ are $x^N = \phi d^N$ and $x^M = \phi d^M + e(\psi + y)$, where now $d^N \leq \hat{m}$ and $d^M \leq \hat{m}$ are dollars that change hands in nonmonitored and monitored trades, and $e \leq \hat{a}$ is

[29] The presentation here has some features in common with the multiple-asset models of Geromichalos, Licari, and Suarez-Lledo (2007), Lagos (2008), Lagos and Rocheteau (2008), and Lester, Postlewaite, and Wright (2010), as well as models of money and credit, such as Sanches and Williamson (2010b).

[30] In the special case mentioned above, where $U^b(X) \equiv 0$ and buyers consume only in the DM, $X^b = 0$, but again this does not really matter for the interesting results.

the amount of equity handed over in a monitored trade (as we said above, no equity changes hands in non-monitored trades).

We can anticipate $d^N = d^M = \hat{m}$, without loss of generality, but we cannot be sure of $e = \hat{a}$, because buyers never want to buy more than x^*. Let a^* be the amount of equity required to buy x^* in a monitored meeting, given the buyer also spends $\hat{m}$, defined by $x^* = \phi\hat{m} + a^*(\psi + y)$. Then $x^M = \phi m + \hat{a}(\psi + y)$ if $\hat{a} < a^*$ and $x^M = x^*$ otherwise, while $e = \hat{a}$ if $\hat{a} < a^*$ and $e = a^*$ otherwise. The DM value function for buyers can now be written

$$(18)\quad \begin{aligned} V^b(\hat{m},\hat{a}) &= \eta\left[u\left(x^N\right)+W\left(0,\hat{a}\right)\right] \\ &+(1-\eta)\left[u\left(x^M\right)+W\left(0,\hat{a}-e\right)\right]. \end{aligned}$$

Differentiating, we have

$$(19)\quad \begin{aligned} \frac{\partial V^b}{\partial \hat{m}} &= \eta u'\left(x^N\right)\frac{\partial x^N}{\partial \hat{m}}+(1-\eta)u'\left(x^M\right)\frac{\partial x^M}{\partial \hat{m}} \\ &-(1-\eta)(\psi+y)\frac{\partial e}{\partial \hat{m}} \end{aligned}$$

$$(20)\quad \begin{aligned} \frac{\partial V^b}{\partial \hat{a}} &= \eta(\psi+y)+(1-\eta)u'\left(x^M\right)\frac{\partial x^M}{\partial \hat{a}} \\ &+(1-\eta)(\psi+y)\left(1-\frac{\partial e}{\partial \hat{a}}\right), \end{aligned}$$

where from the bargaining solution we know the following[31]:

$$(21)\quad \begin{aligned} &\hat{a} < a^* \Rightarrow \frac{\partial x^N}{\partial \hat{m}} = \phi;\ \frac{\partial x^M}{\partial \hat{m}} = \phi; \\ &\frac{\partial x^M}{\partial \hat{a}} = \psi + y;\ \frac{\partial e}{\partial \hat{m}} = 0;\ \frac{\partial e}{\partial \hat{a}} = 1 \end{aligned}$$

$$(22)\quad \begin{aligned} &\hat{a} > a^* \Rightarrow \frac{\partial x^N}{\partial \hat{m}} = \phi;\ \frac{\partial x^M}{\partial \hat{m}} = 0; \\ &\frac{\partial x^M}{\partial \hat{a}} = 0;\ \frac{\partial e}{\partial \hat{m}} = \frac{-\phi}{\psi + y};\ \frac{\partial e}{\partial \hat{a}} = 0 \quad . \end{aligned}$$

In stationary equilibrium $\psi_{t+1} = \psi_t$ and $\phi_{t+1} = \phi_t/(1 + \mu)$, where again μ is both the rate of growth of M_t and the inflation rate. Market clearing requires $\hat{a} = 1$. There are then two possibilities for equilibrium: (i) liquidity is plentiful, $1 > a^*$, which means that in monitored meetings agents have sufficient cash plus equity to buy x^* while handing over only a fraction of their shares $e < 1$; and (ii) liquidity is scarce, $1 < a^*$, which means equity is in short enough supply that in monitored meetings buyers settle for $x^M < x^*$ while handing over all of their shares $e = 1$. In case (i) we insert (19)–(20) into the FOC from the CM problem using (22) to get the relevant derivatives; and in case (ii) we do the same using (21). We now consider each case in turn.[32]

5.1 Case (i)

When $a^* < 1$ and $x^M = x^*$, one could say liquidity is plentiful. Then the above procedure—inserting (19)–(20) into the FOC from equation (17) using equation (22)—yields

$$(23)\quad 1+\mu = \beta\left[\eta u'\left(x^N\right)+1-\eta\right]$$

$$(24)\quad \psi = \beta(\psi + y).$$

Defining the interest rate on a nominal bond that is illiquid (cannot be traded in the DM) by $1 + i = (1 + \mu)/\beta$, (23) can be written $i = \ell(x^N)$, where $\ell(x) = \eta[u'(x) - 1]$ is the formula for the liquidity premium when $\theta = 1$, $c(x) = x$, and the relevant version of the single-coincidence probability is η. As in the model with money and no other assets, there is a unique $x^N > 0$ solving this condition, and it would be correct to say that cash bears a liquidity premium.

By contrast, (24) tells us that equity is priced according to its fundamental value, the present value of its dividend stream, $\psi = \psi^F \equiv \beta y/(1 - \beta)$. In this equilibrium, therefore, equity bears no liquidity premium, and its real return is invariant to inflation, as Irving Fisher would have it. To see when this equilibrium exists, the requirement $a^* < 1$ is easily seen to hold iff $x^* < x^N + y/(1 - \beta)$. Hence, if $y > (1 - \beta)x^*$ this equilibrium always exists. And if $y < (1 - \beta)x^*$ it exists iff $\mu < \bar{\mu}$, where

[31] Notice in particular that when $\hat{a} > a^*$, if we gave a buyer a little more $\hat{m}$ in a monitored meeting, he would not buy more x^M but would reduce e to keep $x^M = x^*$.

[32] We ignore nongeneric cases throughout this section, where, say, buyers have just exactly enough liquidity to get $x^M = x^*$.

$$(25)\quad 1+\bar{\mu}=\beta\left[\eta u'\left(x^*-\frac{y}{1-\beta}\right)+1-\eta\right],$$

since $x^N \to x^*$ as $\mu \to \beta - 1$. An important conclusion is that even if equity is scarce, in the sense that $y < (1-\beta)x^*$, liquidity will not be scarce as long as inflation is low enough. Liquidity is always plentiful at the Friedman rule.

5.2 Case (ii)

When $1 < a^*$ and $x^M < x^*$, one could say liquidity is scarce. Then the procedure described above yields

$$(26)\quad 1+\mu=\beta\left[\eta u'\left(x^N\right)+(1-\eta)u'\left(x^M\right)\right]$$

$$(27)\quad \psi=\beta(\psi+y)\left[\eta+(1-\eta)u'\left(x^M\right)\right].$$

Immediately (26) tells us that equity trades in the CM for more than its fundamental price, $\psi > \psi^F$, as it now bears a liquidity premium. Using the bargaining solution $x^M = \phi m + \hat{a}(\psi + y)$ to eliminate ψ from (27), we are left with two equations in (x^N, x^M), which are easy to analyze. It is easy to check that in this equilibrium Fisher's theory does *not* apply to equity: An increase in inflation reduces the real rate of return of shares. The reason is that an increase in μ causes agents to, at the margin, shift their portfolio from cash into equity, driving up the share price ψ and driving down the real return y/ψ.[33] This equilibrium exists iff $x^M < x^*$. This is the case if equity is scarce, $y < (1-\beta)x^*$, and additionally $\mu > \bar{\mu}$ where $\bar{\mu}$ is given in (25).

5.3 Discussion

To discuss optimality, for the sake of argument, let us add utilities across agents to construct a welfare measure

$$(28)\quad \begin{aligned}\mathcal{W}&=\eta\left[u\left(x^N\right)-x^N\right]\\&+(1-\eta)\left[u\left(x^M\right)-x^M\right]-\omega x^N,\end{aligned}$$

where we take into account the cost of maintaining real money balances, $\omega\phi M = \omega x^N$. If $\omega = 0$ then $\mathcal{W}$ is decreasing in μ and the optimal policy is the Friedman rule $\mu = \beta - 1$. Given $\mu = \beta - 1$, we achieve the first best $x^M = x^N = x^*$, shares trade at their fundamental price in the CM $\psi = \psi^F$, the real return on equity is $y/\psi = r$, and the nominal return is 0. Indeed, in a Friedman rule equilibrium, shares do not have to circulate in the DM, since outside money satiates agents in liquidity. We are not sure what to think of this result, however, since in practice private liquidity appears to be important for many transactions, and it is not clear that currency would replace it entirely even if monetary policy were optimal.

To get at this, we allow outside money to be costly by considering $\omega > 0$, for reasons mentioned above concerning maintenance of the currency, protection against counterfeiting, and so on. Now at the Friedman rule $\mu = \beta - 1$ we have $\partial\mathcal{W}/\partial\mu = -\omega\partial x^N/\partial\mu > 0$, so inflating above the Friedman rule is optimal. Suppose equity is plentiful at the optimum,

$$\frac{\partial\mathcal{W}}{\partial\mu}=\left[\eta u'\left(x^N\right)-\eta-\omega\right]\frac{\partial x^N}{\partial\mu}=0,$$

and the optimal policy is

$$(29)\quad \mu^*=\beta(1+\omega)-1.$$

This is the optimal policy, which means $y > (1-\beta)x^*$, or $y < (1-\beta)x^*$ and $\mu^* > \bar{\mu}$. This will be the case iff $\omega < \bar{\omega}$ for some threshold $\bar{\omega}$. If, however, $y < (1-\beta)x^*$ and $\mu^* > \bar{\mu}$, which is the case iff $\omega > \bar{\omega}$, then equity is scarce at the optimum. In this case we cannot derive a closed-form solution for the optimal policy, but μ is still increasing in ω.[34]

For those who have not kept up with New Monetarist research, this example illustrates how it has moved beyond studying purely cash transactions. Related models, including Duffie Gârleanu, and Pederson (2005 and 2007); Vayanos and Weill (2008); Lagos (2008); Lagos and Rocheteau (2009); Lagos, Rocheteau, and Weill

[33] For an illiquid bond, however, that cannot circulate in the DM, the Fisher equation still holds, of course.

[34] Effectively, the inflation tax falls on the users of currency, but at least for the case where shares are not scarce at the optimum, the inflation tax is not sufficient to finance currency maintenance.

(2009); Rocheteau (2009), Ravikumar and Shao (2006), and Lester, Postlewaite, and Wright (2010), begin to address issues related to liquidity in asset markets, asset price volatility, the roles of public and private liquidity, and how informational frictions might matter. These models capture, in a simple way, optimal deviations from the Friedman rule. It is not common for monetary models, including reduced-form models, to produce an optimal deviation from the Friedman rule, yet central bankers typically target a short-term nominal interest rate of 0 only temporarily—if at all. At some level this is no different than policymakers using positive capital taxes or tariffs, binding minimum wage laws, rent control, agricultural price supports, and so on, which are all suboptimal according to textbook economics. Yet one might at least entertain the hypothesis that $i = 0$ may be suboptimal.

New Keynesian sticky price models typically yield a deviation from the Friedman rule, with a zero inflation rate being the default option. We do not take those results very seriously, however, since those models leave out all the frictions that we think are relevant. For us, elements that are important in generating optimal departures from the Friedman rule might well include costs of operating currency systems, as captured in a simple way in the above example. He, Huang, and Wright (2008) and Sanches and Williamson (2010b) go into more detail analyzing explicit models of theft and show how this leads to the use of currency substitutes at the optimum. Similarly, Nosal and Wallace (2007) and Li and Rocheteau (2010) provide interesting analyses of counterfeiting. While currency maintenance, theft, counterfeiting, and so on are not usually considered first-order issues in mainstream monetary policy analysis, we think they are potentially important enough to take seriously. More work remains to be done on these issues.

6. INTERMEDIATION

While the model in Section 5 has some interesting features—for example, assets other than currency are used in transactions and can bear a liquidity premium—in practice, financial intermediation plays an important role in asset markets, and alternatives to currency in retail transactions are essentially always the liabilities of some private intermediary. Research from the 1980s on financial intermediation provides some alternative approaches to modeling intermediary structures in the class of models under consideration, including the framework of Diamond and Dybvig (1983), and costly-state-verification models like Diamond (1984) or Williamson (1986). Here we show how to integrate Diamond and Dybvig (1983) banking into our benchmark model, where banks provide insurance against the need for liquidity. Moreover, as in earlier attempts by Freeman (1988) or Champ, Smith, and Williamson (1996), in this model money and monetary policy play a role, while the original Diamond and Dybvig (1983) specification has neither currency nor anything that could be interpreted as the use of third-party liabilities facilitating transactions.[35]

The only alteration to the environment in Section 5 concerns the timing. Let's call buyers in a nonmonitored DM meeting type N buyers and those in a monitored meeting type M buyers. Then assume that buyers' types for the next DM are realized at the end of the current CM, after production and consumption decisions have been made but before they part company, and that this is publically observable. This allows buyers to enter into relationships that resemble banking. What is a bank? Any agent can offer the following *deposit contract*: "Make a deposit with me while the CM is still open, either in goods or money or other assets, it does not matter since I can adjust my portfolio frictionlessly in the CM; upon seeing your type, if it is N you can withdraw m^N dollars before going to the DM and retain claims to a^M in the next CM; and if it is M you withdraw nothing, but in the DM you can trade claims against your deposits backed by m^M dollars and a^M equity shares."

[35] The model in this section is related to the model of banking in Berentsen, Camera, and Waller (2007) and Chiu and Meh (2010), although it also goes beyond that work, in ways that we discuss below. A related analysis, using mechanism design, that also takes seriously the role of bank liabilities (deposits) in the exchange process is developed in Mattesini, Monnet, and Wright (2010).

The fact that deposit claims are transferable, allows them to potentially be traded in the DM, but to make things interesting here we treat them symmetrically with actual shares as in Section 5—they can be phony, and only sellers in monitored meetings can verify this, and therefore only sellers in monitored meetings accept these claims.

Banks are competitive, so the equilibrium contract maximizes the welfare of a representative depositor, subject to non-negative profit, and a bank can diversify perfectly against its customers ending up type N or M as long as it attracts a strictly positive mass (although it would also be interesting to add aggregate uncertainty). Suppose the representative buyer acquires and then deposits $\hat{m}$ and $\hat{a}$, where we can restrict attention to the case where buyers bank all their assets. Also, without loss of generality, we can restrict attention to contracts with $m^N > 0$ and $a^N = 0$, since buyers have no use for equity in nonmonitored meetings, and therefore to contracts where $a^M = \hat{a}/(1-\eta)$, but we have to sort out below whether $m^M > 0$ or $m^M = 0$; all we know so far is that $\eta m^N + (1-\eta)m^M = \hat{m}$. We maintain the assumptions that buyers make take-it-or-leave-it offers in the DM and $c(x) = x$, so that $x^N = \phi m^N$ and $x^M = \phi m^M + e(\psi + y)$, as before, except now type N buyers go to the DM with m^N dollars while type M go with transferable deposits of m^N dollars plus $\hat{a}/(1-\eta)$ shares. Still it should be clear that we can again take the following for granted: $d^N = m^N$; $d^M = m^M$; $e = \hat{a}/(1-\eta)$ if $\hat{a}/(1-\eta) < a^*$ and $e = a^*$ otherwise; $x^N < x^*$; and, finally, $x^M = \phi m^M + (\psi + y)\hat{a}/(1-\eta)$ if $\hat{a} < a^*$ and $x^M = x^*$.

The objective function for a buyer, and hence for a competitive banker, is exactly $W^b(\cdot)$ as written in (17), except now

$$(30)\quad \begin{aligned} V^b(\hat{m},\hat{a}) &= \eta\left[u\left(x^N\right)+W^b(0,0)\right] \\ &+(1-\eta)\left[u\left(x^M\right)+W^b\left(0,\frac{\hat{a}}{1-\eta}-e\right)\right], \end{aligned}$$

where $x^N = \phi m^N$ and $x^M = \phi m^M + e(\psi + y)$. The same procedure used in Section 5 applies: Insert into the FOC the derivatives of $V^b(\cdot)$ from (30) taking care of whether $\hat{a}/(1-\eta) > a^*$ or vice versa, and also whether $m^M = 0$ or $m^M > 0$. When $\hat{a}/(1-\eta) > a^*$ it should be clear that $m^M = 0$, since type M buyers are already satiated in liquidity without cash. Also, market clearing implies $\hat{a} = 1$ and $\hat{m} = M(1+\mu)$. Hence, in this model, there are three possibilities for equilibrium: (i) $1 > a^*(1-\eta)$ which implies $m^M = 0$ and $x^M = x^*$; (ii) $1 < a^*(1-\eta)$ and $m^M = 0$, which implies $x^M < x^*$; and (iii) $1 < a^*(1-\eta)$ and $m^M > 0$, which also implies $x^M < x^*$. Again, we study each case in turn.

6.1 Case (i)

In this case the supply of equity is plentiful enough that type M buyers are satiated in liquidity, $1 > a^*(1-\eta)$ which implies $x^M = x^*$ and $m^M = 0$, and therefore $m^N = M/\eta$. The procedure described above immediately yields

$$(31)\quad 1+\mu = \beta u'\left(x^N\right)$$

$$(32)\quad \psi = \beta(\psi + y).$$

Thus, equity trades at its fundamental value in the CM, $\psi = \psi^F$, and x^N satisfies the usual condition, which as above could also be written $i = \ell(x^N)$. For this equilibrium to exist, we require $1 > a^*(1-\eta)$, which holds in this case iff

$$(33)\quad y > (1-\eta)(1-\beta)x^*.$$

Also, in this case, the real rate of return on shares is $1/\beta - 1$ independent of μ, and there is a standard Fisher effect.

