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ABSTRACT

We consider the desirability of modifying a standard Taylor rule for a central bank's interest-rate policy to incorporate either an adjustment for changes in interest-rate spreads (as proposed by Taylor [2008] and by McCulley and Toloui [2008]) or a response to variations in the aggregate volume of credit (as proposed by Christiano et al. [2007]). We consider the consequences of such adjustments for the way in which policy would respond to a variety of types of possible economic disturbances, including (but not limited to) disturbances originating in the financial sector that increase equilibrium spreads and contract the supply of credit. We conduct our analysis using the simple DSGE model with credit frictions developed in Curdia and Woodford (2009), and compare the equilibrium responses to a variety of disturbances under the modified Taylor rules to those under a policy that would maximize average expected utility. According to our model, a spread adjustment can improve upon the standard Taylor rule, but the optimal size is unlikely to be as large as the one proposed, and the same type of adjustment is not desirable regardless of the source of the variation in credit spreads. A response to credit is less likely to be helpful, and the desirable size (and even the right sign) of the response to credit is less robust to alternative assumptions about the nature and persistence of disturbances.

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The recent turmoil in financial markets has confronted the central banks of the world with a number of unusual challenges. To what extent do standard approaches to the conduct of monetary policy continue to provide reasonable guidelines under such circumstances? For example, the Federal Reserve aggressively reduced its operating target for the federal funds rate in late 2007 and January 2008, though official statistics did not yet indicate that real GDP was declining, and according to many indicators inflation was if anything increasing; a simple "Taylor rule" (Taylor, 1993) for monetary policy would thus not seem to have provided any ground for the Fed's actions at the time. Obviously, they were paying attention to other indicators than these ones alone, some of which showed that serious problems had developed in the financial sector.[1] But does a response to such additional variables make sense as a general policy? Should it be expected to lead to better responses of the aggregate economy to disturbances more generally?

Among the most obvious indicators of stress in the financial sector since August 2007 have been the unusual increases in (and volatility of) the spreads between the interest rates at which different classes of borrowers are able to fund their activities.[2] Indeed, McCulley and Toloui (2008) and Taylor (2008) have proposed that the intercept term in a "Taylor rule" for monetary policy should be adjusted downward in proportion to observed increases in spreads. Similarly, Meyer and Sack (2008) propose, as a possible account of recent U.S. Federal Reserve policy, a Taylor rule in which the intercept — representing the Fed's view of "the equilibrium real funds rate" — has been adjusted downward in response to credit market turmoil, and use the size of increases in spreads in early 2008 as a basis for a proposed magnitude of the appropriate adjustment. A central objective of this paper is to assess the degree to which a modification of the classic Taylor rule of this kind would generally improve the way in which the economy responds to disturbances of various sorts, including in particular to those originating in the financial sector. Our model also sheds light on the question whether it is correct to say that the "natural" or "neutral" rate of interest is lower when credit spreads increase (assuming unchanged fundamentals otherwise), and to the extent that it is, how the size of the change in the natural rate compares to the size of the change in credit spreads.

Other authors have argued that if financial disturbances are an important source

[1] For a discussion of the FOMC's decisions at that time by a member of the committee, see Mishkin (2008).

[2] See, for example, Taylor and Williams (2008a, 2008b).

of macroeconomic instability, a sound approach to monetary policy will have to pay attention to the balance sheets of financial intermediaries. It is sometimes suggested, for example, that a Taylor rule that is modified to include a response to variations in some measure of aggregate credit would be an improvement upon conventional policy advice (see, *e.g.,* Christiano *et al.,* 2007). We also consider the cyclical variations in aggregate credit that should be associated with both non-financial and financial disturbances, and the desirability of a modified Taylor rule that responds to credit variations in both of these cases.

Many of the models used both in theoretical analyses of optimal monetary policy and in numerical simulations of alternative policy rules are unsuitable for the analysis of these issues, because they abstract altogether from the economic role of financial intermediation. Thus it is common to analyze monetary policy in models with a single interest rate (of each maturity) — "the" interest rate — in which case we cannot analyze the consequences of responding to variations in spreads, and with a representative agent, so that there is no credit extended in equilibrium and hence no possibility of cyclical variations in credit. In order to address the questions that concern us here, we must have a model of the monetary transmission mechanism with both heterogeneity (so that there are both borrowers and savers at each point in time) and segmentation of the participation in different financial markets (so that there can exist non-zero credit spreads).

The model that we use is one developed in Cúrdia and Woodford (2009), as a relatively simple generalization of the basic New Keynesian model used for the analysis of optimal monetary policy in sources such as Goodfriend and King (1997), Clarida *et al.* (1999), and Woodford (2003). 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 infinite-lived household-firms, and we similarly 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 all non-durable consumer expenditure (yielding immediate utility, at a diminishing marginal rate). The advantage of this very simple framework, in our view, is that it brings the implications of the credit frictions into very clear focus, by using a model that reduces, in the absence of those frictions, to a model that is both simple and already very well understood. The model is also one in which, at least under certain ideal circumstances, a Taylor rule with no adjustment for financial conditions would represent optimal policy. It is thus of particular interest in this context to ask what kinds of possible adjustments for financial conditions are desirable when credit frictions are introduced into the model.

In section 1, we review the structure of the model, stressing the respects in which the introduction of heterogeneity and imperfect financial intermediation requires the equations of the basic New Keynesian model to be generalized, and discuss its numerical calibration. We then consider the economy's equilibrium responses to both non-financial and financial disturbances under the standard Taylor rule, according to this model. Section 2 then analyzes the consequences of modifying the Taylor rule, to incorporate an automatic response to either changes in credit spreads or in a measure of aggregate credit. We consider the welfare consequences of alternative policy rules, from the standpoint of the average level of expected utility of the heterogenous households in our model. Section 3 then summarizes our conclusions.

1 A New Keynesian Model with Financial Frictions

Here we briefly describe the model developed in Cúrdia and Woodford (2009). (The reader is referred to that paper for more details.) We stress the similarity between the model developed there and the basic New Keynesian [NK] model, and show how the standard model is recovered as a special case of the extended model. This sets the stage for a quantitative investigation of the degree to which credit frictions of an empirically realistic magnitude change the predictions of the model about the responses to shocks other than changes in the severity of financial frictions.

1.1 Sketch of the Model

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

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

where $\tau_t(i) \in \{b, s\}$ 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. 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 aggegator 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 $0 \leq \delta < 1$) an event occurs which 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

$$u_c^b(c;\xi) > u_c^s(c;\xi)$$

for all levels of expenditure c in the range that occur in equilibrium. (See Figure 1, where these functions are graphed in the case of the calibration discussed below.) Hence a change in a household's type changes its relative impatience to consume, given the aggregate state ξ_t; in addition, the current impatience to consume of all households is changed by the aggregate disturbance ξ_t. We also assume that the marginal utility of additional expenditure diminishes at different rates for the two types, as is also illustrated in the figure; 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 New Keynesian model, all output is consumed either by households or by the government;[3] 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 that most of the time, households are able to spend an amount different from their current income *only* by depositing funds with or borrowing from financial intermediaries, and 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,[4] 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 or borrowers.) The assumption that households cannot engage in financial contracting other than through the intermediary sector represents the key financial friction.

The analysis is simplified by allowing for an additional form of financial contracting. We assume 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 that households are *only intermittently* able to receive transfers from the insurance agency; between the infrequent occasions when a household has access to the insurance agency,[5] it can only save or borrow through the financial intermediary sector

[3]The "consumption" variable is therefore to be interpreted as representing all of private expenditure, not only consumer expenditure. In reality, one of the most important reasons for some economic units to wish to borrow from others is that the former currently have access to profitable *investment* opportunities. Here we treat these opportunities as if they were opportunities to *consume*, in the sense that we suppose that the expenditure opportunities are valuable to the household, but we abstract from any consequences of current expenditure for future productivity. For discussion of the interpretation of "consumption" in the basic New Keynesian model, see Woodford (2003, pp. 242-243).

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

[5]For simplicity, these are assumed to coincide with the infrequent occasions when the household draws a new "type"; but the insurance payment is claimed before the new type is known, and cannot

mentioned in the previous paragraph. 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.

As long as certain inequalities discussed in our previous paper are satisfied,[6] it turns out that in equilibrium, type b households choose always to borrow from the intermediaries, while type s households deposit their savings with them (and no one chooses to do both, given that $i_t^b \geq i_t^d$ at all times). Moreover, because of the asymptotic risk-sharing, one can show that all households of a given type at any point in time have a common marginal utility of real income (which we denote λ_t^τ for households of type τ) and choose a common level of real expenditure c_t^τ. Household optimization of the timing of expenditure requires that the marginal-utility processes $\{\lambda_t^\tau\}$ satisfy the two Euler equations

$$\lambda_t^b = \beta E_t \left[\frac{1+i_t^b}{\Pi_{t+1}} \left\{ [\delta + (1-\delta)\,\pi_b]\,\lambda_{t+1}^b + (1-\delta)\,\pi_s \lambda_{t+1}^s \right\} \right], \tag{1.1}$$

$$\lambda_t^s = \beta E_t \left[\frac{1+i_t^d}{\Pi_{t+1}} \left\{ (1-\delta)\,\pi_b \lambda_{t+1}^b + [\delta + (1-\delta)\,\pi_s]\,\lambda_{t+1}^s \right\} \right] \tag{1.2}$$

in each period. Here $\Pi_t \equiv P_t/P_{t-1}$ is the gross inflation rate, where P_t is the Dixit-Stiglitz price index for the differentiated goods produced in period t. Note that each equation takes into account the probability of switching type from one period to the next.

Assuming an interior choice for consumption by households of each type, the expenditures of the two types must satisfy

$$\lambda_t^b = u^{b\prime}(c_t^b), \qquad \lambda_t^s = u^{s\prime}(c_t^s),$$

which relations can be inverted to yield demand functions

$$c_t^b = c^b(\lambda_t^b; \xi_t), \qquad c_t^s = c^s(\lambda_t^s; \xi_t).$$

be contingent upon the new type.

[6] We verify that in the case of the numerical parameterization of the model discussed below, these inequalities are satisfied at all times, in the case of small enough random disturbances of any of the kinds discussed.

Aggregate demand Y_t for the Dixit-Stiglitz composite good is then given by

$$Y_t = \pi_b c^b(\lambda_t^b; \xi_t) + \pi_s c^s(\lambda_t^s; \xi_t) + G_t + \Xi_t, \tag{1.3}$$

where G_t indicates the (exogenous) level of government purchases and Ξ_t indicates resources consumed by the intermediary sector (discussed further below). Equations (1.1)–(1.2) together with (1.3) indicate the way in which the two real interest rates of the model affect aggregate demand. This system directly generalizes the relation that exists in the basic NK model as a consequence of the Euler equation of the representative household.

It follows from the same assumptions that optimal labor supply in any given period will be the same for all households of a given type. Specifically, any household of type τ will supply hours $h^\tau(j)$ of labor of type j, so as to satisfy the first-order condition

$$\mu_t^w v_h^\tau(h_t^\tau(j); \xi_t) = \lambda_t^\tau W_t(j)/P_t, \tag{1.4}$$

where $W_t(j)$ is the wage for labor of type j, and the exogenous factor μ_t^w represents a possible "wage markup" (the sources of which are not further modeled). Aggregation of the labor supply behavior of the two types is facilitated if, as in Benigno and Woodford (2005), we assume the isoelastic functional form

$$v^\tau\left(h; \xi_t\right) \equiv \frac{\psi_\tau}{1+\nu} h^{1+\nu} \bar{H}_t^{-\nu}, \tag{1.5}$$

where $\{\bar{H}_t\}$ is an exogenous labor-supply disturbance process (assumed common to the two types, for simplicity); $\psi_b, \psi_s > 0$ are (possibly) different multiplicative coefficients for the two types; and the coefficient $\nu \geq 0$ (inverse of the Frisch elasticity of labor supply) is assumed to be the same for both types. Solving (1.4) for the competitive labor supply of each type and aggregating, we obtain

$$h_t(j) = \bar{H}_t \left[\frac{\tilde{\lambda}_t}{\psi \mu_t^w} \frac{W_t(j)}{P_t} \right]^{1/\nu}$$

for the aggregate supply of labor of type j, where

$$\tilde{\lambda}_t \equiv \psi \left[\pi_b (\frac{\lambda_t^b}{\psi_b})^{1/\nu} + \pi_s (\frac{\lambda_t^s}{\psi_s})^{1/\nu} \right]^\nu, \tag{1.6}$$

$$\psi \equiv \left[\pi_b \psi_b^{-1/\nu} + \pi_s \psi_s^{-1/\nu} \right]^{-\nu}.$$

We furthermore assume an isoelastic production function

$$y_t(i) = Z_t h_t(i)^{1/\phi}$$

for each differentiated good i, where $\phi \geq 1$ and Z_t is an exogenous, possibly time-varying productivity factor, common to all goods. We can then determine the demand for each differentiated good as a function of its relative price using the usual Dixit-Stiglitz demand theory, and determine the wage for each type of labor by equating supply and demand for that type. We finally obtain a total wage bill

$$\int W_t(j)h_t(j)dj = \psi \mu_t^w \frac{P_t}{\tilde{\lambda}_t \bar{H}_t^\nu} \left(\frac{Y_t}{Z_t}\right)^{1+\omega_y} \Delta_t, \tag{1.7}$$

where $\omega_y \equiv \phi(1+\nu) - 1 \geq 0$ and

$$\Delta_t \equiv \int \left(\frac{p_t(i)}{P_t}\right)^{-\theta(1+\omega_y)} di \geq 1$$

is a measure of the dispersion of goods prices (taking its minimum possible value, 1, if and only if all prices are identical), in which $\theta > 1$ is the elasticity of substitution among differentiated goods in the Dixit-Stiglitz aggregator. Note that in the Calvo model of price adjustment, this dispersion measure evolves according to a law of motion

$$\Delta_t = h(\Delta_{t-1}, \Pi_t), \tag{1.8}$$

where the function $h(\Delta, \Pi)$ is defined as in Benigno and Woodford. Finally, since households of type τ supply fraction

$$\pi_\tau \left(\frac{\lambda_t^\tau}{\tilde{\lambda}_t} \frac{\psi}{\psi_\tau}\right)^{\frac{1}{\nu}}$$

of total labor of each type j, they also receive this fraction of the total wage bill each period. This observation together with (1.7) allows us to determine the wage income of each household at each point in time.