6.2 Case (ii)

The by now standard procedure tells us that x^N solves (31), the same as in the previous case. However, (32) becomes

$$(34)\quad \psi = \beta(\psi + y)u'\left(x^M\right),$$

where $x^M < x^*$ implies $\psi > \psi^F$. Equity now bears a liquidity premium because it is scarce—even though type M buyers are able to offer $1/(1-\eta)$ shares, it is not enough to get x^*. Using the bargaining solution, which in this case entails $x^M = (\psi + y)/(1-\eta)$, to eliminate ψ in (34) yields a simple equation in x^M. Notice, interestingly enough, that x^M and hence ψ are independent of μ in this case. One can show that for this equilibrium to exist we require that the inequality in (34) goes the other way, and in addition, we must verify that $m^M = 0$ is part of the equilibrium deposit contract. It is straightforward to show this is the case iff $\mu \geq \tilde{\mu}$, where $\tilde{\mu} \in (\beta - 1, 0)$ solves

$$u'\left[\frac{y}{(1-\eta)\tilde{\mu}}\right] = \frac{1+\tilde{\mu}}{\beta}.$$

Notice the real return on shares is below $1/\beta$ but above the real return on money in this equilibrium. The gross nominal interest rate on shares is

$$(1+\mu)\left(\frac{\psi + y}{\psi}\right),$$

where $\mu > \tilde{\mu}$, and

$$\frac{1+\mu}{\beta} > (1+\mu)\left(\frac{\psi + y}{\psi}\right) > 1.$$

Hence, the nominal interest rate on shares is positive when $\mu > \tilde{\mu}$, although when $\mu = \tilde{\mu}$ it goes to zero. Letting r^j denote the real rate of return faced by a type j buyer, from (31) and (32) we have

$$r^j = \frac{x^j}{\eta(1+\mu)x^N + (1-\eta)\frac{\psi}{\psi+y}x^M}.$$

As well the gross nominal interest rate on deposits is

$$(1+\mu)r^M = \frac{x^M}{\eta x^N + (1-\eta)\frac{\psi}{(1+\mu)(\psi+y)}x^M}.$$

Thus, the nominal interest rate on deposits is positive when $x^N < x^M$ and

$$\frac{\psi + y}{\psi} > \frac{1}{1+\mu}$$

and zero when $x^N = x^M$ and

$$\frac{\psi + y}{\psi} = \frac{1}{1+\mu}.$$

6.3 Case (iii)

In this case the deposit contract sets $m^M > 0$ as well as $m^N > 0$ and $\hat{a} > 0$. It is easily shown that the equilibrium contract equates DM consumption for type M and type N buyers, $x^M = x^N$, and we call the common value $x < x^*$. Also, we have

$$(35)\quad 1+\mu = \beta u'(x)$$

$$(36)\quad \psi = \beta(\psi + y)u'(x).$$

By (35), x is given by the usual condition in monetary trades, and (36) determines $\psi > \psi^F$. One can show this equilibrium exists iff the inequality in (33) again goes the other way and $\mu \in [\beta - 1, \tilde{\mu}]$.

Note that in this equilibrium the gross return on shares is below $1/\beta$, but since the real returns on shares and money are identical, the nominal interest rate on shares is 0, as is the nominal interest rate on deposits. Another interesting feature of this case is that an increase in the money growth rate increases the price of shares, has no effect on the nominal interest rate, and reduces the real interest rate. Further, banks hold reserves in equilibrium. Simplistic intuition might tell us that, given the zero nominal rate, monetary policy would encounter some kind of liquidity trap. But changes in the money growth rate μ will change the real allocation, despite the fact that it brings about a change in the quantity of reserves and no change in the nominal rate. So much for simplistic intuition.

6.4 Discussion

The principal role of a bank here is to allocate public and private liquidity to its most efficient uses in transactions. Without banking, some buyers show up in non-monitored DM meetings with shares that are not accepted, while others show up in monitored DM meetings with money that is dominated in rate of return by shares that are equally acceptable. Buyers would be better off if they knew in advance their type (monitored or nonmonitored) in the next DM. If they knew this, they would typically take only cash to nonmonitored meetings and only equity to monitored meetings. Essentially, with banking it is as if buyers knew in advance their type, which in this case corresponds to their need for currency. Banking allows shares to be concentrated in monitored meetings, so more private liquidity can be allocated to where it is useful, and currency to be allocated to nonmonitored meetings where it has an advantage in terms of acceptability, except in the case where public liquidity is useful at the margin for sharing risk between type 1 and type 2 buyers (the case where the bank holds reserves). This is related to, but also goes beyond, the New Monetarist banking model of Berentsen, Camera, and Waller (2007), where the only role of banks is to allocate currency between buyers and sellers. One advantage of including alternative assets is that we can provide a link between liquidity provision and media of exchange, on the one hand, and investment, on the other; see Williamson (2009) for more on this topic.

One can use this simple banking model to shed new light on several issues. In terms of optimal policy, since the cost of maintaining the currency is now $\eta\omega x^N$, our welfare measure becomes

$$W = \eta\left[u\left(x^N\right) - x^N\right] + (1-\eta)\left[u\left(x^M\right) - x^M\right] - \eta\omega x^N.$$

Notice that outside money held as reserves costs nothing to maintain, as this can be interpreted as electronic account balances with the central bank. If $\omega = 0$, then the Friedman rule $\mu = \beta - 1$ is optimal, we get the first best using currency, and banks become irrelevant (buyers can do just as well trading on their own). However, if $\omega > 0$, then $\mu > \beta - 1$ is optimal. There are three cases to consider.

If (33) holds, so deposits are not scarce for any μ, the optimal policy entails $\mu = \beta(1 + \omega) - 1$ and the nominal interest rates on shares and deposits are strictly positive. If inequality (33) goes the other way, $\beta(1 + \eta\omega) < 1$ and

$$u'\left[\frac{y}{(1-\eta)\left[1-\beta(1+\eta\omega)\right]}\right] \geq 1 + \eta\omega,$$

then the optimal policy is $\mu = \beta(1 + \eta\omega) - 1$. In this case, at the optimum, $\mu \geq \tilde{\mu}$, shares are scarce, the nominal interest rate is zero, and the real interest rate is below the rate of time preference. This is novel, in that the usual Friedman rule prescription is to equate real rates of return on all assets, so that the nominal interest rate should be 0. But if $\omega = 0$, we would reduce the money growth rate to $\mu = \beta - 1$, which would increase the real rate of interest to the rate of time preference. Finally, if (33) goes the other way and either $\beta(1 + \eta\omega) \geq 1$ or

$$u'\left[\frac{y}{(1-\eta)\left[1-\beta(1+\eta\omega)\right]}\right] < 1 + \eta\omega,$$

then $\mu = \beta(1 + \omega) - 1$ at the optimum.

In summary, in this model, as long as $\omega > 0$ banks perform a socially useful function.[36] We now use the model to discuss Friedman's (1960) proposal for 100 percent reserve requirements on all transactions deposits, a scheme sometimes referred to as narrow banking. His reasoning was that variability in real economic activity and in the price level arises, perhaps primarily, from variability in the money stock measured by currency in circulation plus transactions deposits. The central bank cannot control inside money, the quantity of transactions deposits, directly, but only the quantity of outside money. However, if all transactions deposits are backed 100 percent by outside money, then the central bank can control the total stock of money perfectly, and can thus cure monetary instability. According to the model presented above, however, this is wrong.

We start with Friedman's premise, which is informed by the quantity theory, that the behavior of some monetary aggregate like M1 is important. In the model, M1 in the DM of period t+1 is

$$(37)\quad M1_{t+1} = M_t + \frac{(\psi + y)}{\phi_{t+1}} = M_t\left(\frac{\eta x_{t+1}^N + \psi + y}{\eta x_{t+1}^N}\right)$$

in equilibria where no bank reserves are held and

$$(38)\quad M1_{t+1} = M_t\left(\frac{x_{t+1} - \psi - y}{x_{t+1}}\right)$$

in equilibria where bank reserves are positive. Here, x_{t+1}^N denotes the consumption of type N buyers in the DM when no bank reserves are held, and x_{t+1} is the consumption of each buyer in the DM when bank reserves are positive. In (37) and (38), the expression in parentheses in each equa-

[36] Adding theft or counterfeiting to the model makes banks even more useful. Indeed, stories about the need for the safekeeping of liquid assets are often used to help students understand how banks developed as institutions that link the provision of transactions services with portfolio management. See He, Huang, and Wright (2008) for an explicit New Monetarist model of theft and the safekeeping role of banks.

tion is the money multiplier, which plays an important role, for example, in the interpretation of historical data by Friedman and Schwartz (1963).

It is hard to think of an interesting question to which the money multiplier would help us with the answer. The reason is that the money multiplier is not invariant to most policy experiments, except for simple one-time increases in the stock of outside money. Since money is neutral, the multiplier does not depend on the level of the money supply, so the multiplier tells us how much M1 increases per unit increase in the stock of base money. Beyond that, we know that x_{t+1}^N depends on μ in (37) and ψ and x_{t+1} depend on μ in (38). The model tells us the details of how a change in μ affects prices and quantities. However, the quantity theory of money does not help us organize our thinking about banks, liquidity, or exchange in this context. Similar ideas apply for other types of monetary policy experiments. If we want to understand the effects of central bank lending and open market operations, as in Williamson (2009), for example, money multiplier analysis does not seem to help.

Note as well that theory provides no particular rationale for adding up certain public and private liabilities (in this case currency and bank deposits), calling the sum money, and attaching some special significance to it. Indeed, there are equilibria in the model where currency and bank deposits are both used in some of the same transactions, both bear the same rate of return, and the stocks of both turn over once each period. Thus, Friedman, if he were alive, might think he had good reason to call the sum of currency and bank deposits money and proceed from there. But what the model tells us is that public and private liquidity play quite different roles. In reality, many assets are used in transactions, broadly defined, including Treasury bills, mortgage-backed securities, and mutual fund shares. We see no real purpose in drawing some boundary between one set of assets and another, and calling members of one set money.[37]

[37] Related discussions can be found in Wallace (1980) and Sargent and Wallace (1982); in a sense we are just restating their ideas in the context of our New Monetarist model.

Suppose the government were to, misguidedly as it turns out, impose 100 percent reserve requirements. At best, this would be a requirement that outside money be held one-for-one against bank deposits. We are now effectively back to the world of the model without banks in the previous section, as holding bank deposits becomes equivalent to holding currency. Agents receive no liquidity insurance, and are worse off than with unfettered banking, since the efficiency gains from the reallocation of liquidity are lost. At worst, suppose the 100 percent reserve requirement is imposed by constraining every transaction to be a trade of outside money for something else, so that shares cannot be used at all in transactions. Then shares will be held from one CM until the next, never trading in the DM, and any benefits from private liquidity are forgone. This obviously reduces welfare. A flaw in Old Monetarism was that it neglected the role of intermediation in allocating resources efficiently. In other related environments (e.g., Williamson, 1999 and 2009, and some examples presented in Williamson and Wright, forthcoming), banks can also be important in reallocating investment and capital efficiently, with the transactions role of bank liabilities being critical in attracting savings to financial intermediaries that can be channeled into investment. In spite of the weaknesses in the quantity theory of money, the reasoning behind the Friedman rule is impeccable, and we take that to be the important legacy of Old Monetarism.

7. CONCLUSION

New Monetarist economists are committed to modeling approaches that are explicit about the frictions that make monetary exchange and related arrangements socially useful and that capture the relationships among credit, banking, and currency transactions. Ideally, economic theories designed for analyzing and evaluating monetary policy should be able to answer basic questions concerning the necessity and role of central banking, the superiority of one type of central bank operating procedure over another, and the differences in the effects of central bank lending and open market operations. New Monetarist economists have made progress in understanding the basic frictions that make monetary exchange an equilibrium or an efficient arrangement, and in understanding the mechanisms by which policy can affect allocations and welfare. However, much remains to be learned about many issues, including the sources of short-run nonneutralities and their quantitative significance, as well as the role of central banking.

With the examples in this paper, and some other examples in our companion paper (Williamson and Wright, forthcoming) concerning payments systems, labor markets, investment, and several other substantive applications, we hope to give some of the flavor of frontier work in the New Monetarist research program. Our principles and our modeling approaches developed thus far have great potential in explaining asset pricing anomalies; the role of public and private liquidity in transactions, both at the retail level and among financial institutions; the functions of collateral; and the relationship between money and credit. Recent events in financial markets and in the broader economy make it clear how important it is to model basic frictions in the financial system. We look forward to developments in this research and are excited about the future prospects for New Monetarism.

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Asset Prices, Liquidity, and Monetary Policy in the Search Theory of Money

Ricardo Lagos

The author presents a search-based model in which money coexists with equity shares on a risky aggregate endowment. Agents can use equity as a means of payment, so shocks to equity prices translate into aggregate liquidity shocks that disrupt the mechanism of exchange. The author characterizes a family of optimal monetary policies and finds that the resulting equity prices are independent of monetary considerations. The author also studies monetary policies that target a constant, but nonzero, nominal interest rate and finds that to the extent that a financial asset is valued as a means to facilitate transactions, the asset's real rate of return will include a liquidity return that depends on monetary considerations. Through this liquidity channel, persistent deviations from an optimal monetary policy can cause the real prices of assets that can be used to relax trading constraints to exhibit persistent deviations from their fundamental values. (JEL E31, E52, G12)

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Many financial assets are held not only for the intrinsic value of the stream of consumption that they yield, but also for their usefulness in facilitating exchange. Consider a buyer who cannot commit to or be forced to honor debts and who wishes to make a purchase from a seller. This buyer would find any asset that is valuable to the seller (e.g., an equity share, a bond, money) helpful to carry out the transaction. For example, the buyer could settle the transaction on the spot by using the asset directly as a means of payment. In some modern transactions, often the buyer uses a financial asset to enter a repurchase agreement with the seller or as collateral to borrow the funds needed to pay the seller. Once stripped from the subsidiary contractual complexities, the essence of these transactions is that the asset helps the untrustworthy buyer to obtain what he wants from the seller. In this sense, many financial assets are routinely used in the exchange process and play a role akin to a medium of exchange—that is, they provide *liquidity*—the term that monetary theorists use to refer to the usefulness of an asset in facilitating transactions.

Financial assets are subject to price fluctuations resulting from aggregate shocks; therefore, to the extent that these assets serve as a source of liquidity, shocks to their prices translate into aggregate liquidity shocks that disrupt the mechanism of exchange and the ensuing allocations. Recent developments in financial markets have renewed economists' interest in the idea that fluctuations in asset prices can disrupt the exchange process in some key markets and, through this channel, propagate to the macroeconomy.

Much of the policy advice offered to central banks is framed in terms of simple interest rate feedback rules loosely motivated by a particular class of models in which the preeminent friction is a specific type of reduced-form nominal rigidity. Such policy recommendations are based on

Ricardo Lagos is an associate professor of economics at New York University. Financial support from the C.V. Starr Center for Applied Economics at New York University is gratefully acknowledged.

the premise that the primary goal of monetary policy is to mitigate the effects of these rigidities. With no room or role for a notion of liquidity (and typically even no meaningful role for money), this conventional view that dominates policy circles has failed to offer relevant policy guidance in the midst of the recent financial crisis. I interpret this failure as an indication that the consensus stance toward monetary policy, with its theoretical focus on sticky price frictions and its implementation emphasis on ad hoc feedback interest rate rules, is too narrow in that it neglects the fundamental frictions that give rise to a demand for liquidity.

In this article, I present a dynamic equilibrium, microfounded monetary asset–pricing framework with multiple assets and aggregate uncertainty regarding liquidity needs, and discuss the main normative and positive policy implications of the theory. The broad view that emerges from explicitly modeling the role of money and other liquid assets in the exchange process is that of a monetary authority that seeks to provide the private sector with the liquidity needed to conduct market transactions. More precisely, I state and explain three propositions that answer the following questions: How should monetary policy be conducted to mitigate the adverse effects of shocks to the valuations of the financial assets that provide liquidity to the private sector? What are the implications for asset prices of deviating from the optimal monetary policy? Are such deviations capable of inflating real asset prices above their fundamental values for extended periods of time?

MODEL

In this section I outline a bare-bones model that encompasses the key economic mechanisms.[1] The model combines elements of the asset-pricing model of Lucas (1978) with elements of the model of monetary exchange of Lagos and Wright (2005). Time is discrete and the horizon infinite. There is a [0,1] continuum of infinitely lived agents. Each time period is divided into two subperiods during which different activities take place. There are three nonstorable and perfectly divisible consumption goods at each date: *fruit*, *general goods*, and *special goods*. Fruit and general goods are homogeneous goods, whereas special goods come in many varieties. The only durable commodity in the economy is a set of "Lucas trees." The number of trees is fixed and equal to the number of agents. Trees yield (the same amount of) a random quantity x_t of fruit in the second subperiod of every period t. The realization of x_t becomes known to all at the beginning of period t (when agents enter the first subperiod). Production of fruit is entirely exogenous: No resources are used and it is not possible to affect the output at any time. The motion of x_t is assumed to follow a Markov process, defined by its transition function

$$F(x', x) = \Pr(x_{t+1} \leq x' | x_t = x).$$

For each fixed x, $F(\cdot, x)$ is a distribution function with support $\Xi \subseteq (0,\infty)$.

In each subperiod, every agent is endowed with $\bar{n}$ units of time that can be used as labor services. In the second subperiod, each agent has access to a linear production technology that transforms labor services into general goods. In the first subperiod, each agent has access to a linear production technology that transforms his own labor input into a particular variety of the special good that the agent does not consume. This specialization is modeled as follows: Given two agents i and j drawn at random, there are three possible events. The probability that i consumes the variety of special good that j produces but not vice versa (a single coincidence) is denoted α. Symmetrically, the probability that j consumes the special good that i produces but not vice versa is also α. In a single-coincidence meeting, the agent who wishes to consume is the *buyer*, and the agent who produces is the *seller*. The probability that neither wants what the other can produce is $1 - 2\alpha$, with $\alpha \leq 1/2$. Fruit and general goods are homogeneous and hence consumed (and in the case of general goods, also produced) by all agents.

In the first subperiod, agents participate in a *decentralized market* where trade is bilateral (each meeting is a random draw from the set of pairwise meetings), and the terms of trade are

[1] The analysis that follows is based on Lagos (2006, 2009, 2010).

determined by bargaining (a take-it-or-leave-it offer by the buyer, for simplicity). The specialization of agents over consumption and production of the special good, combined with bilateral trade, creates a double-coincidence-of-wants problem in the first subperiod. In the second subperiod, agents trade in a *centralized market*. Agents cannot make binding commitments, and trading histories are private in a way that precludes any borrowing and lending between people, so all trade—both in the centralized and decentralized markets—must be quid pro quo.

Each tree has outstanding one durable and perfectly divisible equity share that represents the bearer's ownership and confers to the owner the right to collect the fruit dividends. A second financial asset, money, is intrinsically useless (it is not an argument of any utility or production function), and unlike equity, ownership of money does not constitute a right to collect any resources. Money is issued by a "government" that at $t = 0$ commits to a monetary policy represented by a sequence of positive real-valued functions, $\{\mu_t\}_{t=0}^{\infty}$. Given an initial stock of money, $M_0 > 0$, a monetary policy induces a money supply process, $\{M_t\}_{t=0}^{\infty}$, by means of $M_{t+1} = \mu_t(x^t)M_t$, where x^t denotes a history of realizations of fruit dividends through period t—that is, $x^t = (x_t, x_{t-1},\ldots, x_0)$. The government injects or withdraws money through lump-sum transfers or taxes in the second subperiod of every period; thus, along every sample path, $M_{t+1} = M_t + T_t$, where T_t is the lump-sum transfer (or tax, if negative). All assets are perfectly recognizable, cannot be forged, and can be traded among agents in both the centralized and decentralized markets. At $t = 0$, each agent is endowed with a_0^s equity shares and a_0^m units of fiat money.

Let the utility function for special goods, $u : \mathbb{R}^+ \to \mathbb{R}^+$, and the utility function for fruit, $U : \mathbb{R}^+ \to \mathbb{R}^+$, be continuously differentiable, bounded by B on Ξ, increasing, and strictly concave, with $u(0) = U(0)$. Let $-n$ be the utility from working n hours in the first subperiod. Also, suppose there exists $q^* \in (0,\infty)$ defined by $u'(q^*) = 1$, with $q^* \le \bar{n}$. Let both the utility for general goods and the disutility from working in the second subperiod be linear. The agent prefers a sequence $\{q_t, n_t, c_t, y_t, h_t\}_{t=0}^{\infty}$ over another sequence $\{\tilde{q}_t, \tilde{n}_t, \tilde{c}_t, \tilde{y}_t, \tilde{h}_t\}_{t=0}^{\infty}$ if

$$\liminf_{T\to\infty} E_0 \sum_{t=0}^{T} \Big\{ \beta^t \big[u(q_t) - n_t + U(c_t) + y_t - h_t \big] - \beta^t \big[u(\tilde{q}_t) - \tilde{n}_t + U(\tilde{c}_t) + \tilde{y}_t - \tilde{h}_t \big] \Big\} \ge 0,$$

where $\beta \in (0,1)$, q_t and n_t are the quantities of special goods consumed and produced in the decentralized market, c_t denotes consumption of fruit, y_t consumption of general goods, h_t the hours worked in the second subperiod, and E_t is an expectations operator conditional on the information available to the agent at time t, defined with respect to the matching probabilities and the probability measure induced by F.

Next, consider the individual optimization problems. Let $\boldsymbol{a}_t = (a_t^s, a_t^m)$ denote the portfolio of an agent who holds a_t^s shares and a_t^m units of money. Let $W_t(\boldsymbol{a}_t)$ and $V_t(\boldsymbol{a}_t)$ be the maximum attainable expected discounted utility of an agent who enters the centralized and decentralized market, respectively, at time t with portfolio $\boldsymbol{a}_t$. Then,

$$W_t(\boldsymbol{a}_t) = \max_{c_t, y_t, h_t, \boldsymbol{a}_{t+1}} \Big\{ U(c_t) + y_t - h_t + \beta E_t V_{t+1}(\boldsymbol{a}_{t+1}) \Big\}$$

$$\text{(1)} \quad \text{s.t. } c_t + w_t y_t + \phi_t^s a_{t+1}^s + \phi_t^m a_{t+1}^m = (\varphi_t^s + x_t) a_t^s + \phi_t^m (a_t^m + T_t) + w_t h_t$$

$$0 \le c_t,\ 0 \le h_t \le \bar{n},\ 0 \le \boldsymbol{a}_{t+1}.$$

The agent chooses consumption of fruit (c_t), consumption of general goods (y_t), labor supply (h_t), and an end-of-period portfolio ($\boldsymbol{a}_{t+1}$). Fruit is used as numéraire: w_t is the relative price of the general good, ϕ_t^s is the (ex-dividend) price of a share, and $1/\phi_t^m$ is the dollar price of fruit.

Let $[q_t(\boldsymbol{a}, \tilde{\boldsymbol{a}}), \boldsymbol{p}_t(\boldsymbol{a}, \tilde{\boldsymbol{a}})]$ denote the terms at which a buyer who owns portfolio $\boldsymbol{a}$ trades with a seller who owns portfolio $\tilde{\boldsymbol{a}}$, where $q_t(\boldsymbol{a}, \tilde{\boldsymbol{a}}) \in \mathbb{R}^+$ is the quantity of a special good traded, and $\boldsymbol{p}_t(\boldsymbol{a}, \tilde{\boldsymbol{a}}) = [p_t^s(\boldsymbol{a}, \tilde{\boldsymbol{a}}), p_t^m(\boldsymbol{a}, \tilde{\boldsymbol{a}})] \in \mathbb{R}^+ \times \mathbb{R}^+$ is the transfer of assets from the buyer to the seller (the first argument is the transfer of equity). Consider a meeting in the decentralized market of period t between a buyer with portfolio $\boldsymbol{a}_t$ and a seller with portfolio $\tilde{\boldsymbol{a}}_t$. The terms of trade, $(q_t, \boldsymbol{p}_t)$, are determined by Nash bargaining where the buyer has all the bargaining power:

$$\max_{q_t,\ \boldsymbol{p}_t \le \boldsymbol{a}_t} \left[u(q_t) + W_t(\boldsymbol{a}_t - \boldsymbol{p}_t) - W_t(\boldsymbol{a}_t)\right]$$
$$\text{s.t. } W_t(\tilde{\boldsymbol{a}}_t + \boldsymbol{p}_t) - q_t \ge W_t(\tilde{\boldsymbol{a}}_t).$$

The constraint $\boldsymbol{p}_t \le \boldsymbol{a}_t$ indicates that the buyer in a bilateral meeting cannot spend more assets than he owns. Let $\boldsymbol{\lambda}_t = (\boldsymbol{\lambda}_t^s, \boldsymbol{\lambda}_t^m)$, with $\boldsymbol{\lambda}_t^s \equiv (\phi_t^s + x_t)/w_t$ and $\boldsymbol{\lambda}_t^m \equiv \phi_t^m/w_t$. The bargaining outcome is as follows: If $\boldsymbol{\lambda}_t\boldsymbol{a}_t \ge q^*$, the buyer buys $q_t = q^*$ in exchange for a vector $\boldsymbol{p}_t$ of assets with real value $\boldsymbol{\lambda}_t\boldsymbol{p}_t = q^* \le \boldsymbol{\lambda}_t\boldsymbol{a}_t$. Otherwise, he pays the seller $\boldsymbol{p}_t = \boldsymbol{a}_t$, in exchange for $q_t = \boldsymbol{\lambda}_t\boldsymbol{a}_t$. Hence, the quantity of the special good exchanged is $\min(\boldsymbol{\lambda}_t\boldsymbol{a}_t, q^*) \equiv q(\boldsymbol{\lambda}_t\boldsymbol{a}_t)$, and the real value of the portfolio used as payment is $\boldsymbol{\lambda}_t\boldsymbol{p}_t(\boldsymbol{a}_t, \tilde{\boldsymbol{a}}_t) = q(\boldsymbol{\lambda}_t\boldsymbol{a}_t)$.

Given the bargaining solution, the value of search to an agent who enters the decentralized market of period t with portfolio $\boldsymbol{a}_t$ can be written as

$$V_t(\boldsymbol{a}_t) = S(\boldsymbol{\lambda}_t\boldsymbol{a}_t) + W_t(\boldsymbol{a}_t),$$

where $S(x) \equiv \alpha\{u[q(x)] - q(x)\}$ is the expected gain from trade in the decentralized market. Substitute the budget constraint (equation (1)) and $V_t(\boldsymbol{a}_t)$ into the right-hand side of $W_t(\boldsymbol{a}_t)$ to arrive at

$$W_t(\boldsymbol{a}_t) = \boldsymbol{\lambda}_t\boldsymbol{a}_t + \tau_t + \max_{c_t \ge 0}\left[U(c_t) - \tfrac{c_t}{w_t}\right]$$
$$+ \max_{\boldsymbol{a}_{t+1} \ge 0}\left\{-\tfrac{\boldsymbol{\phi}_t\boldsymbol{a}_{t+1}}{w_t} + \beta E_t\left[S(\boldsymbol{\lambda}_{t+1}\boldsymbol{a}_{t+1}) + W_{t+1}(\boldsymbol{a}_{t+1})\right]\right\},$$

where $\tau_t = \lambda_t^m T_t$ and $\boldsymbol{\lambda}_t = (\lambda_t^s, \lambda_t^m)$.

Given a process $\{M_t\}_{t=0}^\infty$, an equilibrium is a plan $\{c_t, \boldsymbol{a}_{t+1}\}_{t=0}^\infty$, pricing functions $\{w_t, \boldsymbol{\phi}_t\}_{t=0}^\infty$, and bilateral terms of trade $\{q_t, \boldsymbol{p}_t\}_{t=0}^\infty$ such that (i) given prices and the bargaining protocol, $\{c_t, \boldsymbol{a}_{t+1}\}_{t=0}^\infty$ solves the agent's optimization problem; (ii) the terms of trade are determined by Nash bargaining—that is, $q_t = \min(\boldsymbol{\lambda}_t\boldsymbol{a}_t, q^*)$ and $\boldsymbol{\lambda}_t\boldsymbol{p}_t = q_t$; and (iii) the centralized market clears—that is, $c_t = x_t$ and $a_{t+1}^s = 1$. The equilibrium is *monetary* if $\phi_t^m > 0$ for all t, and in this case the money-market clearing condition is $a_{t+1}^m = M_{t+1}$. The market-clearing conditions imply $\{c_t, a_{t+1}^s, a_{t+1}^m\}_{t=0}^\infty = \{x_t, 1, M_{t+1}\}_{t=0}^\infty$, $w_t = 1/U'(w_t)$, and once $\{\boldsymbol{\phi}_t\}_{t=0}^\infty$ has been found, $\{q_t\}_{t=0}^\infty = \{\boldsymbol{\lambda}_t\boldsymbol{p}_t\}_{t=0}^\infty = \{\min(\Lambda_{t+1}, q^*)\}_{t=0}^\infty$, where $\Lambda_{t+1} \equiv \lambda_{t+1}^s + \lambda_{t+1}^m M_{t+1}$. Therefore, given a money supply process $\{M_t\}_{t=0}^\infty$ and letting $L(\Lambda_{t+1}) \equiv [1 + S'(\Lambda_{t+1})]$, a monetary equilibrium can be summarized by a sequence $\{\boldsymbol{\phi}_t\}_{t=0}^\infty$ that satisfies the following necessary and sufficient conditions for individual optimization:

$$U'(x_t)\phi_t^s = \beta E_t\left[L(\Lambda_{t+1})U'(x_{t+1})(\phi_{t+1}^s + x_{t+1})\right]$$

$$U'(x_t)\phi_t^m = \beta E_t\left[L(\Lambda_{t+1})U'(x_{t+1})\phi_{t+1}^m\right]$$

$$\lim_{t\to\infty} E_0\left[\beta^t U'(x_t)\phi_t^s\right] = 0$$

$$\lim_{t\to\infty} E_0\left[\beta^t U'(x_{t+1})\phi_{t+1}^m M_{t+1}\right] = 0.$$

NORMATIVE RESULTS: OPTIMAL POLICY AND IMPLEMENTATION

The Pareto optimal allocation in this environment can be found by solving the problem of a social planner who wishes to maximize average (equally weighted across agents) expected utility. The planner chooses a plan $\{c_t, q_t, n_t, y_t, h_t\}_{t=0}^\infty$ subject to the feasibility constraints—that is, $0 \le c_t \le d_t$, $y_t \le h_t$, and $0 \le q_t \le n_t$ for those agents who are matched in the first subperiod of period t and $q_t = n_t = 0$ for those agents who are not. Under these constraints, the planner's problem consists of finding a feasible plan $\{c_t, q_t\}_{t=0}^\infty$ such that

$$\liminf_{T\to\infty} E_0 \sum_{t=0}^{T} \left\{\beta^t\left\{\alpha\left[u(q_t) - q_t\right] + U(c_t)\right\} - \beta^t\left\{\alpha\left[u(\tilde{q}_t) - \tilde{q}_t\right] + U(\tilde{c}_t)\right\}\right\} \ge 0$$

for all feasible plans $\{\tilde{c}_t, \tilde{q}_t\}_{t=0}^\infty$. Here, E_0 denotes the expectation with respect to the probability measure over sequences of dividend realizations induced by F. The solution is $\{c_t, q_t\}_{t=0}^\infty = \{x_t, q^*\}_{t=0}^\infty$. In equilibrium, $c_t = x_t$—that is, the equilibrium consumption of fruit is at the efficient level. However, the equilibrium allocation has $q_t \le q^*$, which may hold with strict inequality in some states. That is, in a monetary equilibrium, consumption and production in the decentralized market may be below their efficient levels.

It is convenient to introduce the following notion of a *nominal interest rate* before stating the results. Consider an *illiquid nominal bond*—a one-period, risk-free government bond that pays a unit of money in the centralized market and cannot be used in decentralized exchange. Let ϕ_t^n denote the price of this asset. In equilibrium, this price must satisfy $U'(x_t)\phi_t^n = \beta E_t[U'(x_{t+1})\phi_{t+1}^m]$. Since ϕ_t^n/ϕ_t^m is the money price of a nominal bond, the (net) nominal interest rate in a monetary equilibrium is $i_t = \phi_t^m/\phi_t^n - 1$ or, equivalently,

$$(2) \quad i_t = \frac{E_t\left[L(\Lambda_{t+1})\lambda_{t+1}^m\right]}{E_t\left(\lambda_{t+1}^m\right)} - 1.$$

Proposition 1 *Equilibrium quantities in a monetary equilibrium are Pareto optimal if and only if $i_t = 0$ with probability 1, for all t.*

Proposition 1 establishes the optimality of the *Friedman rule*—Milton Friedman's (1969) prescription that monetary policy should induce a zero nominal interest rate to lead to an optimal allocation of resources. The proof is as follows: The equilibrium allocation is efficient if and only if $q_t(\Lambda_t) = q^*$, and this equality holds if and only if $\Lambda_t \geq q^*$—that is, if and only if the real value of the equilibrium portfolio, Λ_t, is at least as large as the real liquidity needs, represented by q^*. The nominal interest rate, i_t, is zero if and only if $L(\Lambda_{t+1}) = 1$, and this equality holds if and only if $\Lambda_t \geq q^*$. Hence, $q_t(\Lambda_t) = q^*$ if and only if $i_t = 0$. Intuitively, the cost of producing real balances is zero to the government, so the optimum quantity of real balances should be such that the marginal benefit—which in equilibrium equals the marginal cost, i_t—is zero to the economic agents.

I next turn to the question of implementation: Which monetary policies are consistent with a monetary equilibrium in which the nominal interest rate is at its optimal target level of zero? The following result addresses the issue of (weak) implementation by characterizing a family of monetary policies that are consistent with an equilibrium with $i_t = 0$ for all t.

Proposition 2

$$\textit{Let} \quad \phi_t^{s*} = E_t \sum_{j=1}^{\infty} \beta^j \frac{U'(x_{t+j})}{U'(x_t)} x_{t+j},$$

$\lambda_t^{s*} = U'(x_t)(\phi_t^{s*} + x_t)$, and $\mathcal{T}$ be the set of dates for which $q^* - \lambda_t^{s*} > 0$ holds with probability $\pi_t > 0$. Assume that $\inf_{t \in \mathcal{T}} \pi_t > 0$. A monetary equilibrium with $i_t = 0$ with probability 1 for all t exists under a deterministic money supply process $\{M_t\}_{t=0}^{\infty}$ if and only if the following two conditions hold:

$$(3) \quad \lim_{t\to\infty} M_t = 0$$

$$(4) \quad \inf_{t\in\mathcal{T}} M_t \beta^{-t} > 0 \;\text{ if }\; \mathcal{T} \neq \varnothing.$$

Conditions (3) and (4) are rather unrestrictive asymptotic conditions. Condition (3) requires that the money supply converges to zero. Condition (4) requires that asymptotically, on average over the set of dates $\mathcal{T}$ when fiat money plays an essential role, the growth rate of the money supply must be at least as large as the rate of time preference. Versions of this result have been proven by Wilson (1979) and Cole and Kocherlakota (1998) for deterministic competitive economies with cash-in-advance constraints that are imposed on agents every period with probability 1.

Proposition 2 has several implications. First, even though liquidity needs are stochastic in this environment (because equity, whose value is stochastic, can be used alongside money as a means of payment), a deterministic money-supply sequence can suffice to implement a zero nominal rate in every state of the world. Second, even within the class of deterministic monetary policies, there is a large family of policies that can implement the Pareto optimal equilibrium. Finally, it would be impossible for someone with access to a finite time-series for the path of the money supply to determine whether an optimal monetary policy is being followed. On the other hand, a single observation of a positive nominal rate constitutes definitive evidence of a deviation from an optimal monetary policy.

POSITIVE RESULTS: INTEREST RATE TARGETS AND ASSET PRICES

In this section, I consider perturbations of the optimal monetary policy that consist of targeting a constant positive nominal interest rate, and then discuss some positive implications of changes in the nominal interest rate target for the inflation rate, equity prices, and equity returns. To this end, it is convenient to focus on a recursive formulation in which prices are invariant functions of the aggregate state $\boldsymbol{s}_t = (x_t, M_t)$—that is, $\phi_t^s = \phi^s(\boldsymbol{s}_t)$, $\phi_t^m = \phi^m(\boldsymbol{s}_t)$, and $\boldsymbol{\lambda}_t = (\lambda^s(\boldsymbol{s}_t), \lambda^m(\boldsymbol{s}_t))$, where $\lambda^s(\boldsymbol{s}_t) = U'(x_t)[\phi^s(\boldsymbol{s}_t) + x_t]$, $\lambda^m(\boldsymbol{s}_t) = U'(x_t)\phi^m(\boldsymbol{s}_t)$, and $\Lambda_t = \lambda^s(\boldsymbol{s}_t) + \lambda^m(\boldsymbol{s}_t)M_t$. Also, I restrict attention to stationary monetary policies—that is, $\mu : \Xi \to \mathbb{R}^+$, so that $M_{t+1} = \mu(x_t)M_t$. To illustrate the main ideas as simply as possible, the following proposition focuses the analysis on the case of i.i.d. dividends and liquidity constraints that would bind with probability 1 at every date in the absence of money.