These solutions for expenditure on the one hand and wage income on the other for each type allow us to solve for the evolution of the net saving or borrowing of households of each type. We let the credit spread $\omega_t \geq 0$ be defined as the factor such that

$$1 + i_t^b = (1 + i_t^d)(1 + \omega_t), \tag{1.9}$$

and observe that in equilibrium, aggregate deposits with intermediaries must equal aggregate saving by type s households in excess of b_t^g, the real value of (one-period, riskless nominal) government debt (the evolution of which is also specified as an exogenous disturbance process[7]), which in equilibrium must pay the same rate of interest i_t^d as deposits with intermediaries. It is then possible to derive a law of motion for aggregate private borrowing b_t, of the form

$$\begin{aligned}(1+\pi_b\omega_t)b_t &= \pi_b\pi_s B(\lambda_t^b, \lambda_t^s, Y_t, \Delta_t; \xi_t) - \pi_b b_t^g \\ &\quad + \delta[b_{t-1}(1+\omega_{t-1}) + \pi_b b_{t-1}^g]\frac{1+i_t^d}{\Pi_t}, \end{aligned} \tag{1.10}$$

where the function B (defined in Cúrdia and Woodford, 2009) indicates the amount by which the expenditure of type b households in excess of their current wage income is greater than the expenditure of type s households in excess of their current wage income. This equation, which has no analog in the representative-household model, allows us to solve for the dynamics of private credit in response to various types of disturbances. It becomes important for the general-equilibrium determination of other variables if (as assumed below) the credit spread and/or the resources used by intermediaries depend on the volume of private credit.

We can similarly use the above model of wage determination to solve for the marginal cost of producing each good as a function of the quantity demanded of it, again obtaining a direct generalization of the formula that applies in the representative-household case. This allows us to derive equations describing optimal price-setting by the monopolistically competitive suppliers of the differentiated goods. As in the basic NK model, Calvo-style staggered price adjustment then implies an inflation equation of the form

$$\Pi_t = \Pi(z_t), \tag{1.11}$$

where z_t is a vector of two forward-looking variables, recursively defined by a pair of relations of the form

$$z_t = G(Y_t, \lambda_t^b, \lambda_t^s; \xi_t) + E_t[g(\Pi_{t+1}, z_{t+1})], \tag{1.12}$$

[7]Our model includes three distinct fiscal disturbances, the processes G_t, τ_t, and b_t^g, each of which can be independently specified. The residual income flow each period required to balance the government's budget is assumed to represent a lump-sum tax or transfer, equally distributed across households regardless of type.

where the vector-valued functions G and g are defined in Cúrdia and Woodford (2009). (Among the arguments of G, the vector of exogenous disturbances ξ_t now includes an exogenous sales tax rate τ_t, in addition to the disturbances already mentioned.)

These relations are of exactly the same form as in the basic NK model, except that two distinct marginal utilities of income are here arguments of G; in the case that $\lambda_t^b = \lambda_t^s = \lambda_t$, the relations (1.12) reduce to exactly the ones in Benigno and Woodford (2005). The system (1.11)–(1.12) indicates the nature of the short-run aggregate-supply trade-off between inflation and real activity at a point in time, given expectations regarding the future evolution of inflation and of the variables $\{z_t\}$.

It remains to specify the frictions associated with financial intermediation, that determine the credit spread ω_t and the resources Ξ_t consumed by the intermediary sector. We allow for two sources of credit spreads — one of which follows from an assumption that intermediation requires real resources, and the other of which does not — which provide two distinct sources of "purely financial" disturbances in our model. On the one hand, we assume that real resources $\Xi_t(b_t)$ are consumed in the process of originating loans of real quantity b_t, and that these resources must be produced and consumed in the period in which the loans are originated. The function $\Xi_t(b_t)$ is assumed to be non-decreasing and at least weakly convex. In addition, we suppose that in order to originate a quantity of loans b_t that will be repaid (with interest) in the following period, it is necessary for an intermediary to also make a quantity $\chi_t(b_t)$ of loans that will be defaulted upon, where $\chi_t(b_t)$ is also a non-decreasing, weakly convex function. (We assume that intermediaries are unable to distinguish the borrowers who will default from those who will repay, and so offer loans to both on the same terms, but that they are able to accurately predict the fraction of loans that will not be repaid as a function of a given scale of expansion of their lending activity.) Hence total (real) outlays in the amount $b_t + \chi_t(b_t) + \Xi_t(b_t)$ are required[8] in a given period in order to originate a quantity b_t of loans that will be repaid (yielding $(1 + i_t^b)b_t$ in the following period). Competitive loan supply by

[8] It might be thought more natural to make the resource requirement Ξ_t a function of the total quantity $b_t + \chi_t(b_t)$ of loans that are originated, rather than a function of the "sound" loans b_t. But since under our assumptions $b_t + \chi_t(b_t)$ is a (possibly time-varying) function of b_t, it would in any event be possible to express Ξ_t as a (possibly time-varying) function of b_t, with the properties assumed in the text.

intermediaries then implies that

$$\omega_t = \omega_t(b_t) \equiv \chi'_t(b_t) + \Xi'_t(b_t). \tag{1.13}$$

It follows that in each period, the credit spread ω_t will be a non-negative-valued, non-decreasing function of the real volume of private credit b^g_t. This function may shift over time, as a consequence of exogenous shifts in either the resource cost function Ξ_t or the default rate χ_t.[9] Allowing these functions to be time-varying introduces the possibility of "purely financial" disturbances, of a kind that will be associated with increases in credit spreads and/or reduction in the supply of credit.

Finally, we assume that the central bank is able to control the deposit rate i^d_t (the rate at which intermediaries are able to fund themselves),[10] though this is no longer also equal to the rate i^b_t at which households are able to borrow, as in the basic NK model. Monetary policy can then be represented by an equation such as

$$i^d_t = i^d_t(\Pi_t, Y_t/Y^n_t), \tag{1.14}$$

which represents a Taylor rule subject to exogenous random shifts that can be given a variety of interpretations. Here the "natural rate of output" Y^n_t — defined for present purposes as the equilibrium level of aggregate output under flexible prices and in the absence of financial frictions[11] — is a function of exogenous fundamentals that does not depend on monetary policy, and that by assumption does not depend on "purely financial" disturbances. (This is of course only one simple specification of monetary policy; we consider central-bank reaction functions with additional arguments in section 2.)

[9] Of course, these shifts must not be purely additive shifts, in order for the function $\omega_t(b_t)$ to shift. In our numerical work below, the two kinds of purely financial disturbances that are considered are multiplicative shifts of the two functions.

[10] If we extend the model by introducing central-bank liabilities that supply liquidity services to the private sector, the demand for these liabilities will be a decreasing function of the spread between i^d_t and the interest rate paid on central-bank liabilities (reserves). The central bank will then be able to influence i^d_t by adjusting either the supply of its liabilities (through open-market purchases of government debt, for example) or the interest rate paid on them. Here we abstract from this additional complication by treating i^d_t as directly under the control of the central bank.

[11] For the definition of this quantity as a function of technology, preferences and fiscal variables in the context of the basic (representative-household) NK model, see Woodford (2003, chap. 3). The definition here is identical, up to a log-linear approximation, except that the parameter σ in the equations of Woodford (2003) is replaced by the parameter $\bar{\sigma}$ defined in (1.17) below.

If we substitute the functions $\omega_t(b_t)$ and $\Xi_t(b_t)$ for the variables ω_t and Ξ_t in the above equations, then the system consisting of equations (1.1)–(1.3), (1.8)–(1.12), and (1.14) comprise a system of 10 equations per period to determine the 10 endogenous variables $\Pi_t, Y_t, i_t^d, i_t^b, \lambda_t^b, \lambda_t^s, b_t, \Delta_t$, and z_t, given the evolution of the exogenous disturbances. The disturbances that affect these equations include the productivity factor Z_t; the fiscal disturbances G_t, τ_t, and b_t^g; a variety of potential preference shocks (variations in impatience to consume, that may or may not equally affect households of the two types, and variations in attitudes toward work, assumed to be common to the two types) and variations in the wage markup μ_t^w; purely financial shocks (shifts in either of the functions $\Xi_t(b_t)$ and $\chi_t(b_t)$); and monetary policy shocks (shifts in the function $i_t(\Pi_t, Y_t)$). We consider the consequences of systematic monetary policy for the economy's response to all of these types of disturbances below. Note that this system of equations reduces to the basic NK model (as presented in Benigno and Woodford, 2005) if we identify λ_t^b and λ_t^s and identify i_t^d and i_t^b (so that the pair of Euler equations (1.1)–(1.2) reduces to a single equation, relating the representative household's marginal utility of income to the single interest rate); identify the two expenditure functions $c^s(\lambda; \xi)$ and $c^b(\lambda; \xi)$; set the variables ω_t and Ξ_t equal to zero at all times; and delete equation (1.10), which describes the dynamics of a variable (b_t) that has no significance in the representative-household case.