Proposition 3 *Assume* $dF(x', x) = dF(x)$. Let $l(\delta) = 1 - \alpha + \alpha u'(\delta q^*)$ *and* $\underline{\delta}$ *be defined by* $l(\underline{\delta}) = 1/\beta$. *Let* $\delta_0 \in (\underline{\delta},1)$ *be given, and suppose that* $B \leq [1 - \beta l(\delta_0)]\delta_0 q^*$. *Then for any* $\delta \in [\delta_0,1]$, *there exists a recursive monetary equilibrium under the monetary policy*

$$\mu(x;\delta) = \beta l(\delta)\frac{\delta q^* - \frac{1}{1-\beta l(\delta)}\int x'U'(x')dF(x')}{\delta q^* - \frac{\beta l(\delta)}{1-\beta l(\delta)}\int x'U'(x')dF(x') - xU'(x)}. \tag{5}$$

The equilibrium prices of equity and money are

$$\phi^s(x;\delta) = \frac{\beta l(\delta)}{1-\beta l(\delta)}\frac{\int x'U'(x')dF(x')}{U'(x)} \quad \text{and} \tag{6}$$

$$\phi^m(\boldsymbol{s};\delta) = \frac{\delta q^* - \frac{\beta l(\delta)}{1-\beta l(\delta)}\int x'U'(x')dF(x') - xU'(x)}{U'(x)M}. \tag{7}$$

Together with equation (2), the asset prices in equations (6) and (7) imply that the monetary policy (equation (5)) induces an equilibrium gross nominal interest rate that is constant (independent of $\boldsymbol{s}$) and equal to $l(\delta) \geq 1$ (with equality only if $\delta = 1$). The function $\mu(\cdot;\delta)$ defines a class of monetary policies indexed by the parameter δ, which effectively determines the level of the constant nominal interest rate implemented by the policy. According to equation (7), real money balances and the value of money are decreasing in the nominal interest rate target (increasing in δ). According to equation (6), under the proposed policy, the real price of equity is increasing in the nominal interest rate target (decreasing in δ). As $\delta \to 1$, $l(\delta) \to 1$, and therefore (according to Proposition 1) the policy $\mu(x;\delta)$ approaches an optimal policy under which the recursive monetary equilibrium decentralizes the Pareto optimal allocation.

Notice that $\phi^s(x;1)$ is the "fundamental" equilibrium equity price that would result in a Lucas (1978) economy with no liquidity needs. Therefore, the fact that $\phi^s(x;1) < \phi^s(x;\delta)$ for all x and any $\delta \in [\delta_0,1)$ implies that deviations from the optimal policy "inflate" real asset prices above the value that a financial analyst would calculate based on the expected stream of dividends discounted by the Lucas stochastic discount factor, $\beta U'(x_{t+1})/U(x_t)$.

On average, liquidity considerations generate a negative relationship between the nominal interest rate (and the inflation rate) and equity returns: If the target nominal rate, $l(\delta) - 1$, is higher, the average inflation rate is higher, real money balances are lower, and the liquidity return on equity rises, which causes its price to rise and its measured real rate of return to fall. Intuitively, a higher nominal interest rate target implies that buyers are on average short of liquidity, so equity becomes more valuable as it is used by buyers to relax their trading constraints. This additional liquidity value causes the real financial return on equity to be lower, on average, at a higher interest rate.

Proposition 3 also shows explicitly how monetary policy must be conducted to support a recursive monetary equilibrium with a constant nominal interest rate (with the Pareto optimal equilibrium in which the nominal rate is zero as a special case): The growth rate of the money supply must be relatively low following states in which the real value of the equilibrium equity holdings is below average. Equivalently, the implied inflation rate will be relatively low between state x and a next-period state x', if the realized real value of the equilibrium equity holdings in state x is below the state-x conditional expectation of its value next period.

CONCLUSION

I have presented a simple version of a prototypical search-based monetary model in which money coexists with a financial asset that yields a risky real return. In this formulation, money is not assumed to be the only asset that must, nor the only asset that can, play the role of a medium of exchange: Nothing in the environment prevents agents from using equity along with money, or instead of money, as a means of payment. Since the equity share is a claim to a risky aggregate endowment, the fact that agents can use equity to finance purchases implies that they face aggregate liquidity risk, in the sense that in some states of the world, the value of equity holdings may ultimately be too low relative to what would be needed to carry out the transactions that require a medium of exchange. This seems like a natural starting point to study the role of money and monetary policy in providing liquidity to lubricate the mechanism of exchange in modern economies.

In this context, I characterized a large family of optimal monetary policies. Every policy in this family implements Friedman's prescription of zero nominal interest rates. Under an optimal policy, equity prices and returns are independent of monetary considerations. I have also studied a class of monetary policies that target a constant, but nonzero, nominal interest rate. For this perturbation of the family of optimal policies, I found that the model articulates the idea that, to the extent that a financial asset is valued as a means to facilitate transactions, the asset's real rate of return will include a liquidity return that depends on monetary considerations. As a result of this liquidity channel, persistent deviations from the optimal monetary policy will cause the real prices of assets that can be used to relax borrowing or other trading constraints to exhibit persistent deviations from their fundamental values.

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Reading the Recent Monetary History of the United States, 1959-2007

Jesús Fernández-Villaverde, Pablo Guerrón-Quintana, and Juan F. Rubio-Ramírez

In this paper the authors report the results of the estimation of a rich dynamic stochastic general equilibrium (DSGE) model of the U.S. economy with both stochastic volatility and parameter drifting in the Taylor rule. They use the results of this estimation to examine the recent monetary history of the United States and to interpret, through this lens, the sources of the rise and fall of the Great Inflation from the late 1960s to the early 1980s and of the Great Moderation of business cycle fluctuations between 1984 and 2007. Their main findings are that, while there is strong evidence of changes in monetary policy during Chairman Paul Volcker's tenure at the Federal Reserve, those changes contributed little to the Great Moderation. Instead, changes in the volatility of structural shocks account for most of it. Also, although the authors find that monetary policy was different under Volcker, they do not find much evidence of a big difference in monetary policy among the tenures of Chairmen Arthur Burns, G. William Miller, and Alan Greenspan. The difference in aggregate outcomes across these periods is attributed to the time-varying volatility of shocks. The history for inflation is more nuanced, as a more vigorous stand against it would have reduced inflation in the 1970s, but not completely eliminated it. In addition, they find that volatile shocks (especially those related to aggregate demand) were important contributors to the Great Inflation.
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1. INTRODUCTION

Uncovering the rationales behind monetary policy is hard. While the instruments of policy, such as the federal funds rate or reserve requirements, are directly observable, the process that led to their choice is not. Instead, we have the documentary record of the minutes of different meetings, the memoirs of participants in the process, and the internal memos circulated within the Federal Reserve System.

Although this paper trail is valuable, it is not and cannot be a complete record of the policy process. First and foremost, documents are not a perfect photograph of reality. For example, participants at Federal Open Market Committee (FOMC) meetings do not necessarily say or vote what they really would like to say or vote, but what they think is appropriate at the moment given their objectives and their assessment of the strategic interactions among the members of the committee. (The literature on cheap talk and strategic voting is precisely based on those insights.) Also, memoirs are often incomplete or faulty and staff memos are the product of negotiations and compromises among several actors. Second, even the most com-

Jesús Fernández-Villaverde is an associate professor of economics at the University of Pennsylvania, a research associate for the National Bureau of Economic Research, a research affiliate for the Centre for Economic Policy Research, and a research associate chair for FEDEA (Fundación de Estudios de Economía Aplicada). Pablo Guerrón-Quintana is an economist at the Federal Reserve Bank of Philadelphia. Juan F. Rubio-Ramírez is an associate professor of economics at Duke University and a visiting scholar at the Federal Reserve Bank of Atlanta and FEDEA. The authors thank André Kurmann, Jim Nason, Frank Schorfheide, Tao Zha, and participants at several seminars for useful comments and Béla Személy for invaluable research assistance. The authors also thank the National Science Foundation for financial support.

plete documentary evidence cannot capture the full richness of a policy decision process in a modern society. Even if it could, it would probably be impossible for any economist or historian to digest the whole archival record.[1] Third, even if we could forget for a minute about the limitations of the documents, we would face the fact that actual decisions tell us only about what was done, but say little about what would have been done in other circumstances. And while the absence of an explicit counterfactual may be a minor problem for historians, it is a deep flaw for economists who are interested in evaluating policy rules and making recommendations regarding the response to future events that may be very different from past experiences.

Therefore, in this paper we investigate the history of monetary policy in the United States from 1959 to 2007 from a different perspective. We build and estimate a rich dynamic stochastic general equilibrium (DSGE) model of the U.S. economy with both stochastic volatility and parameter drifting in the Taylor rule that determines monetary policy. Then, we use the results of our estimation to examine, through the lens of the model, the recent monetary policy history of the United States. Our attention is focused primarily on understanding two fundamental observations: (i) the rise and fall of the Great Inflation from the late 1960s to the early 1980s, the only significant peacetime inflation in U.S. history, and (ii) the Great Moderation of business cycle fluctuations that the U.S. economy experienced between 1984 and 2007, as documented by Kim and Nelson (1998), McConnell and Pérez-Quirós (2000), and Stock and Watson (2003).

All the different elements in our exercise are necessary. We need a DSGE model because we are interested in counterfactuals. Thus, we require a model that is structural in the sense of Hurwicz (1962)—that is, invariant to interventions such as the ones that we consider. We need a model with stochastic volatility because, otherwise, any changes in the variance of aggregate variables would be interpreted as the consequence of variations in monetary policy. The evidence in Sims and Zha (2006), Fernández-Villaverde and Rubio-Ramírez (2007), and Justiniano and Primiceri (2008) points out that these changes in volatility are first-order considerations when we explore the data. We need a model with parameter drifting in the monetary policy rule because we want to introduce changes in policy that obey a fully specified probability distribution, and not a once-and-for-all change around 1979-80, as is often postulated in the literature (for example, in Clarida, Galí, and Gertler, 2000, and Lubick and Schorfheide, 2004).

In addition to using our estimation to interpret the recent monetary policy history of the United States, we follow Sims and Zha's (2006) call to connect estimated changes to historical events. (We are also inspired by Cogley and Sargent, 2002 and 2005.) In particular, we discuss how our estimation results relate to both the observations about the economy—for instance, how our model interprets the effects of oil shocks—and the written record.

Our main findings are that, although there is strong evidence of changes in monetary policy during Chairman Paul Volcker's tenure at the Fed, those changes contributed little to the Great Moderation. Instead, changes in the volatility of structural shocks account for most of it. Also, although we find that monetary policy was different under Volcker, we do not find much evidence of a difference in monetary policy among the tenures of Chairmen Arthur Burns, G. William Miller, and Alan Greenspan. The reduction in the volatility of aggregate variables after 1984 is attributed to the time-varying volatility of shocks. The history for inflation is more subtle. According to our estimated model, a more aggressive stance of monetary policy would have reduced inflation in the 1970s, but not completely eliminated it. In addition, we find that volatile shocks (especially

[1] For instance, Allan Meltzer (2010), in his monumental *A History of the Federal Reserve*, uses the summaries of the minutes of FOMC meetings compiled by nine research assistants (volume 2, book 1, page X). This shows how even a several-decades-long commitment to getting acquainted with the archives is not enough to process all the relevant information. Instead, it is necessary to rely on summaries, with all the potential biases and distortions that they might bring. This is, of course, not a criticism of Meltzer: He just proceeded, as many other great historians do, by standing on the shoulders of others. Otherwise, modern archival research would be plainly impossible.

those related to aggregate demand) were important contributors to the Great Inflation.

Most of the material in this paper is based on a much more extensive and detailed work by Fernández-Villaverde, Guerrón-Quintana, and Rubio-Ramírez (2010), in which we (i) present the DSGE model in all of its detail, (ii) characterize the decision rules of the agents, (iii) build the likelihood function, and (iv) estimate the model. Here, we concentrate instead on understanding recent U.S. monetary history through the lens of our theory.

2. A DSGE MODEL OF THE U.S. ECONOMY WITH STOCHASTIC VOLATILITY AND PARAMETER DRIFTING

As we argued in the introduction, we need a structural equilibrium model of the economy to evaluate the importance of each of the different mechanisms behind the evolution of inflation and aggregate volatility in the United States over the past several decades. However, while the previous statement is transparent, it is much less clear how to decide which particular elements of the model to include. On the one hand, we want a model that is sufficiently detailed to account for the dynamics of the data reasonably well. But this goal conflicts with the objective of having a parsimonious and soundly microfounded description of the aggregate economy.

Given our investigation, a default choice for a model is a standard DSGE economy with nominal rigidities, such as the ones in Christiano, Eichenbaum, and Evans (2005) or Smets and Wouters (2003). This class of models is currently being used to inform policy in many central banks and is a framework that has proven to be successful at capturing the dynamics of the data. However, we do not limit ourselves to a standard DSGE model. Instead, we extend it in what we think are important and promising directions by incorporating stochastic volatility into the structural shocks and parameter drifting in the Taylor rule that governs monetary policy.

Unfortunately, for our purposes, the model has two weak points that we must acknowledge before proceeding further: money and Calvo pricing. Most DSGE models introduce a demand for money through money in the utility function (MIA) or cash in advance (CIA). By doing so, we endow money with a special function without sound justification. This hides inconsistencies that are difficult to reconcile with standard economic theory (Wallace, 2001). Moreover, the relation between structures wherein money is essential and the reduced forms embodied by MIA or CIA is not clear. This means that we do not know whether that relation is invariant to changes in monetary policy or to the stochastic properties of the shocks that hit the economy, such as the ones we study. This is nothing more than the Lucas critique dressed in a different way.

The second weakness of our DSGE model is the use of Calvo pricing. Probably the best way to think about Calvo pricing is as a convenient reduced form of a more-complicated pricing mechanism that is easier to handle, thanks to its memoryless properties. However, if we are entertaining the idea that monetary policy or the volatility of shocks has changed over time, it is exceedingly difficult to believe that the parameters that control Calvo pricing have been invariant over the same period (see the empirical evidence that supports this argument in Fernández-Villaverde and Rubio-Ramírez, 2008).

However, getting around these two limitations seems, at the moment, infeasible. Microfounded models of money are either too difficult to work with (Kiyotaki and Wright, 1989) or rest in assumptions nearly as implausible as MIA (Lagos and Wright, 2005) or that the data find too stringent (Aruoba and Schorfheide, forthcoming). State-dependent models of pricing are too cumbersome computationally for estimation (Dotsey, King, and Wolman, 1999).

So, with a certain reluctance, we use a mainstream DSGE model with households; firms (a labor packer, a final-good producer, and a continuum of intermediate-good producers); a monetary authority, the Federal Reserve, which implements monetary policy through open market operations following a Taylor rule; and nominal rigidities in the form of Calvo pricing with partial indexation.

2.1 Households

We begin our discussion of the model with households. We work with a continuum of them, indexed by j. Households are different because each supplies a specific type of labor in the market: Some households are carpenters and some households are economists. If, in addition, each household has some market power over its own wage and stands ready to supply any amount of labor at posted prices, it is relatively easy to introduce nominal rigidities in wages. Some households are able to change their wages and some are not, and the relative demand for each type of labor adjusts to compensate for these differences in input prices.

At the same time, we do not want a complicated model with heterogeneous agents that is daunting to compute. We resort to two tricks to get around that problem. First, we have a utility function that is separable among consumption, c_{jt}, real money balances, m_{jt}/p_t, and hours worked, l_{jt}. Second, we have complete markets in Arrow securities. Complete markets allow us to equate the marginal utilities of consumption across all households in all states of nature. And, since by separability this marginal utility depends only on consumption, all households will consume the same amount of the final good. The result makes aggregation trivial. Of course, it also has the unpleasant feature that those households that do not update their wages will work different numbers of hours than those that do. If, for example, we have an increase in the average wage, those households stuck with the old, lower wages will work longer hours and have lower total utility. This is the price we need to pay for tractability.

Given our previous choice of a separable utility function and our desire to have a balanced growth path for the economy (which requires a marginal rate of substitution between labor and consumption that is linear in consumption), we postulate a utility function of the form

$$(1)\quad \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t d_t \left\{ \begin{array}{l} \log\left(c_{jt} - hc_{jt-1}\right) \\ +\upsilon \log\left(\dfrac{m_{jt}}{p_t}\right) - \varphi_t \psi \dfrac{l_{jt}^{1+\vartheta}}{1+\vartheta} \end{array} \right\},$$

where $\mathbb{E}_0$ is the conditional expectation operator, β is the discount factor for one quarter (the time period for our model), h controls habit persistence, and ϑ is the inverse of the Frisch labor supply elasticity. In addition, we introduce two shifters to preferences, common to all households: The first is a shifter to intertemporal preference, d_t, that makes utility today more or less desirable. This is a simple device to capture shocks to aggregate demand. A prototypical example could be increases in aggregate demand caused by fiscal policy, an aspect of reality ignored in our model. Another possibility is to think about d_t as the consequence of demographic shocks that propagate over time. The second is a shifter to labor supply, φ_t. As emphasized by Hall (1997), this shock is crucial for capturing the fluctuation of hours in the data.

A simple way to parameterize the evolution of the two shifters is to assume AR(1) processes:

$$\log d_t = \rho_d \log d_{t-1} + \sigma_{dt} \varepsilon_{dt},$$

where $\varepsilon_{dt} \sim \mathcal{N}(0,1)$, and

$$\log \varphi_t = \rho_\varphi \log \varphi_{t-1} + \sigma_{\varphi t} \varepsilon_{\varphi t},$$

where $\varepsilon_{\varphi t} \sim \mathcal{N}(0,1)$. The most interesting feature of these processes is that the standard deviations (SDs), σ_{dt} and $\sigma_{\varphi t}$, of the innovations, ε_{dt} and $\varepsilon_{\varphi t}$, evolve over time. This is the first place where we introduce time-varying volatility in the model: Sometimes the preference shifters are highly volatile; sometimes they are less so. This changing volatility may reflect, for instance, the different regimes of fiscal policy or the consequences of demographic forces (Jaimovich and Siu, 2009).

We can specify many different processes for σ_{dt} and $\sigma_{\varphi t}$. A simple procedure is to assume that σ_{dt} and $\sigma_{\varphi t}$ follow a Markov chain and take a finite number of values. While this specification seems straightforward, it is actually quite involved. The distribution that it implies for σ_{dt} and $\sigma_{\varphi t}$ is discrete and, therefore, perturbation methods (such as the ones that we use later) are ill designed to deal with it. Such conditions would force us to rely on global solution methods that are too slow for estimation.