1.2 Log-Linearized Structural Equations

In our numerical analysis of the consequences of alternative monetary policy rules, we plot impulse responses to a variety of shocks under a candidate policy rule. The responses that we plot are linear approximations to the actual response, accurate in the case of small enough disturbances. These linear approximations to the equilibrium responses are obtained by solving a system of linear (or log-linear) approximations to the model structural equations (including a linear equation for the monetary policy rule). Here we describe some of these log-linearized structural equations, as they provide further insight into the implications of our model, and facilitate comparison with the basic NK model.

We log-linearize the model structural relations around a deterministic steady state with zero inflation each period, and a constant level of aggregate output $\bar{Y}$. (We assume that, in the absence of disturbances, the monetary policy rule (1.14) is consistent with this steady state, though the small disturbances in the structural equations that we consider using the log-linearized equations may include small departures from the inflation target of zero.) These log-linear relations will then be appropriate for analyzing the consequences of alternative monetary policy rules only in the case of rules consistent with an average inflation rate that is not too far from zero. But in Cúrdia and Woodford (2009), we show that under an optimal policy commitment (Ramsey policy), the steady state is indeed the zero-inflation steady state. Hence all policy rules that represent approximations to optimal policy will indeed have this property.

We express our log-linearized structural relations in terms of deviations of the logarithms of quantities from their steady-state values ($\hat{Y}_t \equiv \log(Y_t/\bar{Y})$, etc.), the inflation rate $\pi_t \equiv \log \Pi_t$, and deviations of (continuously compounded) interest rates from their steady-state values ($\hat{\imath}_t^d \equiv \log(1 + i_t^d/1 + \bar{\imath}^d)$, etc.). We also introduce isoelastic functional forms for the utility of consumption of each of the two types, which imply that

$$c^\tau(\lambda; \xi_t) = \bar{C}_t^\tau \lambda^{-\sigma_\tau}$$

for each of the two types $\tau \in \{b, s\}$, where $\bar{C}_t^\tau$ is a type-specific exogenous disturbance (indicating variations in impatience to consume, or in the quality of spending opportunities) and $\sigma_\tau > 0$ is a type-specific intertemporal elasticity of substitution.

Then as shown in Cúrdia and Woodford (2009), log-linearization of the system consisting of equations (1.1)–(1.3) allows us to derive an "intertemporal IS relation"

$$\begin{aligned} \hat{Y}_t &= -\bar{\sigma}(\hat{\imath}_t^{avg} - E_t\pi_{t+1}) + E_t\hat{Y}_{t+1} - E_t\Delta g_{t+1} - E_t\Delta\hat{\Xi}_{t+1} \\ &\quad -\bar{\sigma}s_\Omega\hat{\Omega}_t + \bar{\sigma}(s_\Omega + \psi_\Omega)E_t\hat{\Omega}_{t+1}, \end{aligned} \tag{1.15}$$

where

$$\hat{\imath}_t^{avg} \equiv \pi_b\hat{\imath}_t^b + \pi_s\hat{\imath}_t^d \tag{1.16}$$

is the average of the interest rates that are relevant (at the margin) for all of the savers and borrowers in the economy; g_t is a composite "autonomous expenditure" disturbance as in Woodford (2003, pp. 80, 249), taking account of the exogenous fluctuations in $G_t, \bar{C}_t^b$, and $\bar{C}_t^s$ (and again weighting the fluctuations in the spending opportunities of the two types in proportion to their population fractions);

$$\hat{\Omega}_t \equiv \hat{\lambda}_t^b - \hat{\lambda}_t^s,$$

the "marginal-utility gap" between the two types, is a measure of the inefficiency of the intratemporal allocation of resources as a consequence of imperfect financial intermediation; and

$$\hat{\Xi}_t \equiv (\Xi_t - \bar{\Xi})/\bar{Y}$$

measures departures of the quantity of resources consumed by the intermediary sector from its steady-state level.[12] In this equation, the coefficient

$$\bar{\sigma} \equiv \pi_b s_b \sigma_b + \pi_s s_s \sigma_s > 0 \tag{1.17}$$

is a measure of the interest-sensitivity of aggregate demand, using the notation s_τ for the steady-state value of c_t^τ / Y_t; the coefficient

$$s_\Omega \equiv \pi_b \pi_s \frac{s_b \sigma_b - s_s \sigma_s}{\bar{\sigma}}$$

is a measure of the asymmetry in the interest-sensitivity of expenditure by the two types; and the coefficient

$$\psi_\Omega \equiv \pi_b(1 - \chi_b) - \pi_s(1 - \chi_s)$$

is also a measure of the difference in the situations of the two types. Here we use the notation

$$\chi_\tau \equiv \beta(1 + \bar{r}^\tau)[\delta + (1 - \delta)\pi_\tau]$$

for each of the two types, where $\bar{r}^\tau$ is the steady-state real rate of return that is relevant at the margin for type τ. Note that except for the presence of the last three terms on the right-hand side (all of which are identically zero in a model without financial frictions), equation (1.15) has the same form as the intertemporal IS relation in the basic NK model; the only differences are that the interest rate that appears is a weighted average of two interest rates (rather than simply "the" interest rate), the elasticity $\bar{\sigma}$ is a weighted average of the corresponding elasticities for the two types of households (rather than the elasticity of expenditure by a representative household), and the disturbance term g_t involves a weighted average of the expenditure demand shocks $\bar{C}_t^\tau$ for the two types (rather than the corresponding shock for a representative household).

Equation (1.15) is derived by taking a weighted average of the log-linearized forms of the two Euler equations (1.1)–(1.2), and then using the log-linearized form of (1.3)

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

to relate average marginal utility to aggregate expenditure. If we instead subtract the log-linearized version of (1.2) from the log-linearized (1.1), we obtain

$$\hat{\Omega}_t = \hat{\omega}_t + \hat{\delta} E_t \hat{\Omega}_{t+1}. \tag{1.18}$$

Here we define

$$\hat{\omega}_t \equiv \log(1 + \omega_t / 1 + \bar{\omega}),$$

so that the log-linearized version of (1.9) is

$$\hat{\imath}^b_t = \hat{\imath}^d_t + \hat{\omega}_t. \tag{1.19}$$

and

$$\hat{\delta} \equiv \chi_b + \chi_s - 1 < 1.$$

Equation (1.18) can be "solved forward" for $\hat{\Omega}_t$ as a forward-looking moving average of the expected path of the credit spread $\hat{\omega}_t$. This now gives us a complete theory of the way in which time-varying credit spreads affect aggregate demand, given an expected forward path for the policy rate. One the one hand, higher current and/or future credit spreads raise the expected path of $\hat{\imath}^{avg}_t$ for any given path of the policy rate, owing to (1.19), and this reduces aggregate demand $\hat{Y}_t$ according to (1.15). And on the other hand, higher current and/or future credit spreads increase the marginal-utility gap $\hat{\Omega}_t$, owing to (1.18), and (under the parameterization that we find most realistic) this further reduces aggregate demand for any expected forward path for $\hat{\imath}^{avg}_t$, as a consequence of the $\hat{\Omega}_t$ terms in (1.15). The fact that larger credit spreads reduce aggregate demand for a given path of the policy rate is consistent with the implicit model behind the proposal of McCulley and Toloui (2008) and Taylor (2008). But our model does *not* indicate, in general, that it is *only* the borrowing rate i^b_t that matters for aggregate demand determination. Hence there is no reason to expect that the effect of an increased credit spread on aggregate demand can be fully neutralized through an offsetting reduction of the policy rate, as the simple proposal of a one-for-one offset seems to presume.

Log-linearization of the aggregate-supply block consisting of equations (1.11)–(1.12) similarly yields a log-linear aggregate-supply relation of the form

$$\pi_t = \kappa(\hat{Y}_t - \hat{Y}^n_t) + \beta E_t \pi_{t+1} + \xi(s_\Omega + \pi_b - \gamma_b)\hat{\Omega}_t - \xi \bar{\sigma}^{-1} \hat{\Xi}_t, \tag{1.20}$$

where $\hat{Y}^n_t$ (the "natural rate of output") is a composite exogenous disturbance term (a function of all of the real disturbances, other than the purely financial disturbances and the shock to the level of public debt), corresponding to the equilibrium level of output in a representative-household version of the model with flexible prices.[13] The coefficients in this equation are given by

$$\gamma_b \equiv \pi_b \left(\frac{\psi \bar{\lambda}^b}{\psi_b \bar{\bar{\lambda}}} \right)^{1/\nu} > 0;$$

$$\xi \equiv \frac{1-\alpha}{\alpha} \frac{1-\alpha\beta}{1+\omega_y \theta} > 0,$$

where $0 < \alpha < 1$ is the fraction of prices that remain unchanged from one period to the next; and

$$\kappa \equiv \xi(\omega_y + \bar{\sigma}^{-1}) > 0.$$

Note that except for the presence of the final two terms on the right-hand side, (1.20) is exactly the "New Keynesian Phillips curve" relation of the basic NK model (as expounded, for example, in Clarida *et al.*, 1999), and the definitions of both the disturbance terms and the coefficient κ are exactly the same as in that model (except that $\bar{\sigma}$ replaces the elasticity of the representative household). The two new terms, proportional to $\hat{\Omega}_t$ and $\hat{\Xi}_t$, respectively, are present only to the extent that there are credit frictions. These terms indicate that, in addition to their consequences for aggregate demand, variations in the size of credit frictions also have "cost-push" effects on the short-run aggregate-supply tradeoff between aggregate real activity and inflation.

Finally, the central-bank reaction function (1.14) can be log-linearized to yield

$$\hat{\imath}_t^d = r_t^n + \phi_\pi \pi_t + \phi_y(\hat{Y}_t - \hat{Y}_t^n) + \epsilon_t^m. \tag{1.21}$$

where r_t^n represents exogenous variations in the "natural rate of interest" — the equilibrium real rate of interest in a flexible-price equilibrium, in the case of a representative-household version of the model — and ϵ_t^m is an additional exogenous disturbance term, assumed to be unrelated to economic "fundamentals," to which we shall refer as a "monetary policy shock." Except for the disturbance ϵ_t^m, this is the

[13]The notation here differs from that in Cúrdia and Woodford (2009), so that the "output gap" that appears in this equation coincides with the one to which policy is assumed to respond in the Taylor rules considered below. See the technical appendix for a precise definition of the term $\hat{Y}_t^n$ in this paper.

form of linear rule recommended by Taylor (1993). The implications of such a rule for the evolution of the composite interest rate $\hat{\imath}_t^{avg}$ that appears in the IS relation (1.15) can be derived by using (1.19) to write

$$\hat{\imath}_t^{avg} = \hat{\imath}_t^d + \pi_b \hat{\omega}_t. \tag{1.22}$$

The policy rule (1.21) in our baseline specification is intended as a simple representation of conventional policy advice for an economy in which purely financial disturbances are not an important source of aggregate economic instability. Apart from its familiarity (and some degree of realism), we also note that in the context of a version of our model without financial frictions, this kind of policy rule would represent an optimal policy, at least under certain ideal circumstances. To be precise, in the representative-household version of our model[14] (where we therefore abstract entirely from financial frictions), if we set $\epsilon_t^m = 0$ at all times and choose coefficients ϕ_π and ϕ_y consistent with the "Taylor Principle" (as defined in Woodford, 2003, chap. 4), this rule leads to a determinate equilibrium in which inflation is equal to zero at all times, and the "output gap" $\hat{Y}_t - \hat{Y}_t^n$ is equal to zero at all times as well, as long as there are no cost-push shocks ($u_t = 0$ at all times). Such a policy is optimal from the standpoint of an *ad hoc* stabilization objective that involves only squared deviations of the inflation rate and of the output gap from zero; it is also optimal in the sense of maximizing the expected utility of the representative household under somewhat more special circumstances,[15] as discussed in Woodford (2003, chap. 6). Because the Taylor rule would be optimal, at least under certain circumstances, in the absence of credit frictions, it is of interest to consider the extent to which the introduction of credit frictions makes it desirable to modify the baseline rule by responding in addition to measures of financial conditions.

[14] This case can be nested as a special parametric case of the model expounded here, as discussed in Cúrdia and Woodford (2009).

[15] In addition to requiring the absence of cost-push shocks, this result requires a subsidy that offsets the distortion due to the market power of the monopolistically competitive producers. Benigno and Woodford (2005) discuss still more restrictive cases in which full inflation stabilization remains the optimal policy, even in the presence of steady-state distortions due to market power or taxes.

1.3 Numerical Calibration

The numerical values for parameters that are used in our calculations below are the same as in Cúrdia and Woodford (2009). Many of the model's parameters are also parameters of the basic NK model, and in the case of these parameters we assume similar numerical values as in the numerical analysis of the basic NK model in Woodford (2003, Table 6.1.), which in turn are based on the empirical model of Rotemberg and Woodford (1997). The new parameters that are also needed for the present model are those relating to heterogeneity or to the specification of the credit frictions. The parameters relating to heterogeneity are the fraction π_b of households that are borrowers, the degree of persistence δ of a household's "type", the steady-state expenditure level of borrowers relative to savers, s_b/s_s, and the interest-elasticity of expenditure of borrowers relative to that of savers, σ_b/σ_s.[16]

In the calculations reported here, we assume that $\pi_b = \pi_s = 0.5$, so that there are an equal number of borrowers and savers. We assume that $\delta = 0.975$, so that the expected time until a household has access to the insurance agency (and its type is drawn again) is 10 years. This means that the expected path of the spread between lending and deposit rates for 10 years or so into the future affects current spending decisions, but that expectations regarding the spread several decades in the future are nearly irrelevant.

We calibrate the degree of heterogeneity in the steady-state expenditure shares of the two types so that the implied steady-state debt $\bar{b}$ is equal to 80 percent of annual steady-state output.[17] This value matches the median ratio of private (non-financial, non-government, non-mortgage) debt to GDP over the period 1986-2008.[18] This requires a ratio $s_b/s_s = 1.27$. We calibrate the value of σ_b/σ_s to equal 5. This is an arbitrary choice, though the fact that borrowers are assumed to have a greater willingness to substitute intertemporally is important, as this results in the prediction that an exogenous tightening of monetary policy (a positive value of the residual ϵ_t^m in (1.14)) results in a reduction in the equilibrium volume of credit b_t (see Figures 2

[16] Another new parameter that matters as a consequence of heterogeneity is the steady-state level of government debt relative to GDP, $\bar{b}^g/\bar{Y}$; here we assume that $\bar{b}^g = 0$.