Instead, we can postulate simple AR(1) processes in logs (to ensure the positivity of the SDs):

$$\log\sigma_{dt} = \left(1-\rho_{\sigma_d}\right)\log\sigma_d + \rho_{\sigma_d}\log\sigma_{dt-1} + \eta_d u_{dt},$$

where $u_{dt} \sim \mathcal{N}(0,1)$, and

$$\log\sigma_{\varphi t} = \left(1-\rho_{\sigma_\varphi}\right)\log\sigma_\varphi + \rho_{\sigma_\varphi}\log\sigma_{\varphi t-1} + \eta_\varphi u_{\varphi t},$$

where $u_{\varphi t} \sim \mathcal{N}(0,1)$. This specification is both parsimonious (with only four new parameters, ρ_{σ_d}, ρ_{σ_φ}, η_d, and η_φ) and rather flexible. Because of these advantages, we impose the same specification for the other three time-varying SDs in the model that appear below (the ones affecting an investment-specific technological shock, a neutral technology shock, and a monetary policy shock). Hereafter, agents perfectly observe the structural shocks and the level and innovation to the SDs and have rational expectations about their stochastic properties.

Households keep a rich portfolio: They own (physical) capital, k_{jt}; nominal government bonds, b_{jt}, that pay a gross return R_{t-1}; Arrow securities, a_{jt+1}, which pay one unit of consumption in event $\omega_{jt+1,t}$ traded at time t at unitary price $q_{jt+1,t}$; and cash.

The evolution of capital deserves some description. Given a depreciation rate δ, the amount of capital owned by household j at the end of period t is

$$k_{jt} = (1-\delta)k_{jt-1} + \mu_t\left(1 - V\left[\frac{x_{jt}}{x_{jt-1}}\right]\right)x_{jt}.$$

Investment, x_{jt}, is multiplied by a term that depends on a quadratic adjustment cost function,

$$V\left[\frac{x_t}{x_{t-1}}\right] = \frac{\kappa}{2}\left(\frac{x_t}{x_{t-1}} - \Lambda_x\right)^2,$$

written in deviations with respect to the balanced growth rate of investment, Λ_x, with adjustment parameter κ and an investment-specific technology level μ_t. This technology level evolves as a random walk in logs:

$$\log\mu_t = \Lambda_\mu + \log\mu_{t-1} + \sigma_{\mu t}\varepsilon_{\mu t},$$

where $\varepsilon_{\mu t} \sim \mathcal{N}(0,1)$ with drift Λ_μ and innovation $\varepsilon_{\mu t}$, whose SD $\sigma_{\mu t}$ evolves according to our favorite autoregressive process:

$$\log\sigma_{\mu t} = \left(1-\rho_{\sigma_\mu}\right)\log\sigma_\mu + \rho_{\sigma_\mu}\log\sigma_{\mu t-1} + \eta_\mu u_{\mu t},$$

where $u_{\mu t} \sim \mathcal{N}(0,1)$.

We introduce this shock convinced by the evidence in Greenwood, Herkowitz, and Krusell (1997) that this is a key mechanism to understanding aggregate fluctuations in the United States over the past 50 years.

Thus, the jth household's budget constraint is

$$c_{jt} + x_{jt} + \frac{m_{jt}}{p_t} + \frac{b_{jt+1}}{p_t} + \int q_{jt+1,t}a_{jt+1}d\omega_{jt+1,t}$$
$$= w_{jt}l_{jt} + \left(r_t u_{jt} - \mu_t^{-1}\Phi\left[u_{jt}\right]\right)k_{jt-1}$$
$$+\frac{m_{jt-1}}{p_t} + R_{t-1}\frac{b_{jt}}{p_t} + a_{jt} + T_t + F_t,$$

where w_{jt} is the real wage, r_t is the real rental price of capital, $u_{jt} > 0$ is the rate of use of capital, $\mu_t^{-1}\Phi[u_{jt}]$ is the cost of using capital at rate u_{jt} in terms of the final good, μ_t is an investment-specific technology level, T_t is a lump-sum transfer, and F_t is the profits of the firms in the economy. We postulate a simple quadratic form for $\Phi[\cdot]$,

$$\Phi[u] = \Phi_1(u-1) + \frac{\Phi_2}{2}(u-1)^2,$$

and normalize u, the utilization rate in the balanced growth path of the economy, to 1. This imposes the restriction that the parameter Φ_1 must satisfy $\Phi_1 = \Phi'[1] = \tilde{r}$, where $\tilde{r}$ is the balanced growth path rental price of capital (rescaled by technological progress, as we explain later).

Of all the choice variables of the households, the only one that requires special attention is hours. As we explained previously, each household j supplies its own specific type of labor. This labor is aggregated by a labor packer into homogeneous labor, l_t^d, according to a constant elasticity of substitution technology,

$$l_t^d = \left(\int_0^1 l_{jt}^{\frac{\eta-1}{\eta}}dj\right)^{\frac{\eta}{\eta-1}}.$$

The labor packer is perfectly competitive and takes all the individual wages, w_{jt}, and the wage w_t for l_t^d as given.

The household decides, given the demand function for its type of labor generated by the labor packer,

$$l_{jt} = \left(\frac{w_{jt}}{w_t}\right)^{-\eta} l_t^d \quad \forall j,$$

which wage maximizes its utility and stands ready to supply any amount of labor at that wage. However, when it chooses the wage, the household is subject to a nominal rigidity: a Calvo pricing mechanism with partial indexation. At the start of every quarter, a fraction $1 - \theta_w$ of households are randomly selected and allowed to reoptimize their wages. All other households can only index their wages to past inflation with an indexation parameter $\chi_w \in [0,1]$.

2.2 Firms

In addition to the labor packer, we have two other types of firms in this economy. The first, the final-good producer, is a perfectly competitive firm that aggregates a continuum of intermediate goods with the technology:

$$(2) \quad y_t^d = \left(\int_0^1 y_{it}^{\frac{\varepsilon-1}{\varepsilon}} di\right)^{\frac{\varepsilon}{\varepsilon-1}}.$$

This firm takes as given all intermediate-good prices, p_{ti}, and the final-good price, p_t, and generates a demand function for each intermediate good:

$$(3) \quad y_{it} = \left(\frac{p_{it}}{p_t}\right)^{-\varepsilon} y_t^d \quad \forall i.$$

Second, we have the intermediate-good producers, each of which has access to a Cobb-Douglas production function,

$$y_{it} = A_t k_{it-1}^{\alpha} \left(l_{it}^d\right)^{1-\alpha},$$

where k_{it-1} is the capital, l_{it}^d is the packed labor rented by the firm, and A_t (our fourth structural shock) is the neutral productivity level, which evolves as a random walk in logs:

$$\log A_t = \Lambda_A + \log A_{t-1} + \sigma_{At}\varepsilon_{At},$$

where $\varepsilon_{At} \sim \mathcal{N}(0,1)$ with drift Λ_A and innovation ε_{At}. We keep the same specification for the SD of this innovation as we did for all previous volatilities:

$$\log \sigma_{At} = \left(1 - \rho_{\sigma_A}\right)\log \sigma_A + \rho_{\sigma_A} \log \sigma_{At-1} + \eta_A u_{At},$$

where $u_{At} \sim \mathcal{N}(0,1)$.

The quantity sold of the good is determined by the demand function (equation (3)). Given equation (3), the intermediate-good producers set prices to maximize profits. As was the case for households, intermediate-good producers are subject to a nominal rigidity in the form of Calvo pricing. In each quarter, a proportion of them, $1 - \theta_p$, can reoptimize their prices. The remaining fraction θ_p indexes their prices by a fraction $\chi \in [0,1]$ of past inflation.

2.3 The Policy Rule of the Federal Reserve

In our model, the Federal Reserve implements monetary policy through open market operations (that generate lump-sum transfers, T_t, to maintain a balanced budget). In doing so, the Fed follows a modified Taylor rule that targets the ratio of nominal gross return, R_t, of government bonds over the balanced growth path gross return, R:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\gamma_R} \left(\left(\frac{\Pi_t}{\Pi}\right)^{\gamma_{\Pi,t}} \left(\frac{\frac{y_t}{y_{t-1}}}{\exp\left(\Lambda_y\right)}\right)^{\gamma_{y,t}} \right)^{1-\gamma_R} \xi_t.$$

This rule depends on (i) the past R_{t-1}, which smooths changes over time; (ii) the "inflation gap," Π_t/Π, where Π is the balanced growth path of inflation[2]; (iii) the "growth gap," which is the ratio

[2] Here we are being careful with our words: Π is inflation in the balanced growth path, not the target of inflation in the stochastic steady state. As we will see later, we solve the model using a second-order approximation. The second-order terms move the mean of the ergodic distribution of inflation, which corresponds in our view to the usual view of the inflation target, away from the balanced growth path level. We could have expressed the policy rule in terms of this mean of the ergodic distribution, but it would amount to solving a complicated fixed-point problem (for every inflation level, we would need to solve the model and check that indeed this is the mean of the ergodic distribution), which is too complicated a task for the potential benefits we can derive from it.

between the growth rate of the economy, y_t/y_{t-1}, and Λ_y, the balanced path gross growth rate of y_t, dictated by the drifts of neutral and investment-specific technological change; and (iv) a monetary policy shock, $\xi_t = \exp^{\sigma_{m,t}\varepsilon_{mt}}$, with an innovation $\varepsilon_{mt} \sim \mathcal{N}(0,1)$ and SD of the innovation, $\sigma_{m,t}$, that evolves as

$$\log\sigma_{mt} = \left(1-\rho_{\sigma_m}\right)\log\sigma_m + \rho_{\sigma_m}\log\sigma_{mt-1} + \eta_m u_{m,t}.$$

Note that, since we are dealing with a general equilibrium model, once the Fed has chosen a value of Π, R is not a free target, as it is determined by technology, preferences, and Π.

We introduce monetary policy changes through a parameter drift over the responses of R_t to inflation, $\gamma_{\Pi,t}$, and growth gaps, $\gamma_{y,t}$:

$$\log\gamma_{\Pi t} = \left(1-\rho_{\gamma_\Pi}\right)\log\gamma_\Pi + \rho_{\gamma_\Pi}\log\gamma_{\Pi t-1} + \eta_\pi\varepsilon_{\pi t},$$

where $\varepsilon_{\pi t} \sim \mathcal{N}(0,1)$ and

$$\log\gamma_{yt} = \left(1-\rho_{\gamma_y}\right)\log\gamma_y + \rho_{\gamma_y}\log\gamma_{yt-1} + \eta_y\varepsilon_{yt},$$

where $\varepsilon_{yt} \sim \mathcal{N}(0,1)$.

In preliminary estimations, we discovered that, while other parameters such as γ_R could also be changing, the likelihood function of the model did not react much to that possibility and, thus, we eliminated those channels.

Our parameter-drifting specification tries to capture mainly two different phenomena. First, changes in the composition of the voting members of the FOMC (through changes in governors and in the rotating votes of presidents of regional Reserve Banks) may affect how strongly the FOMC responds to inflation and output growth because of variations in the political-economic equilibrium in the committee.[3] Similarly, changes in staff may have effects as long as their views have an impact on the voting members through briefings and other, less-structured interactions. This may have been particularly true in the late 1960s, when a majority of staff economists embraced Keynesian policies and the MIT-Penn-Federal Reserve System (MPS) model was built.[4] The second phenomenon is the observation that, even if we keep constant the members of the FOMC, their reading of the priorities and capabilities of monetary policy may evolve (or be more or less influenced by the general political climate of the nation). We argue below that this is a good description of Martin, who changed his beliefs about how strongly the Fed could fight inflation in the late 1960s, or of Greenspan's growing conviction in the mid-1990s that the long-run growth rate of the U.S. economy had risen.

While this second channel seems well described by a continuous drift in the parameters (beliefs plausibly evolving slowly), changes in the voting members, in particular the Chairman, might potentially be better understood as discrete jumps in $\gamma_{\Pi,t}$ and $\gamma_{y,t}$. In fact, our smoothed path of $\gamma_{\Pi,t}$, which we estimate from the data, gives some support to this view. But in addition to our pragmatic consideration that computing models with discrete jumps is hard, we argue in Section 6 that, historically, changes have occurred more slowly and even new Chairmen have required some time before taking a decisive lead on the FOMC (Goodfriend and King, 2005).

In Section 7, we discuss other objections to our form of parameter drifting—in particular the objection to the assumption that agents observe the changes in parameters without problem, its exogeneity, or its avoidance of open economy considerations.

2.4 Aggregation and Equilibrium

The model is closed by finding an expression for aggregate demand,

$$y_t^d = c_t + x_t + \mu_t^{-1}\Phi\left[u_t\right]k_{t-1},$$

and another for aggregate supply,

[3] According to Walter Heller, President Kennedy clearly stated, "About the only power I have over the Federal Reserve is the power of appointment, and I want to use it" (cited by Bremner, 2004, p. 160). The slowly changing composition of the Board of Governors may lead to situations, such as the one in February 1986 (discussed later in the text), when Volcker was outvoted by Ronald Reagan's appointees on the Board.

[4] The MPS model is the high-water mark of traditional Keynesian macroeconometric models in the Cowles tradition. The MPS model was used operationally by staff economists at the Fed from the early 1970s to the mid-1990s (see Brayton et al., 1997).

$$y_t^s = \frac{1}{v_t^p} A_t \left(u_t k_{t-1}\right)^{\alpha} \left(l_t^d\right)^{1-\alpha},$$

where

$$l_t^d = \frac{1}{v_t^w} \int_0^1 l_{jt} dj$$

is demanded labor,

$$v_t^w = \int_0^1 \left(\frac{w_{jt}}{w_t}\right)^{-\eta} dj$$

is the aggregate loss of labor input induced by wage dispersion, and

$$v_t^p = \int_0^1 \left(\frac{p_{it}}{p_t}\right)^{-\varepsilon} di$$

is the aggregate loss of efficiency induced by price dispersion of the intermediate goods. By market clearing, $y_t = y_t^d = y_t^s$.

The definition of "equilibrium" for this model is rather standard: It is just the path of aggregate quantities and prices that maximize the problems of households and firms, the government follows its Taylor rule, and markets clear. But while the definition of equilibrium is straightforward, its computation is not.

3. SOLUTION AND LIKELIHOOD EVALUATION

The solution of our model is challenging. We have 19 state variables, 5 innovations to the structural shocks (ε_{dt}, $\varepsilon_{\varphi t}$, ε_{At}, $\varepsilon_{\mu t}$, ε_{mt}), 2 innovations to the parameter drifts ($\varepsilon_{\pi t}$, ε_{yt}), and 5 innovations to the volatility shocks (u_{dt}, $u_{\varphi t}$, $u_{\mu t}$, u_{At}, u_{mt}), for a total of 31 variables that we must consider.

A vector of 19 states makes it impossible to use value-function iteration or projection methods (finite elements or Chebyshev polynomials). The curse of dimensionality is too acute even for the most powerful of existing computers. Standard linearization techniques do not work either: Stochastic volatility is inherently a nonlinear process. If we solved the model by linearization, all terms associated with stochastic volatility would disappear because of certainty equivalence and our investigation would be essentially worthless.

Nearly by default, then, using perturbation to obtain a higher-order approximation to the equilibrium dynamics of our model is the only option. A second-order approximation includes terms that depend on the level of volatility. Thus, these terms capture the responses of agents (households and firms) to changes in volatility. At the same time, a second-order approximation can be found sufficiently fast, which is of the utmost importance since we want to estimate the model and that forces us to solve it repeatedly for many different parameter values. Thus, a second-order approximation is an interesting compromise between accuracy and speed.

The idea of perturbation is simple. Instead of the exact decision rule of the agents in the model, we use a second-order Taylor expansion to the rule around the steady state. That Taylor expansion depends on the state variables and on the innovations. However, we do not know the coefficients multiplying each term of the expansion. Fortunately, we can find them by an application of the implicit function theorem as follows (see also Judd, 1998, and Schmitt-Grohé and Uribe, 2006).

First, we write all the equations describing the equilibrium of the model (optimality conditions for the agents, budget and resource constraints, the Taylor rule, and the laws of motion for the different stochastic processes). Second, we rescale all the variables to remove the balanced growth path induced by the presence of the drifts in the evolution of neutral and investment-specific technology. Third, we find the steady state implied by the rescaled variables. Fourth, we linearize the equilibrium conditions around the steady state found in the previous step. Then, we solve for the unknown coefficients in this linearization, which happen to be, by the implicit function theorem, the coefficients of the first-order terms of the decision rules in the rescaled variables that we are looking for (which can be easily rearranged to deliver the decision rules in the original variables). The next step is to take a second-order approximation of the equilibrium conditions, plugging in the terms found before, and solve for the coefficients of the second-order terms of the decision rules.

While we could keep iterating in this procedure for as long as we want, Aruoba, Fernández-Villaverde, and Rubio-Ramírez (2006) show that, for the basic stochastic neoclassical growth model (the backbone of our model) calibrated to the U.S. data, a second-order approximation delivers excellent accuracy at great computational speed. In our actual computation, we undertake the symbolic derivatives of the equilibrium conditions using Mathematica 6.0. The code generates all of the relevant expressions and exports them automatically into Fortran files. Then, Fortran sends particular parameter values in each step of the estimation, evaluates those expressions, and determines the terms of the Taylor expansions that we need.

Once we have the approximated solution to the model, given some parameter values, we use it to build a state-space representation of the dynamics of states and observables. This representation is, as we argued before, nonlinear and hence standard techniques such as the Kalman filter cannot be applied to evaluate the associated likelihood function. Instead, we resort to a simulation method known as the particle filter, as applied to DSGE models by Fernández-Villaverde and Rubio-Ramírez (2007). The particle filter generates a simulation of different states of the model and evaluates the probability of the innovations that make these simulated states explain the observables. These probabilities are also called weights. A simple application of a law of large numbers tells us that the mean of the weights is an evaluation of the likelihood. The secret of the success of the procedure is that, instead of performing the simulation over the whole sample, we perform it only period by period, resampling from the set of simulated state variables according to the weights we just found. This sequential structure, which makes the particle filter a case of a more general class of algorithms called sequential Monte Carlo methods, ensures that the simulation of the state variables remains centered on the true but unknown value of the state variables. This dramatically limits the numerical variance of the procedure.

Now that we have an evaluation of the likelihood of the model given observables, we only need to search over different parameter values according to our favorite estimation algorithm. This can be done in two ways. One is with a regular maximum likelihood algorithm: We look for a global maximum of the likelihood. This procedure is complicated by the fact that the evaluation of the likelihood function that we obtain from the particle filter is nondifferentiable with respect to the parameters because of the inherent discreteness of the resampling step. An easier alternative, and one that allows the introduction of presample information, is to follow a Bayesian approach. In this route, we specify a prior over the parameters, multiply the likelihood by it, and sample from the resulting posterior by means of a random-walk Metropolis-Hastings algorithm. In this paper, we choose this second route. In our estimation, however, we do not take full advantage of presample information since we impose flat priors to facilitate the communication of the results to other researchers: The shape of our posterior distributions will be proportional to the likelihood. We must note, however, that relying on flat priors forces us to calibrate some parameters to values typically used in the literature (see Fernández-Villaverde, Guerrón-Quintana, and Rubio-Ramírez, 2010 [FGR hereafter], for the values and justification of the calibrated values).

While our description of the solution and estimation method has been necessarily brief, the reader is invited to check FGR for additional details. In particular, FGR characterize the structure of the higher-order approximations, showing that many of the relevant terms are zero and exploiting this result to quickly solve for the innovations that explain the observables given some states. This result, proved for a general class of DSGE models with stochastic volatility, is bound to have wide application in all cases where stochastic volatility is an important aspect of the problem.

4. ESTIMATION

To estimate our model, we use five time series for the U.S. economy: (i) the relative price of

Table 1

Posterior Distributions: Parameters of the Stochastic Processes for Volatility Shocks

Parameter				
$\log\sigma_d$	$\log\sigma_\varphi$	$\log\sigma_\mu$	$\log\sigma_A$	$\log\sigma_m$
–1.9834 (0.0726)	–2.4983 (0.0917)	–6.0283 (0.1278)	–3.9013 (0.0745)	–6.000 (0.1471)
ρ_{σ_d}	ρ_{σ_φ}	ρ_{σ_μ}	ρ_{σ_A}	ρ_{σ_m}
0.9506 (0.0298)	0.1275 (0.0032)	0.7508 (0.035)	0.2411 (0.005)	0.8550 (0.0231)
η_d	η_φ	η_μ	η_A	η_m
0.3246 (0.0083)	2.8549 (0.0669)	0.4716 (0.006)	0.7955 (0.013)	1.1034 (0.0185)

NOTE: Numbers in parentheses indicate standard deviations.

investment goods with respect to the price of consumption goods, (ii) the federal funds rate, (iii) real per capita output growth, (iv) the consumer price index, and (v) real wages per capita. Our sample covers 1959:Q1 to 2007:Q1.

Figure 1 plots three of the five series: inflation, (per capita) output growth, and the federal funds rate—the three series most commonly discussed when commentators talk about monetary policy. By refreshing our memory about their evolution in the sample, we can frame the rest of our discussion. For ease of reading, each vertical bar corresponds to the tenure of one Fed Chairman: Martin, Burns-Miller (we merge these two because of Miller's short tenure), Volcker, Greenspan, and Bernanke.

The top panel shows the history of the Great Inflation: From the late 1960s to the mid-1980s, the U.S. experienced its only significant inflation in peace time, with peaks of around 12 to 14 percent during the 1973 and 1979 oil shocks. The middle panel shows the Great Moderation: A simple inspection of the series after 1984 reveals a much smaller amplitude of fluctuations (especially between 1993 and 2000) than before that date. The Great Inflation and the Great Moderation are the two main empirical facts to keep in mind for the rest of the paper. The bottom panel shows the federal funds rate, which follows a pattern similar to inflation: It rises in the 1970s (although less than inflation during the earlier years of the decade and more during the last years) and stays much lower in the 1990s, reaching historical minima by the end of the sample.

The point estimates we get from our posterior distribution agree with other estimates in the literature. For example, we document a fair amount of nominal rigidities in the economy. In any case, we refer the reader to FGR to avoid a lengthy discussion. Here, we report only the modes and SDs of the posterior distributions associated with the parameters governing stochastic volatility (Table 1) and policy (Table 2). In our view, those parameters are the most relevant for our reading of the recent history of monetary policy in the United States.

The main lesson from Table 1 is that the scale parameters, η_i, are clearly positive and bounded away from zero, confirming the presence of time-variant volatility in the data. Shocks to the volatility of the intertemporal preference shifter, σ_d, are the most persistent (also, the SDs are tight enough to suggest that we are not suffering from serious identification problems). The innovations to the volatility of the intratemporal labor shock, η_φ, are large in magnitude, which suggests that labor supply shocks may have played an important role during the Great Inflation by moving the marginal

Figure 1

Time Series for Inflation, Output Growth, and the Federal Funds Rate

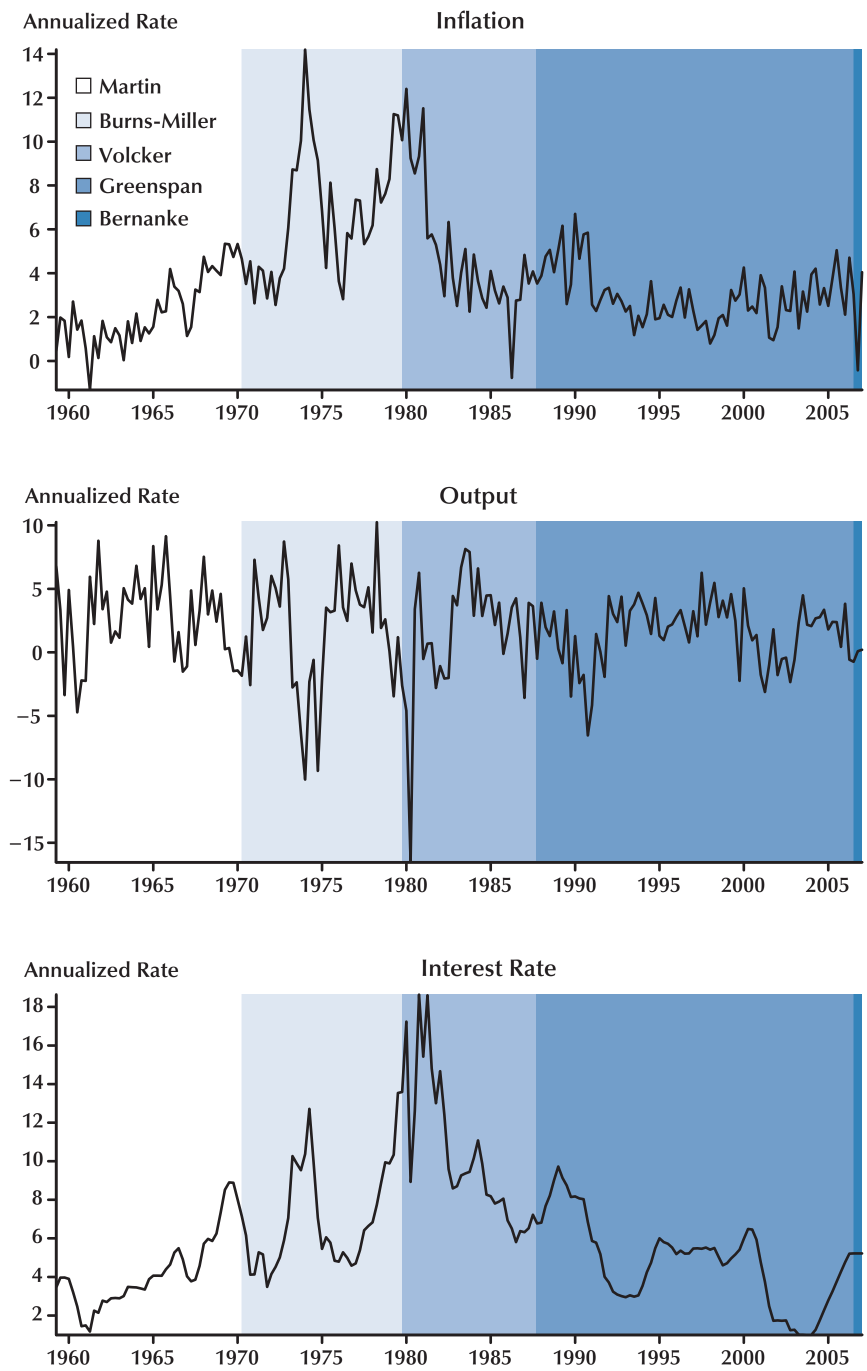


Table 2

Posterior Distribution: Policy Parameters

Parameter				
γ_R	$\log\gamma_y$	Π	$\log\gamma_\Pi$	η_π
0.7855	–1.4034	1.0005	0.0441	0.1479
(0.0162)	(0.0498)	(0.0043)	(0.0005)	(0.002)

NOTE: Numbers in parentheses indicate standard deviations.

cost of intermediate-good producers. Finally, the estimates for the volatility process governing investment-specific productivity suggest that such shocks are important in accounting for business cycles fluctuations in the United States (Fisher, 2006).

The results from Table 2 indicate that the central bank smooths interest rates ($\gamma_R > 0$). The parameter γ_Π is the average magnitude of the response to inflation in the Taylor rule. Its estimated value (1.045 in levels) is just enough to guarantee determinacy in the model (Woodford, 2003).[5] The size of the innovations to the drifting inflation parameter, η_π, reaffirms our view of a time-dependent response to inflation in monetary policy. The estimates for $\gamma_{y,t}$ (the response to output deviations in the Taylor rule) are not reported because preliminary attempts at estimation convinced us that η_y was nil. Hence, in our next exercises, we set ρ_{γ_y} and η_y to zero.

5. TWO FIGURES

In this section, we present two figures that show us much about the evolution and effects of monetary policy: (i) the estimated smoothed path of $\gamma_{\Pi t}$ over our sample and (ii) the evolution during the same years of a measure of the real interest rate. In the next section, we map these figures into the historical record.

Figure 2, perhaps the most important figure in this paper, plots the smoothed estimate of the evolution of the response of monetary policy to inflation plus or minus a 2-SD interval given our point estimates of the structural parameters. The message of Figure 2 is straightforward. According to our model, at the arrival of the Kennedy administration, the response of monetary policy to inflation was around its estimated mean, slightly over 1.[6] It grew more or less steadily during the 1960s, until reaching a peak at the end of 1967 and beginning of 1968. Subsequently, $\gamma_{\Pi t}$ fell so quickly that it was below 1 by 1971. For nearly all of the 1970s, $\gamma_{\Pi t}$ stayed below 1 and picked up only with the arrival of Volcker. Interestingly, the two oil shocks did not have an impact on the estimated $\gamma_{\Pi t}$. The parameter stayed high throughout the Volcker years and fell after a few quarters into Greenspan's tenure, when it returned to levels even lower than during the Burns and Miller years. The likelihood function favors an evolving monetary policy even after introducing stochastic volatility in the model. In FGR, we assess this statement more carefully with several measures of model fit, including the construction of Bayes factors and the computation of Bayesian information criteria between different specifications of the model.

The reader could argue, with some justification, that we have estimated a large DSGE model and that it is not clear what is driving the results and what variation in the data is identifying the movements in monetary policy. While a fully worked-out identification analysis is beyond the scope of this paper, as a simple reality check, we plot in Figure 3 a measure of the (short-term)

[5] In this model, local determinacy depends only on the mean of γ_Π.

[6] This number nearly coincides with the estimate of Romer and Romer (2002a) of the coefficient using data from the 1950s.

Figure 2

Smoothed Path for the Taylor Rule Parameter on Inflation ±2 SDs

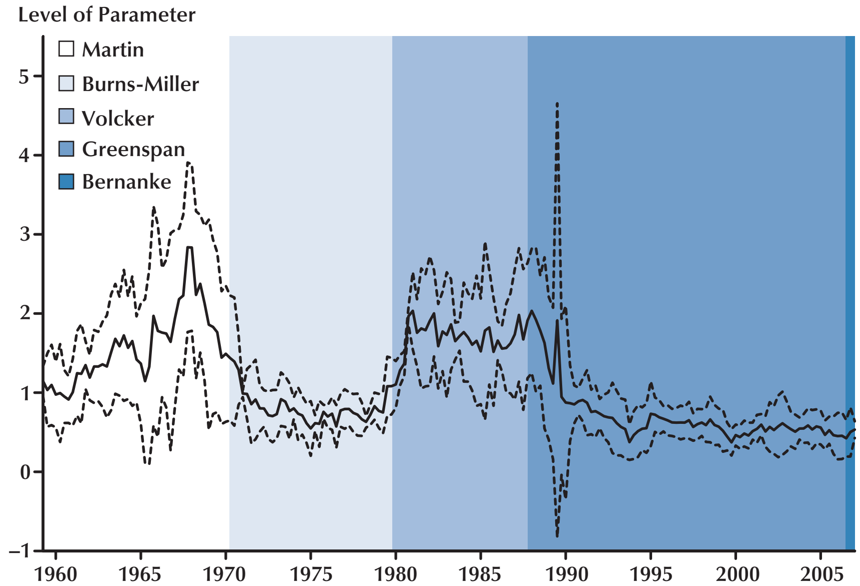
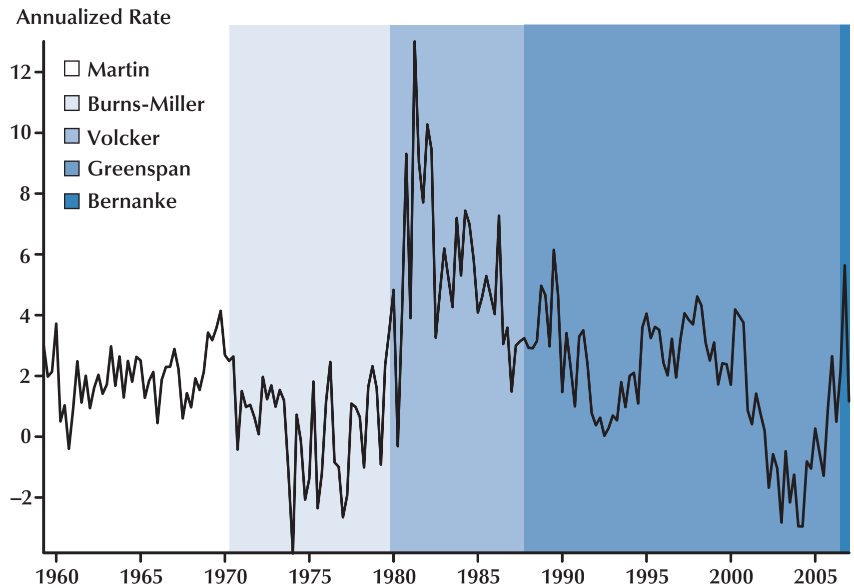


Figure 3

Real Interest Rate (Federal Funds Rate Minus Inflation)



real interest rate defined as the federal funds rate minus current inflation.[7]

This figure shows that Martin kept the real interest rate at positive values around 2 percent during the 1960s (with a peak by the end, which corresponds with the peak of our estimated $\gamma_{\Pi t}$). However, during the 1970s, the real interest rate was often negative and only rarely above 2 percent, a rather conservative lower bound on the balanced growth real interest rate given our point estimates. The likelihood function can interpret those observations only as a very low $\gamma_{\Pi t}$ (remember that the Taylor principle calls for increases in the real interest rate when inflation rises; that is, nominal interest rates must grow more than inflation). Real interest rates skyrocketed with the arrival of Volcker, reaching a historic record of 13 percent by 1981:Q2. After that date, they were never even close to zero, and only in two quarters were they below 3 percent. Again, the likelihood function can interpret that observation only as a high $\gamma_{\Pi t}$. The Greenspan era is more complicated because real interest rates were not particularly low in the 1990s. However, output growth was very positive, which pushed the interest rates up in the Taylor rule. Since the federal funds rate was not as high as the policy rule would have predicted with a high $\gamma_{\Pi t}$, the smoothed estimate of the parameter is lowered. During the 2000s, real interest rates close to zero were enough, by themselves, to keep $\gamma_{\Pi t}$ low.

6. READING MONETARY HISTORY THROUGH THE LENS OF OUR MODEL

Now that we have our model and our estimates of the structural parameters, we smooth the structural and volatility shocks implied by the data and use them to read the recent monetary history of the United States. Somewhat conventionally, we organize our discussion around the different Chairmen of the Fed from Martin to Greenspan—except for Miller, whom we group with Burns because of his short tenure.

One fundamental lesson from this exercise is that Figure 2 can successfully guide our interpretation of policy from 1959 to 2007. We document how both Martin and Volcker believed that inflation was dangerous and that the Fed had both the responsibility and the power to fight it, although growing doubts about that power overcame Martin during his last term as Chairman. Burns, on the other hand, thought the costs of inflation were lower than the cost of a recession triggered by disinflation. In any case, he was rather skeptical about the Fed's ability to successfully disinflate. Greenspan, despite his constant warnings about inflation, had in practice a much more nuanced attitude. According to our estimated model, good positive shocks to the economy gave him the privilege of skipping a daunting test of his resolve.

Because by using a DSGE model we have a complete set of structural and volatility shocks, in FGR, we complete this analysis with the construction of counterfactual exercises. In those exercises, we build artificial histories of economies in which some source of variation has been eliminated or modified in an illustrative manner. For example, we can evaluate how the economy would have behaved in the absence of changes in the volatility of the structural shocks or if the average monetary policy of one period had been applied in another. By interpreting those counterfactual histories, we attribute most of the defeat of the Great Inflation to monetary policy under Volcker and most of the Great Moderation after 1984 to good shocks. We incorporate information from those counterfactuals as we move along.

Our exercise in this section is closely related to the work of Christina and David Romer (1989; 2002a,b; 2004), except that we attack the problem from exactly the opposite perspective. While they let their narrative approach guide their empirical specification and like to keep a flexible relation with equilibrium models, we start from a tightly parameterized DSGE model of the U.S. economy and use the results of our estimation to read the narrative told by the documents. We see both strategies as complementary since each can teach us much of interest. Quite remarkably, given the

[7] Since inflation is nearly a random walk (Stock and Watson, 2007), its current value is an excellent proxy for its expected value. In any case, our argument is fully robust to slightly different definitions of the real interest rate.

different research designs, many of our conclusions are similar to the views expressed by Romer and Romer.

6.1 The Martin Era: Resistance and Surrender

William McChesney Martin, the Chairman of the Fed between April 2, 1951, and January 31, 1970, knew how to say no. On December 3, 1965, he dared to raise the discount rate for the first time in more than five years, despite warnings from the Treasury secretary, Henry Fowler, and the chairman of the Council of Economic Advisors, Gardner Ackley, that President Lyndon Johnson disapproved of such a move. Johnson, a man not used to seeing his orders ignored, was angered by Martin's unwelcome display of independence and summoned him to a meeting at his Texas ranch. There, for over an hour, he tried to corner the Chairman of the Fed with the infamous bullying tactics that had made him a master of the Senate in years past. Martin, however, held his ground and carried the day: The raise would stand. Robert Bremner starts his biography of Martin with this story.[8] The choice is most appropriate. The history of this confrontation illustrates better than any other event our econometric results.