[17] In our quarterly model, this means that $\bar{b}/\bar{Y} = 3.2$.

[18] We exclude mortgage debt when calibrating the degree of heterogeneity of preferences in our model, since mortgage debt is incurred in order to acquire an asset, rather than to consume current produced goods in excess of current income.

and 5 below). This is consistent with VAR evidence on the effects of an identified monetary policy shock on household borrowing.[19]

It is also necessary to specify the steady-state values of the functions $\omega(b)$ and $\Xi(b)$ that describe the financial frictions, in addition to making clear what kinds of random perturbations of these functions we wish to consider when analyzing the effects of "financial shocks." We here present results for two cases. In each case, we assume that the steady-state credit spread is due entirely to the marginal resource cost of intermediation;[20] but we do allow for exogenous shocks to the default rate, and this is what we mean by the "financial shock" in Figures 6 and 13 below.[21] In treating the "financial shock" as involving an increase in markups but no increase in the real resources used in banking, we follow Gerali *et al.* (2008).[22]

The two cases considered differ in the specification of the (time-invariant) intermediation technology $\Xi(b)$. In the case of a *linear intermediation technology,* we suppose that $\Xi(b) = \tilde{\Xi}b$, while in the case of a *convex intermediation technology,* we assume that

$$\Xi(b) = \tilde{\Xi}b^{\eta} \tag{1.23}$$

for some $\eta > 1$.[23] In both cases, in our numerical analyses we assume a steady-state

[19]See, for example, Den Haan *et al.* (2004).

[20]We assume this in the results presented here because we do not wish to appear to have sought to minimize the differences between a model with financial frictions and the basic NK model, and the use of real resources by the financial sector (slightly) increases the differences between the two models.

[21]Note that our conclusions regarding both equilibrium and optimal responses to shocks *other* than the "financial shock" are the same as in an economy in which the banking system is perfectly competitive (and there are no risk premia), up to the linear approximation used in the numerical results reported below.

[22]These authors cite the Eurosystem's quarterly Bank Lending Survey as showing that since October 2007, banks in the euro area had "strongly increased the margins charged on average and riskier loans" (p. 24).

[23]One interpretation of this function is in terms of a monitoring technology of the kind assumed in Goodfriend and McCallum (2007). Suppose that a bank produces monitoring according to a Cobb-Douglas production function, $k^{1-\eta^{-1}}\Xi_t^{\eta^{-1}}$, where k is a fixed factor ("bank capital"), and must produce a unit of monitoring for each unit of loans that it manages. Then the produced goods Ξ_t required as inputs to the monitoring technology in order to manage a quantity b of loans will be given by a function of the form (1.23), where $\tilde{\Xi} = k^{1-\eta}$. A sudden impairment of bank capital, treated as an exogenous disturbance, can then be represented as a random increase in the multiplicative factor $\tilde{\Xi}$. This is another form of "financial shock", with similar, though not identical,

credit spread $\bar{\omega}$ equal to 2.0 percentage points per annum,[24] following Mehra *et al.*, (2008).[25] (Combined with our assumption that "types" persist for 10 years on average, this implies a steady-state "marginal utility gap" $\bar{\Omega} \equiv \bar{\lambda}^b/\bar{\lambda}^s = 1.22$, so that there would be a non-trivial welfare gain from transferring further resources from savers to borrowers.) In the case of the convex technology, we set η so that a one-percent increase in the volume of credit increases the credit spread by one percentage point (per annum).[26] The assumption that $\eta > 1$ allows our model to match the prediction of VAR estimates that an unexpected tightening of monetary policy is associated with a slight reduction in credit spreads (see, *e.g.*, Lown and Morgan, 2002, and Gerali *et al.*, 2008). We have chosen a rather extreme value for this elasticity in our calibration of the convex-technology case, in order to make more visible the difference that a convex technology makes for our results. (In the case of a smaller value of η, the results for the convex technology are closer to those for the linear technology, and in fact are in many respects similar to those for an economy with no financial frictions at all.)

As a first exercise, we consider the implied equilibrium responses of the model's endogenous variables to the various kinds of exogenous disturbances, under the assumption that monetary policy is described by a Taylor rule of the form (1.21). The coefficients of the monetary policy rule are assigned the values $\phi_\pi = 1.5$ and $\phi_y = 0.5$[27] as recommended by Taylor (1993).[28] Among other disturbances, we consider the effects of random disturbances to the error term ϵ_t^m in the monetary policy rule. In section 2, we consider the predicted dynamics under a variety of other monetary policy specifications as well.

In all of the cases that we consider, we assume that each of the exogenous distur-

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effects as the default rate shock considered below.

[24] In our quarterly numerical model, this means that we choose a value such that $(1 + \bar{\omega})^4 = 1.02$.

[25] Mehra *et al.* argue for this calibration by dividing the net interest income of financial intermediaries (as reported in the National Income and Product Accounts) by a measure of aggregate private credit (as reported in the Flow of Funds). As it happens, this value also corresponds to the median spread between the FRB index of commercial and industrial loan rates and the federal funds rate, over the period 1986-2007.

[26] This requires that $\eta = 51.6$.

[27] This is the value of ϕ_y if $\hat{\imath}_t^d$ and π_t are quoted as annualized rates, as in Taylor (1993). If, instead, (1.21) is written in terms of quarterly rates, then the coefficient on $\hat{Y}_t$ is only 0.5/4.

[28] See, for example, Taylor (2007) as an example of more recent advocacy of a rule with these same coefficients.

bances ξ_{it} evolves according to an AR(1) process,

$$\xi_{it} = \rho_i \xi_{i,t-1} + \epsilon_{it},$$

where ϵ_{it} is a mean-zero i.i.d. random process, and that these processes are independent for the different disturbances i. We make various assumptions about the size of the coefficient of serial correlation ρ_i and the standard deviation of the innovations ϵ_{it}, that are explained below.

1.4 Credit Frictions and the Propagation of Disturbances

We can explore the consequences of introducing financial frictions into our model by considering the predicted responses to aggregate disturbances of a kind that also exist in the basic NK model, and see how much difference to our results the allowance for credit frictions makes. A special case in which we obtain a simple result is that in which (i) Ξ_t is an exogenous process (i.e., independent of b_t — there are no variable resource costs of intermediation), and (ii) $\chi_t(b)$ is a linear function, $\chi_t(b) = \tilde{\chi}_t b$, at all times (i.e., the default rate is independent of the volume of lending), though the default rate may vary (exogenously) over time. In this case, (1.13) implies that ω_t will also be an exogenous process (equal to $\tilde{\chi}_t$), and (1.18) implies that $\hat{\Omega}_t$ will be an exogenous process (determined purely by the evolution of $\tilde{\chi}_t$).

In this case, the set of equations (1.15), (1.20), (1.21) and (1.22) comprise a complete system for determination of the equilibrium evolution of the variables $\pi_t, \hat{Y}_t, \hat{\imath}_t^d$, and $\hat{\imath}_t^{avg}$, given the evolution of the exogenous disturbances, that now include $\hat{\Xi}_t$ and $\hat{\omega}_t$ disturbances. If we use (1.22) to substitute for $\hat{\imath}_t^d$ in (1.21), we obtain an equation in which the policy rule is written in terms of its implications for the average interest rate $\hat{\imath}_t^{avg}$,

$$\hat{\imath}_t^{avg} = r_t^n + \phi_\pi \pi_t + \phi_y (\hat{Y}_t - \hat{Y}_t^n) + \pi_b \hat{\omega}_t + \epsilon_t^m. \tag{1.24}$$

Then equations (1.15), (1.20) and (1.24) comprise a complete system for determination of $\pi_t, \hat{Y}_t$, and $\hat{\imath}_t^{avg}$. This system of equations is a direct generalization of the familiar "three-equation system" in expositions of the log-linearized basic NK model, as in Clarida *et al.* (1999).