The early 1960s were the high years of Martin's tenure. The era of the "New Economics" combined robust economic growth, in excess of 5 percent, and low inflation, below 3 percent. According to our estimated model, this moderate inflation was, in part, a reflection of Martin's views about economic policy. Bremner (2004, p. 122) summarizes Martin's guiding principles this way: Stable prices were crucial for the correct working of a market economy and the Fed's main task was to maintain that stability. In Martin's own words, "the Fed has a responsibility to use the powers it possesses over economic events to dampen excesses in economic activity [by] keeping the use of credit in line with resources available for production of goods and services."[9] Martin was also opposed to the idea (popular at the time) that the U.S. economy had a built-in bias toward inflation, a bias the Fed had to accommodate through monetary policy. Sumner Slichter, an influential professor of economics at Harvard, was perhaps the most vocal proponent of the built-in bias hypothesis. In Martin's own words, "I refuse to raise the flag of defeatism in the battle of inflation" and "there is no validity whatever in the idea that any inflation, once accepted, can be confined to moderate proportions."[10] As we will see in the next subsection, this opposition stands in stark contrast to Burns's pessimistic view of inflation, which had many points of contact with Slichter's.

Our estimates of $\gamma_{\Pi,t}$, above 1 and growing during the period, clearly tell us that Martin was doing precisely that: working to keep inflation low. Our result also agrees with Romer and Romer's (2002a) narrative and statistical evidence regarding the behavior of the Fed during the late 1950s. We must not forget, however, that our estimates in FGR suggest as well that the good performance of the economy from 1961 to 1965 was also the consequence of good positive shocks.

The stand against inflation started to be tested around 1966. Intellectually, more and more voices had been raised since the late 1950s defending the notion that an excessive concern with inflation was keeping the economy from working at full capacity. Bremner (2004, p. 138) cites Walter Heller and Paul Samuelson's statements before the Joint Economic Committee in February 1959 as examples of an attitude that would soon gain strength. The following year, Samuelson and Robert Solow's (1960) classic paper about the Phillips curve was taken by many as providing

[8] Bremner (2004, pp. 1-2). This was not the only clash of Martin with a president of the United States. In late 1952, Martin bumped into Harry Truman leaving the Waldorf Astoria Hotel in New York City. To Martin's "Good afternoon," Truman wryly replied, "Traitor!" Truman was deeply displeased by how the Fed had implemented the accord of March 3, 1951, between the Fed and the Treasury that ended the interest rate peg in place since 1942 (Bremner, 2004, p. 91).

[9] Martin's testimony to the Joint Economic Committee, February 5, 1957 (cited by Bremner 2004, p. 123).

[10] The first quotation is from the *New York Times*, March 16, 1957, where Martin was expressing dismay for having reached a 2 percent rate of inflation. The second quotation is from the *Wall Street Journal*, August 19, 1957. Martin also thought that Keynes himself had changed his views on inflation after the war (they had talked privately on several occasions) and that, consequently, Keynesian economists were overemphasizing the benefits of inflation. See Bremner (2004, pp. 128 and 229).

an apparently sound empirical justification for a much more sanguine position with respect to inflation: "In order to achieve the nonperfectionist's goal of high enough output to give us no more than 3 percent unemployment, the price index might have to rise by as much as 4 to 5 percent per year. That much price rise would seem to be the necessary cost of high employment and production in the years immediately ahead" (Samuelson and Solow, 1960, p. 192).[11] Heller's and Tobin's arrival on the Council of Economic Advisors transformed the critics into the insiders.

The pressures on monetary policy were contained during Kennedy's administration, in good part because C. Douglas Dillon, the secretary of the Treasury and a Rockefeller Republican, sided on many occasions with Martin against Heller.[12] But the changing composition of the Board of Governors and the arrival of Johnson, with his expansionary fiscal programs, the escalation of the Vietnam War, and the departure of Dillon from the Treasury Department, changed the weights of power.

While the effects of the expansion of federal spending in the second half of the 1960s often play a central role in the narrative of the start of the Great Inflation, the evolution of the Board of Governors has received less attention. Heller realized that, by carefully selecting the governors, he could shape monetary policy without the need to ease Martin out. This was an inspired observation, since up to that moment, the governors who served under the Chairman had played an extremely small role in monetary policy and the previous administrations had, consequently, shown little interest in their selection. The strategy worked. Heller's first choice, George W. Mitchell, would become a leader of those preferring a more expansionary monetary policy on the FOMC.

By 1964, Martin was considerably worried about inflation. He told Johnson: "I think we're heading toward an inflationary mess that we won't be able to pull ourselves out of."[13] In 1965, he ran into serious problems with the president, as discussed at the beginning of this section. The problems appeared again in 1966 with the appointment of Brimmer as a governor against Martin's recommendation. During all this time, Martin stuck to his guns, trying to control inflation even if it meant erring on the side of overtightening the economy. Our estimated $\gamma_{\Pi,t}$ captures this attitude with an increase from around 1965 to around 1968.

But by the summer of 1968, Martin gave in to an easing of monetary policy after the tax surcharge was passed by Congress. As reported by Hetzel (2008), at the time, the FOMC was divided into two camps: members more concerned about inflation (such as Al Hayes, the president of the Federal Reserve Bank of New York) and members more concerned about output growth (Brimmer,[14] Maisel,[15] and Mitchell, all three appointees of Kennedy and Johnson). Martin, always a seeker of consensus, was growlingly incapable of carrying the day.[16] Perhaps Martin felt that the political climate had moved away from a commitment

[11] The message of the paper is, however, much more subtle than laying down a simple textbook Phillips curve. As Samuelson and Solow (1960) also say in the next page of their article (p. 193), "All of our discussion has been phrased in short-run terms, dealing with what might happen in the next few years. It would be wrong, though, to think that our Figure 2 menu that relates obtainable price and unemployment behavior will maintain its shape in the longer run. What we do in a policy way during the next few years might cause it to shift in a definite way."

[12] In particular, Dillon's support for Martin's reappointment for a new term in 1963 was pivotal. Hetzel (2008, p. 69) suggests that President Kennedy often sided with Dillon and Martin over Heller to avoid a gold crisis on top of the problems with the Soviet Union over Cuba and Berlin.

[13] Oral history interview with Martin, Lyndon B. Johnson Library (quoted by Bremner, 2004, p. 191).

[14] Brimmer is also the first African American to have served as a governor and was, for a while, a faculty member at the University of Pennsylvania.

[15] Sherman Maisel was a member of the Board of Governors between 1965 and 1972. Maisel, a professor at the Haas School of Business at the University of California–Berkeley, has the honor of being the first academic economist appointed as a governor after Adolph Miller, one of the original governors in 1914. As he explained in his book, *Managing the Dollar* (one of the first inside looks at the Fed and still a fascinating read today), Maisel was also a strong believer in the Phillips curve: "There is a trade-off between idle men and a more stable value of the dollar. A conscious decision must be made as to how much unemployment and loss of output is acceptable in order to get smaller price rises" (Maisel, 1973, p. 285). Maisel's academic and Keynesian background merged in his sponsoring of the MPS model mentioned in Section 2.

[16] On one occasion, Maisel felt strongly enough to call a press conference to explain his dissenting vote in favor of more expansion.

to fight inflation.[17] Or perhaps he was just exhausted after many years running the Fed (at the last meeting of the FOMC in which he participated, he expressed feelings of failure for not having controlled inflation). No matter what the exact reason was, monetary policy eased drastically in comparison with what was being called for by the Taylor rule with a $\gamma_{\Pi,t}$ above 1. Thus, our estimated $\gamma_{\Pi,t}$ starts to plunge in the spring of 1968, reflecting that the increases in the federal funds rate passed at the end of 1968 and in 1969 were, according to our estimated Taylor rule, not aggressive enough given the state of the economy. The genie of the Great Inflation was out of the bottle.

6.2 The Burns-Miller Era: Monetary Policy in the Time of Turbulence

Arthur F. Burns started his term as Chairman of the Fed on February 1, 1970. A professor of economics at Columbia University and the president of the National Bureau of Economic Research between 1957 and 1967, Burns was the first academic economist to hold the chairmanship. All the previous nine Chairmen had been bankers or lawyers. However, any hope that his economics education would make him take an aggressive stand against the inflation brewing during the last years of Martin's tenure quickly disappeared. The federal funds rate fell from an average of 8.02 percent during 1970:Q1 to 4.12 percent by 1970:Q4. The justification for those reductions was the need to jump-start the economy, which was stacked in the middle of the first recession in nearly a decade, since December 1969. But since inflation stayed at 4.55 percent by the end of 1970, the reduction in the nominal rate meant that real interest rates sank into the negative region.

Our smoothed estimate of $\gamma_{\Pi,t}$ in Figure 2 responds to this behavior of the Fed by quickly dropping during the same period. This indicates that the actual reduction in the federal funds rate was much more aggressive than the reduction suggested by the (important) fall in output growth and the (moderate) fall in inflation. Furthermore, the likelihood function accounts for the persistent fall in the real interest rate with a persistent fall in $\gamma_{\Pi,t}$.

Burns did little over the next few years to return $\gamma_{\Pi,t}$ to higher values. Even if the federal funds rate had started to grow by the end of 1971 (after the 90-day price controls announced on August 15 of that year as part of Nixon's New Economic Policy) and reached new highs in 1973 and 1974, it barely kept up with inflation. The real interest rate was not above our benchmark value of 2 percent until the second quarter of 1976. Later, in 1977, the federal funds rate was only raised cautiously, despite the evidence of strong output growth after the 1973-75 recession and that inflation remained relatively high.

Our econometric results come about because the Taylor rule does not care about the level of the interest rate in itself, but by how much inflation deviates from Π. If $\gamma_{\Pi,t} > 1$, the increases in the federal funds rate are bigger than the increases in inflation. This is not what happened during Burns's tenure: The real interest rate was above the cutoff of 2 percent that we proposed before only in three quarters: his first two quarters as Chairman (1970:Q2 and 1970:Q3) and in 1976:Q2. This observation, by itself, should be sufficient proof of the stand of monetary policy during the period.[18]

Burns's successor, William Miller, did not have time to retract these policies in the brief interlude of his tenure, from March 8, 1978, to August 6, 1979. But he also did not have either the capability, since his only experience in the conduct of monetary policy was serving as a

[17] Meltzer (2010, p. 549) points out that Martin and the other Board members might have been worried by Johnson's appointment, at the suggestion of Arthur Okun (the chairman of the Council of Economic Advisors at the time), of a task force to review changes in the Federal Reserve System. That message only became reinforced with the arrival of a new administration in 1969, given Richard Nixon's obsession with keeping unemployment as low as possible. (Nixon was convinced that he had lost the 1960 presidential election to a combination of vote fraud and tight monetary policy.)

[18] A memorandum prepared at the end of December 1997 by two of Carter's advisers reveals the climate of the time, proposing not to reappoint Chairman Burns for a third term because he was more concerned with inflation than unemployment (memo for the president on the role of the Federal Reserve, Box 16, R.K. Lipshitz Files, Carter Library, December 10, 1977, pp. 1-2; cited by Meltzer, 2010, p. 922).

director of the Federal Reserve Bank of Boston, or the desire, since he had little faith in restrictive monetary policy's ability to lower inflation.[19] Thus, our estimated $\gamma_{\Pi,t}$ remains low during that time.[20]

Burns was subject to strong pressure from Nixon.[21] His margin of maneuver was also limited by the views among many leading economists that overestimated the costs of disinflation and who were in any case skeptical of monetary policy.[22] But his own convictions leaned in the same direction. According to the recollections of Stephen H. Axilrod, a senior staff member at the Board back then, Burns did not believe any theory of the economy—whether Keynesian or monetarist—could account for the business cycle; he dismissed the relation between the stock of money and the price level; and he was unwilling or unable to make a persuasive case against inflation to the nation and to the FOMC.[23]

In addition, Burns had a sympathetic attitude toward price and wage controls. For instance, he testified to Congress on February 7, 1973:

> [T]here is a need for legislation permitting some direct controls over wages and prices...The structure of our economy—in particular, the power of many corporations and trade unions to exact rewards that exceed what could be achieved under conditions of active competition—does expose us to upward pressure on costs and prices that may be cumulative and self-reinforcing (cited by Hetzel, 2008, p. 79).

He reiterated that view in a letter to the president on June 1, 1973, in which he proposed to reintroduce mandatory price controls for large firms.[24] In his view, controls could break the cost-push spiral of the economy and the inflationary pressures triggered by the social unrest of the late 1960s and be a more effective instrument than open market operations, which could be quite costly in terms of employment and financial disturbances.[25] In fact, many members of the FOMC believed that the introduction of price and wage controls in different phases between 1971 and 1973 had not only eased the need for monetary tightening, but also positively suggested that monetary policy should not impose further restraint on the economy.[26] More interestingly, if price and wage controls were an argument for loose monetary policy, their easing was also an argument for expansionary policy, or as Governor Charles Partee put it during the FOMC meeting of January 11, 1973, the lifting of controls "might necessitate a somewhat faster rate of monetary

[19] Miller stated, "Our attempts to restrain inflation by using conventional stabilization techniques have been less than satisfactory. Three years of high unemployment and underutilized capital stock have been costly in terms both of lost production and of the denial to many of the dignity that comes from holding a productive job. Yet, despite this period of substantial slack in the economy, we still have a serious inflation problem" (Board of Governors, 1978, p. 193; quoted by Romer and Romer, 2004, p. 140).

[20] The situation with Miller reached the surrealistic point when, as narrated by Kettl (1986), Charles Schultze, the chairman of the Council of Economic Advisors, and Michael Blumenthal, the Treasury secretary, were leaking information to the press to pressure Miller to tighten monetary policy.

[21] Perhaps the clearest documented moment is the meeting between Nixon and Burns on October 23, 1969, right after Burns's nomination, as narrated by John Ehrlichman (1982, pp. 248-49): "I know there's the myth of the autonomous Fed...Nixon barked a quick laugh…and when you go up for confirmation some Senator may ask you about your friendship with the President. Appearances are going to be important, so you can call Ehrlichman to get messages to me, and he'll call you." The White House continued its pressure on Burns by many different methods, from constant conversations to leaks to the press (falsely) accusing Burns of requesting a large wage increase. These, and many other histories, are collected in a fascinating article by Abrams (2006).

[22] Three examples. First, Franco Modigliani testified before the U.S. Congress on July 20, 1971: "[Y]ou have to recognize that prices are presently rising, and no measure we can take short of creating massive unemployment is going to make the rate of change of prices substantially below 4 percent." Second, Otto Eckstein, the builder of one of the large macroeconometric models at the time, the DRI U.S. model, argued that it was not the Fed's job to solve structural inflation. Third, James Tobin (1974): "For the rest of us, the tormenting difficulty is that the economy shows inflationary bias even when there is significant involuntary unemployment. The bias is in some sense a structural defect of the economy and society… Chronic and accelerating inflation is then a symptom of a deeper social disorder, of which involuntary unemployment is an alternative symptom. Political economists may differ about whether it is better to face the social conflicts squarely or to let inflation obscure them and muddle through. I can understand why anyone who prefers the first alternative would be working for structural reform, for a new social contract. I cannot understand why he would believe that the job can be done by monetary policy. Within limits, the Federal Reserve can shift from one symptom to the other. But it cannot cure the disease." The examples are quoted by Hetzel (2008, pp. 86, 89, and 128).

[24] Burns papers, B_N1, June 1, 1973, as cited by Meltzer (2010, p. 787).

[25] At the time, many financial institutions were subject to ceiling rates on deposits, which could have made them bankrupt in the case of a fast tightening of monetary policy.

[26] Maisel's diary entry for August 25, 1971; cited by Meltzer, 2010, p. 790.

growth to finance the desired growth in real output under conditions of greater cost-push inflation than would have prevailed with tighter controls" (cited by Meltzer, 2010, p. 815).

Burns's 1979 Per Jacobsson lecture is a revealing summary of Burns's own views on the origins and development of inflation. He blamed the growing demands of different social groups during the late 1960s and early 1970s and the federal government's willingness to concede to them as the real culprit behind inflation. Moreover, he felt that the Fed could not really stop the inflationary wave: If the Federal Reserve then sought to create a monetary environment that fell seriously short of accommodating the upward pressures on prices that were being released or reinforced by governmental action, severe difficulties could be quickly produced in the economy. Not only that, the Federal Reserve would be frustrating the will of Congress to which it was responsible.

But beyond Burns's own defeatist attitude toward inflation, he was a most unfortunate Chairman. He was in charge during a period of high turbulence and negative shocks, not only the 1973 oil shock, but also poor crops in the United States and the Soviet Union. Our model estimates large and volatile intertemporal shocks, d_t, and labor supply shocks, φ_t, during his tenure (see FGR for a plot of these shocks). Examples of intertemporal shocks include the final breakdown of the Bretton Woods Agreement, fiscal policy during the 1973-75 recession (with a temporary tax cut signed in March 1975 and increases in discretionary spending), and Nixon's price and wage controls (which most likely distorted intratemporal allocations). Examples of labor supply shocks include the historically high level of strikes in American industry during the early 1970s. (A major issue in the Republican primary of 1976 between Ford and Reagan was picketing rules for striking workers, a policy issue most unlikely to grab many voters' attention nowadays.)

Both types of shocks complicated monetary policy. Large positive intertemporal shocks increase aggregate demand. In our model, this translates partly into higher output and partly into higher inflation. Positive labor supply shocks increase wages, which pushes up the marginal cost and, therefore, inflation. Moreover, FGR show that, if volatility had stayed at historical levels, even with negative innovations, inflation would have been much lower and the big peak of 1973 avoided.

However, these negative shocks should not make us forget that, according to our model, if monetary policy had engineered higher real interest rates during those years, the history of inflation could have been different. In FGR we calculate that, had monetary policy behaved under Burns and Miller as it did under Volcker, inflation would have been 4.36 percent on average, instead of the observed 6.23 percent. The experience of Germany or Switzerland, which had much lower inflation than the United States during the same time, suggests that this was possible. After all, the peak of inflation in Germany was in 1971, well before any of the oil shocks. And in neither of these two European countries do we observe statements such as that by Governor Sheehan on the January 22, 1974, FOMC meeting: "[T]he Committee had no choice but to validate the rise in prices if it wished to avoid compounding the recession" (Hetzel, 2008, p. 93).

Thus, our reading of monetary policy during the Burns years through the lens of our model emphasizes the confluence of two phenomena: an accommodating position with respect to inflation and large and volatile shocks that complicated the implementation of policy. There is ample evidence in the historical record to support this view. This was, indeed, monetary policy in the time of turbulence.

6.3 The Volcker Era: High Noon

In his 1979 Per Jacobsson lecture cited earlier, Burns had concluded: "It is illusory to expect central banks to put an end to the inflation that now afflicts the industrial democracies." Paul Volcker begged to differ. He had been president of the Federal Reserve Bank of New York since August 1975 and, from that position, a vocal foe of inflation. In particular, during his years as a member of the FOMC, Volcker expressed concern that the Fed was consistently underpredicting inflation and that, therefore, monetary policy was more expansionary than conventionally understood (Meltzer, 2010, p. 942).[27]

In the summer of 1979, Jimmy Carter moved Miller to the Treasury Department. Then, he offered Volcker the chairmanship of the Board of Governors. Volcker did not hesitate to take it, but not before warning the president "of the need for tighter money—tighter than Bill Miller had wanted" (Volcker and Gyothen, 1992, p. 164) and the Senate in his confirmation hearings that "the only sound foundation for the continuing growth and prosperity of the American economy is much greater price stability" (U.S. Senate, 1979, p. 16; quoted by Romer and Romer, 2004, p. 156). Deep changes were coming and the main decision-makers were aware of them.

We should be careful not to attribute all of the sharp break in monetary policy to Volcker's appointment. In 1975, the House passed Concurrent Resolution 133, the brainchild of Karl Brunner (Weintraub, 1977). This resolution, which asked the Fed to report to the House Banking Committee on objectives and plans with respect to the ranges of growth or diminution of monetary and credit aggregates in the upcoming twelve months, was a first victory for monetarism. Although the resolution probably did little by itself, it was a sign that times were changing. Congress acted again with the Full Employment and Balanced Growth Act of 1978, which required the Fed to report monetary aggregates in its reports to Congress. In April 1978, the federal funds rate started growing quickly, from a monthly average of 6.9 percent to 10 percent by the end of the year. This reflected a growing consensus on the FOMC (still with many dissenting voices) regarding the need for lower inflation. Figure 2 shows the start of an increase in $\gamma_{\Pi,t}$ around that time. At the same time, the new procedures for monetary policy that targeted money growth rates and reserves instead of the federal funds rate were not announced until October 6, 1979. Additionally, Goodfriend and King (2005) have argued that Volcker required some time before asserting his control over the FOMC. For instance, in the Board meeting of September 18, 1979, Volcker did obtain a rise in the discount rate, but only with three dissenting votes. As we argued in Section 2, all of these observations suggest that modeling the evolution of monetary policy as a smooth change may be more appropriate than assuming a pure break.

Regardless of the exact timing of changes in monetary policy, the evidence in Figure 2 is overwhelming: On or about August 1979, the character of monetary policy changed. The federal funds rate jumped to new levels, with the first significant long-lasting increase in the real interest rate in many years. Real interest rates would remain high for the remainder of the decade of the 1980s, partly reflecting high federal fund rates and partly reflecting the deeply rooted expectations of inflation among the agents. In any case, the response of monetary policy to inflation, $\gamma_{\Pi,t}$, was consistently high during the whole of Volcker's years.

An important question is the extent to which the formalism of the Taylor rule can capture the way in which monetary policy was conducted at the time, when money growth targeting and reserve management were explicitly tried (what Volcker called "practical monetarism"). We are not overly concerned about this aspect of the data because, in our DSGE model, there is a mapping between money targeting and the Taylor rule (Woodford, 2003). Thus, as long as we are careful to interpret the monetary policy shocks during the period (which we estimate were, indeed, larger than in other parts of the sample), our exercise should be relatively robust to this consideration.[28] A much more challenging task could be to build a DSGE model with a richer set of monetary pol-

[27] This position links to an important point made by Orphanides (2002): Monetary policy decisions are implemented using real-time data, a point that our model blissfully ignores. In turbulent times such as the 1970s, this makes steering the ship of policy targets exceedingly difficult.

[28] This begets the question of why Volcker spent so much effort on switching the operating procedure of the Fed between 1979 and 1982. Volcker himself ventures that it was easier to sell a restrictive monetary policy in terms of money growth rates than in terms of interest rates: "More focus on the money supply also would be a way of telling the public that we meant business. People don't need an advanced course in economics to understand that inflation has something to do with too much money" (Volcker and Gyohten, 1992, pp. 167-68).

icy rules and switches between them. However, at the moment, this goal seems infeasible.[29]

The impressions of participants in the monetary policy process reinforced the message of Figure 2. For instance, Axilrod (2009, p. 91) states:

> During Paul Volcker's eight-year tenure as chairman of the Fed...policy changed dramatically. He was responsible for a major transformation—akin to a paradigm shift—that was intended to greatly reduce inflation, keep it under control, and thereby restore the Fed's badly damaged reputation. Furthermore, it was almost solely because of Volcker that this particular innovation was put in place—one of the few instances in my opinion where a dramatic shift in policy approach could be attributed to a particular person's presence rather than mainly or just to circumstances.

Volcker himself was very explicit about his views[30]:

> [M]y basic philosophy is over time we have no choice but to deal with the inflationary situations because over time inflation and unemployment go together...Isn't that the lesson of the 1970s? We sat around [for] years thinking we could play off a choice between one or the other...It had some reality when everybody thought processes were going to be stable...So in a very fundamental sense, I don't think we have the choice.

In fact, Volcker's views put him in the rather unusual position of being outvoted on February 24, 1986. In that meeting, a majority of four members of the Board voted against Volcker and two other dissenting members to lower the discount rate 50 basis points.

At the same time, and according to our model, Volcker was also an unlucky Chairman. The economy still suffered from large and negative shocks during his tenure, since the level and volatility of the intratemporal preference shifter did not fall until later in his term. In FGR, we build a counterfactual in which Volcker is faced with the same structural shocks he faced in real life, but with the historical average volatility. In this counterfactual history, inflation falls to negative values by the end of 1983, instead of still hovering around 3 to 4 percent. It was a tough policy in a difficult time. However, despite these misfortunes and heavy inheritance from the past, our model tells us that monetary policy conquered the Great Inflation. The Great Moderation would have to wait for better shocks.

We started this subsection with Burns's own words in the 1979 Per Jacobsson lecture. In 1989, Volcker was invited to give the same lecture. What a difference a decade can make! While Burns was sad and pessimistic (his lecture was entitled "The Anguish of Central Banking"), Volcker was happy and confident (his lecture was entitled "The Triumph of Central Banking?"). Inflation had been defeated and he warned that "our collective experience strongly emphasizes the importance of dealing with inflation at an early stage" (Volcker, 1990, p. 14).

6.4 The Greenspan Era: Speaking Like a Hawk and Walking Like a Dove

These are the colorful words with which Laurence Meyer (2004, p. 83) summarizes Greenspan's behavior during Meyer's time as a governor (June 1996 to January 2002). Once and again,

> [Greenspan] seemed to fall into a pattern: The Chairman would ask for no change in the funds rate, suggest that the time was approaching for action, and indicate that there was a high probability of a move at the next meeting. Then at the next meeting, he would explain that the data did not yet provide a credible basis for tightening, and in any case, that the markets didn't expect a move. However, he would conclude that he expected the Committee would be forced to move at the next meeting.

Meyer means these words in a positive way. In his opinion, Greenspan discovered before he did

[29] The impact of the credit controls imposed by the Carter administration starting on March 14, 1980, is more difficult to gauge. Interestingly, we estimate a large negative innovation to the intratemporal preference shifter at that point in time, a likely reflection of the distortions of the controls in the intertemporal choices of households (see the historical description in Shreft, 1990).

[30] Volcker papers, Federal Reserve Bank of New York, speech at the National Press Club, Box 97657, January 2, 1980; quoted by Meltzer, 2010, p. 1034.

that the economy was being hit during the second half of the 1990s by an unusual sequence of positive shocks and directed monetary policy to take advantage of them.

We quote Meyer because it illustrates that Greenspan showed from the start that he knew how to respond to changing circumstances. He was appointed on August 11, 1987. In his confirmation hearings, he clearly reaffirmed the need to fight inflation.[31] But after just a couple of months, on October 19, 1987, he reacted to the big crash of the stock market by declaring the Fed's disposition to serve as a source of liquidity, even if, in the short run, this could complicate the control of inflation.

Later, in early 1989, the federal funds rate started to fall, despite the fact that inflation remained at around 6 percent until the end of 1990. As shown in Figure 2, our estimate of $\gamma_{\Pi,t}$ picks up this fall by dropping itself. Moreover, it dropped fast. We estimate that $\gamma_{\Pi,t}$ was soon below 1, back to the levels of Burns-Miller (although, for a while, there is quite a bit of uncertainty in our estimate). The parameter stayed there for the rest of Greenspan's tenure. The reason for this estimated low level of $\gamma_{\Pi,t}$ is that the real interest rate also started to fall rather quickly. At the same time, a remarkable sequence of good shocks delivered rapid output growth and low inflation.

In fact, in FGR we find that all of the shocks went right for monetary policy during the 1990s. A large string of positive and stable investment-specific technological shocks delivered fast productivity growth, a falling intertemporal shifter lowered demand pressures, and labor supply shocks pressured wages downward—and, with them, marginal costs. This fantastic concatenation of shocks accounted for the bulk of the Great Moderation. In FGR, we calculate that without changes in volatility, the Great Moderation would have been much smaller. The SD of inflation would have fallen by only 13 percent (instead of 60 percent in the data), the SD of output growth would have fallen by 16 percent (instead of 46 percent in the data), and the SD of the federal funds rate would have fallen by 35 percent (instead of 39 percent in the data). That is, the moderation in inflation fluctuations would have been only one-fifth as large as in the data (and the counterfactual mean would have actually been higher than in the data) and the moderation for output growth's SD only one-third.

We can push the argument even further. In FGR we build the counterfactual in which the average $\gamma_{\Pi,t}$ during the Greenspan years is plugged into the model at the time of Burns's appointment. Then, we keep $\gamma_{\Pi,t}$ at that level and hit the model with exactly the same shocks that we backed out from our estimation. This exercise is logically coherent, since we are working with a DSGE model and, therefore, the structural and volatility shocks are invariant to this class of interventions. We compute that the average monetary policy during Greenspan's years would not have made much of a difference in the 1970s. If anything, inflation would have been even slightly higher (6.83 percent in the counterfactual instead of 6.23 percent in the data). This finding contrasts with our counterfactual in which Volcker is moved to the Burns-Miller era. In this counterfactual, inflation would have been only 4.36 percent. To summarize, our reading of monetary policy during the Greenspan years is that it was not too different from the policy in the Burns-Miller era; it just faced much better shocks.

Is this result credible? First, it is clear that it is not a pure artifact of our model. A similar result is found in Sims and Zha (2006). These authors, using structural vector autoregressions with Markov switching, which imposes many fewer cross-equation restrictions than our analysis, do not find much evidence of differences in monetary policy across time (actually, Sims and Zha's position is even stronger than ours, since they do find that monetary policy was different even under Volcker). Second, there are hints in the data that lead us to believe that the results make sense. At the start of the 1994 inflation scare,

[31] Greenspan stated in his confirmation hearings: "[W]e allowed our system to take on inflationary biases which threw us into such a structural imbalance that, in order to preserve the integrity of the system, the Federal Reserve had to do what it did. Had it not acted in the way which it did at that time, the consequences would have been far worse than what subsequently happened" (U.S. Senate, 1987, p. 35; quoted by Romer and Romer, 2004, p. 158).

when there were no signs of the "new economy" anywhere to be seen, Greenspan argued[32]:

> You know, I rarely feel strongly about an issue, and I very rarely sort of press this Committee. But let me tell you something about what's gnawing at me here. I am very sympathetic with the view that we've got to move and that we're going to have an extended period of moves, assuming the changes that are going on now continue in the direction of strength. It is very unlikely that the recent rate of economic growth will not simmer down largely because some developments involved in this particular period are clearly one-shot factors—namely, the very dramatic increase in residential construction and the big increase in motor vehicle sales. Essentially the two of those have added one-shot elements to growth. In the context of a saving rate that is not high, the probability is in the direction of this expansion slowing from its recent pace, which at the moment is well over 4 percent and, adjusting for weather effects, may be running over 5 percent. This is not sustainable growth, and it has nothing to do with monetary policy. In other words, it will come down. And the way a 3 percent growth feels, if I may put it that way, is a lot different from the way the expansion feels now.
>
> I would be very concerned if this Committee went 50 basis points now because I don't think the markets expect it...I've been in the economic forecasting business since 1948, and I've been on Wall Street since 1948, and I am telling you I have a pain in the pit of my stomach, which in the past I've been very successful in alluding to. I am telling you—and I've seen these markets—this is not the time to do this. I think there will be a time; and if the staff's forecast is right, we can get to 150 basis points pretty easily. We can do it with a couple of ½ point jumps later when the markets are in the position to know what we're doing and there's continuity. I really request that we not do this. I do request that we be willing to move again fairly soon, and maybe in larger increments; that depends on how things are evolving.

We construe this statement as revealing a low $\gamma_{\Pi t}$. We could present similar evidence regarding the behavior of policy in the aftermath of the Long Term Capital Management fiasco or in the exit from the 2001 recession. But we feel the point has been made. We believe that our estimates are right: Monetary policy in the Greenspan years was similar to monetary policy under Burns and Miller. Instead, time-varying structural shocks were the mechanism that played a key role in the Great Moderation and the low inflation of 1987-2007.

7. WHAT ARE WE MISSING?

What is our model missing that is really important? The answer will tell us much about where we want to go in terms of research and where we need to be careful in our reading of monetary history. Of all the potential problems of our specification, we are particularly concerned about the following.

First, households and firms in the model observe the changes in the coefficients $\gamma_{\Pi t}$ and γ_{yt} when they occur. A more plausible scenario would involve filtering in real time by the agents who need to learn the stand of the monetary authority from observed decisions.[33] A similar argument can be made for the values of the SDs of all the other shocks in the economy. Unfortunately, introducing learning suffers from two practical difficulties: It is not obvious what is the best way to model learning about monetary policy, especially in a nonlinear environment such as ours where least-square rules may not work properly. And it would make the computation of the model nearly infeasible.

Second, we assume that monetary policy changes are independent of the events in the economy. However, many channels make this assumption untenable. For instance, each administration searches for governors of the Board who conform with its views on the economy (after all,

[32] Board of Governors FOMC Transcripts, February 3-4, 1994, p. 55.

[33] The difficulties in observing monetary policy changes can be illustrated by Axilrod's description of a lunch with Arthur Burns shortly after the announcement of Volcker's new policy. According to Axilrod (2009, p. 100), Burns stated: "You are not really going to be doing anything different from what we were doing. If an insider like Burns had difficulties in filtering Volcker's behavior, it is hard to conclude anything but that the average agents in the economy had difficulties as well."

this is what a democracy is supposed to be about). We saw how Heller discovered that an administration could select governors to twist the FOMC toward its policy priorities. This is a tradition that has continued. Meyer (2004, p. 17) describes the process for his own appointment as one clearly guided by the desire of the Clinton administration to make monetary policy more accommodative and growth-oriented. As long as the party in power is a function of the state of the economy, the composition of the FOMC will clearly be endogenous. Similarly, changes in public perception of the dangers of inflation certainly weighed heavily on Carter when he appointed Volcker to lead the Fed in 1979.

Third, and related to our two previous points, evolving beliefs about monetary policy might be endogenous to the developments of events and lead to self-confirming equilibria. This is a point emphasized by Cho, Williams, and Sargent (2002) and Sargent (2008).

Fourth, our technological drifts are constant over time. The literature on long-run risk has highlighted the importance of slow-moving components in growth trends (Bansal and Yaron, 2004). It may be relevant to judge monetary policy to estimate a model in which we have these slow-moving components, since the productivity slowdown of the 1970s and the productivity acceleration of the late 1990s are bound to be reflected in our assessment of the stance of monetary policy during those years. This links us back to some of the concerns expressed by Orphanides (2002). At the same time and nearly by definition, there is very little information in the data about this component.

Fifth, our model is a closed economy. However, the considerations regarding exchange rates have often played an important role in monetary policymaking. For instance, during the late 1960s, the United States fought an increasingly desperate battle to keep the Bretton Woods Agreement alive, which included the Fed administering a program to voluntarily reduce the amount of funds that American banks could lend abroad (Meltzer, 2010, p. 695) and purchasing long-term Treasury bonds to help the British pound stabilize after its 1967 devaluation. The end of Bretton Woods also deeply influenced policymakers in the early 1970s. Later, Volcker's last years at the Fed were colored by the Plaza and Louvre Accords and the attempts to manage the exchange rate between the U.S. dollar and the Japanese yen.

Finally, our model ignores fiscal policy. The experience of the 1960s, in which there was an explicit attempt at coordinating fiscal and monetary policies, and the changes in long-run interest rates possibly triggered by the fiscal consolidations of the 1990s indicate that the interaction between fiscal and monetary policies deserves much more attention, a point repeatedly made by Chris Sims (for example in Sims, 2009).

8. CONCLUDING REMARKS

The title of this paper is not only a tribute to Friedman and Schwartz's (1971) opus magnum, but also a statement of the limitations of our investigation. Neither the space allocated to us[34] nor our own abilities allow us to get even close to Friedman and Schwartz's achievements. We have tried to demonstrate, only, that the use of modern equilibrium theory and econometric methods allows us to read the monetary policy history of the United States since 1959 in ways that we find fruitful. We proposed and estimated a DSGE model with stochastic volatility and parameter drifting. The model gave us a clear punch line: First, there is ample evidence of both strong changes in the volatility of the structural shocks that hit the economy and changes in monetary policy. The changes in volatility accounted for most of the Great Moderation. The changes in monetary policy mattered for the rise and conquest of the Great Inflation. Inflation stayed low during the next decades in large part due to good shocks. When we go to the historical record and use the results of our estimation to read and assess the documentary evidence, we find ample confirmation, in our opinion, that the model, despite all its limitations, is teaching us important lessons.

[34] For an only slightly longer period than ours, Meltzer (2010) requires 1,300 pages to cover the details of the history of monetary policy in the United States, including the evolution of operational procedures that we have not even mentioned.

As we argued in the previous section, we leave much unsaid. Hopefully, the results in this paper will be enticing enough for other researchers to continue a close exploration of recent monetary policy history with the tools of modern dynamic macroeconomics.

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