In fact, this system of equations is *identical* to the structural equations of the basic NK model, if the latter model is parameterized by assigning the representative household an intertemporal elasticity of substitution that is an appropriately weighted average of the intertemporal elasticities of the two types in this model.[29] The only differences from the equations of the basic model are that the interest rate $\hat{\imath}_t^{avg}$ in this system need not correspond to the policy rate, and that each of the three equations contains additional additive disturbance terms ($\hat{\omega}_t, \hat{\Omega}_t$, and $\hat{\Xi}_t$ terms) owing to the possibility of time variation in the credit frictions.

This means that the predictions of the model about the equilibrium responses of inflation, output and nominal interest rates to any of the non-financial disturbances — disturbances to tastes, technology, monetary policy, or fiscal policy, all of which are also allowed for in the basic NK model — under a given monetary policy rule are identical to those of the basic NK model. (The linearity of the approximate model equations implies that the impulse responses to any of the non-financial disturbances are independent of what we assume about the size of the financial disturbances.) Hence our conclusions about the desirability of a given form of Taylor rule — at least from the standpoint of success in stabilizing inflation, output or interest rates — will be exactly the same as in the basic NK model, *except* to the extent that we may be concerned about the ability of policy to stabilize the economy in response to purely financial disturbances (which are omitted in the basic NK model).

This conclusion requires somewhat special assumptions; but numerical analysis of our calibrated model suggests that the conclusion is not too different even when one allows ω_t and Ξ_t to vary endogenously with variations in the volume of private credit. In the numerical results shown in Figures 2-5, we plot the equilibrium responses to various types of disturbances (a different disturbance in each figure, with the responses of different variables in the separate panels of each figure). In each figure, we compare the equilibrium responses to the same disturbance in three different models. The "FF" model is the model with heterogeneity and financial frictions described in the previous sections. The "NoFF" model is a model with preference heterogeneity of the same type (and correspondingly parameterized), but in which there are no financial frictions (ω_t and Ξ_t are set equal to zero at all times). Finally, the "RepHH" model is a representative household model, with parameters that are present in the FF model

[29] A key parameter of the basic NK model is $\sigma \equiv s_c\tilde{\sigma}$, where $\tilde{\sigma}$ is the intertemporal elasticity of substitution of private expenditure, and s_c is the steady-state share of private expenditure in total aggregate demand. (See Woodford, 2003, p. 243.) For the equivalence asserted in the text to obtain, it is necessary to parameterize the representative-household model so that σ has the value of the coefficient $\bar{\sigma}$ (defined in (1.17)) in our model.

calibrated in the same way as in the other two models.[30]

We first consider the case of a linear intermediation technology ($\eta = 1$). In this case, the credit spread ω_t still evolves exogenously, as assumed in the discussion above, but Ξ_t is no longer independent of b_t. Nonetheless, in this case we continue to find that for an empirically plausible specification of the quantity of resources used in intermediation, the existence of credit frictions makes virtually no difference for the predicted equilibrium responses to shocks.

This is illustrated in Figure 2 for the case of a contractionary monetary policy shock, represented by a unit (one percentage point, annualized) increase in ϵ_t^m. We furthermore assume that the policy disturbance is persistent; specifically, ϵ_t^m is assumed to follow an AR(1) process with coefficient of autocorrelation $\rho = 0.6$.[31] The separate panels of the figure indicate the impulse responses of output, inflation,[32] the deposit rate (policy rate), the credit spread,[33] and aggregate private credit respectively.

We observe that the impulse responses of output, inflation, and the two interest rates are virtually identical under all three parameterizations of the model. (The same is true for all of the other non-financial aggregate disturbances in the model, though we do not include these figures here.) Even when we assume that intermediation uses resources (and indeed that credit spreads are entirely due to the marginal resource cost of making additional loans), and that the required resources are proportional to the volume of lending, heterogeneity and the existence of a steady-state credit spread (of a realistic magnitude) still make only a negligible difference. This is because the

[30]The intertemporal elasticity of substitution of the representative household is a weighted average of the elasticities of the two types in the models with preference heterogeneity, as discussed in the previous footnote.

[31]We assume a lower degree of persistence for this disturbance than for the others considered below, in order to make the shock considered in this figure similar in its implications to the identified monetary policy shocks in VAR studies. This value also makes the results shown in Figure 2 for the "RepHH" model directly comparable to those reported for the case $\rho = 0.6$ in the discussion of the basic NK model in Woodford (2003, chap. 4).

[32]In the plots, both the inflation rate and the interest rates are reported as annualized rates, so that 0.10 means an increase in the inflation rate of 10 basis points per annum. In terms of our quarterly model, what is plotted is not the response of π_t, but rather the response of $4\pi_t$.

[33]In the present model, the spread is exogenously fixed, and so there is necessarily a zero response of this variable, except in the case of a shock to the exogenous credit spread itself. However, we include this panel as we use the same format for the figures to follow, when the spread is an endogenous variable.

contribution of the banking sector to the overall variation in the aggregate demand for produced goods and services is still quite small.

The inclusion of heterogeneity and an intermediary sector in the model does have one important consequence, even in this case, and that is that the model now makes predictions about the evolution of the volume of credit. As noted earlier, under our proposed calibration, a tightening of monetary policy causes credit to contract (as VARs show, especially in the case of consumer credit), despite the fact that there is no mechanical connection between monetary policy and credit supply in our model.[34] The size of the credit contraction in response to a monetary policy shock is smaller in the "FF" model than in the "NoFF" model, but it remains of the same sign.

Financial frictions matter somewhat more for equilibrium dynamics if we also assume that credit spreads vary endogenously with the volume of lending. Figure 3 shows the responses to the same kind of monetary policy shock as in Figure 2, but in the case of the "convex intermediation technology" calibration ($\eta >> 1$) discussed in the previous section. We again find that the equilibrium responses of output and inflation are nearly the same in all three models, though the "FF model" is no longer quite so indistinguishable from the "NoFF" model. The most important effect of allowing for endogeneity of the credit spread is on the implied responses of interest rates to the shock. Because credit contracts in response to this shock (as noted earlier, though now by less than in Figure 2, because the supply of credit is less elastic), the spread between the lending rate and the deposit rate decreases, in accordance with the empirical finding of Lown and Morgan (2002). This means that the deposit rate rises more than does the lending rate. As a result, the increase in the policy rate is somewhat higher in the "FF model" than in the absence of credit frictions.[35]

The differences are more visible in the case of an exogenous increase in the productivity factor Z_t, shown in Figure 4. (In both Figures 4 and 5, the exogenous disturbance is assumed to be an AR(1) process with autoregressive coefficient $\rho_\xi = 0.9$.) Though again the largest effect is on the path of the deposit rate, in this case the endogeneity of the markup also has non-negligible effects on the equilibrium response of

[34] We do not, for example, assume that credit can only be supplied by commercial banks, that in turn can only finance their lending by attracting deposits subject to a reserve requirement — so that variations in the supply of reserves by the central bank have a direct effect on loan supply.

[35] This is consistent with the Taylor rule, because output declines slightly less in the "FF model" than in the "NoFF" model, though the difference is not large enough to be easily visible in Figure 3.

output. (The primary reason for the difference is that this shock has a larger immediate effect on the path of credit, and hence a larger immediate effect on the equilibrium spread in the case of the convex technology.) Because an increase in productivity leads to an expansion of credit, credit spreads now increase in the 'FF model'; this is has a contractionary effect on aggregate demand, so that output increases less than in the "NoFF model." Similar effects of financial frictions are observed in the case of a disturbance to the disutility of working (an exogenous increase in the multiplicative factor $\bar{H}_t$ in (1.5)). The effects of an increase in the wage markup μ_t^w or the tax rate τ_t are likewise similar, but with opposite signs to the effects shown in Figure 4.

Finally, the consequences of financial frictions are of particular qualitative significance in the case of a disturbance to the path of government debt (Figure 5). Here we consider a disturbance to fiscal policy that temporarily increases the level of government debt, through a lump-sum transfer to households, which is then gradually taken back over a period of time, so that the path of real government debt is eventually the same as it would have been in the absence of the shock. In the case of the "NoFF model", *Ricardian equivalence* holds, as in the representative household model; and so in these cases, the fiscal shock has no effect on output, inflation, or interest rates. However, an increase in government borrowing crowds out private borrowing, and in the case of the convex intermediation technology, the reduced private borrowing implies a reduction in spreads. This has an expansionary effect on aggregate demand, with the consequence that both output and inflation increase, as shown in the figure.[36]

To sum up, we find that under an empirically realistic calibration of the average size of credit spreads, the mere existence of a positive credit spread does not imply any substantial quantitative difference for our model's predictions, either about the effects of a monetary policy shock or about the effects of other kinds of exogenous disturbances under a given systematic monetary policy. What matters somewhat more is the degree to which there is *variation* in credit spreads. If spreads vary endogenously (as in our model with a convex intermediation technology), then the effects of

[36]Ricardian equivalence does not hold precisely in the "FF model" even in the case of the linear intermediation technology. However, in this case (not shown) there is no reduction in credit spreads in response to the shock, and the only consequence for aggregate demand comes from the reduction in the resources used by the banking sector, so that shock is actually (very slightly) *contractionary* in this case. But there is very little difference in the predictions of the "NoFF" and "FF" models in the case of that technology, so that we omit the figure here.

disturbances are somewhat different, especially in the case of types of disturbances — such as variations in government borrowing, or changes in the relative spending opportunities available to savers as opposed to borrowers — that particularly affect the evolution of the equilibrium volume of private credit.

Another important difference of the model with credit frictions is the possibility of exogenous disturbances to the financial sector itself, represented by exogenous variation in either the intermediation technology $\Xi_t(b)$ or the default rate schedule $\chi_t(b)$. Again, these disturbances matter to the determination of aggregate output, inflation and interest rates primarily to the extent that they imply variation in credit spreads. Figure 6 shows the responses (for the "FF" model only, and in the case of the convex intermediation technology) to an exogenous shift up in the schedule $\chi_t(b)$, of a size that would increase the credit spread by 4 percentage points (as an annualized rate) for a given volume of private credit.[37] (Because of the contraction of credit that results, in equilibrium the shock increases the credit spread by less than three percentage points.) Under the baseline Taylor rule, this kind of "purely financial" disturbance increases the credit spread and contracts aggregate credit; it also contracts real activity and lowers inflation. (An increase in the credit spread owing to an increase in the marginal resource cost of intermediation has similar effects, not shown.) We show below that these responses to the shock are not desirable on welfare grounds. One of key issues taken up in the next section is whether modification of the baseline Taylor rule to directly respond to financial variables can improve upon these responses.

2 Adjustments to the Baseline Taylor Rule

We turn now to the consequences of modifying the baseline Taylor rule by including a direct response to some measure of financial conditions. We first discuss the welfare criterion that we use to evaluate candidate policy rules, and then turn to our results for some simple examples of modified Taylor rules.

[37] The discussion here refers to the responses marked "$\phi_\omega = 0$" in Figure 6, which corresponds to the Taylor rule (1.21).

2.1 Welfare criterion

We shall suppose that the objective of policy is to maximize the average ex ante expected utility of the households. As shown in Cúrdia and Woodford (2009), this implies an objective of the form

$$E_0 \sum_{t=0}^{\infty} \beta U(Y_t, \lambda_t^b, \lambda_t^s, \Delta_t; \tilde{\xi}_t) \tag{2.1}$$

where

$$\begin{aligned} U(Y_t, \lambda_t^b, \lambda_t^s, \Delta_t; \tilde{\xi}_t) \quad \equiv \quad & \pi_b u^b(c^b(\lambda_t^b; \xi_t); \xi_t) + \pi_s u^s(c^s(\lambda_t^s; \xi_t); \xi_t) \\ & - \frac{\psi}{1+\nu} \left(\frac{\tilde{\lambda}_t}{\tilde{\Lambda}_t} \right)^{-\frac{1+\nu}{\nu}} \bar{H}_t^{-\nu} \left(\frac{Y_t}{Z_t} \right)^{1+\omega} \Delta_t, \end{aligned} \tag{2.2}$$

and

$$\tilde{\Lambda}_t \equiv \psi^{\frac{1}{1+\nu}} \left[\pi_b \psi_b^{-\frac{1}{\nu}} \left(\lambda_t^b \right)^{\frac{1+\nu}{\nu}} + \pi_s \psi_s^{-\frac{1}{\nu}} \left(\lambda_t^s \right)^{\frac{1+\nu}{\nu}} \right]^{\frac{\nu}{1+\nu}}.$$

Note that the final term in (2.2) represents the average disutility of working, averaging both over the entire continuum of types of labor j and over the two types of households, using the model of equilibrium labor supply discussed in section 1.1.

Using this welfare criterion, we can compute the equilibrium responses to the various types of shocks in our model under an optimal policy commitment (the Ramsey policy problem). This problem is treated in more detail in Cúrdia and Woodford (2009). Here we are interested not in characterizing fully optimal policy, but in the extent to which various simple modifications of the Taylor would result in a closer approximation to Ramsey policy. One way in which we judge the closeness of the approximation is by comparing the responses to shocks under candidate policy rules to those that would occur under the Ramsey policy.

We also evaluate the level of welfare associated with alternative simple rules (modified Taylor rules of various types), using a method proposed by Benigno and Woodford (2008). Under this approach, one computes (for the equilibrium associated with each candidate policy rule) the value of a quadratic approximation to the Lagrangian for an optimization problem that corresponds to the continuation of a previously chosen Ramsey policy; this approximate Lagrangian is minimized by a time-invariant linear rule under which the responses to shocks are the same (to a linear approximation) as under the Ramsey policy. By computing the value of this Lagrangian under a given time-invariant policy rule, we have a criterion that would rank as best (among all possible linear rules) a rule that achieves exactly the responses to shocks associated with the Ramsey policy. We use this method to rank the benefits from alternative spread-adjusted or credit-adjusted Taylor rules; this is a more formal way of assessing the degree to which a given modification of the Taylor rule leads to responses to shocks that are closer to those implied by Ramsey policy.[38]

2.2 Spread-Adjusted Taylor Rules

Let us first consider generalizations of (1.21) of the form

$$\hat{\imath}_t^d = r_t^n + \phi_\pi \pi_t + \phi_y(\hat{Y}_t - \hat{Y}_t^n) - \phi_\omega \hat{\omega}_t. \tag{2.3}$$

for some coefficient $0 \leq \phi_\omega \leq 1$. These rules reflect the idea that the funds rate should be lowered when credit spreads increase, so as to prevent the increase in spreads from "effectively tightening monetary conditions" in the absence of any justification from inflation or high output relative to potential. They essentially correspond to the proposal of authors such as McCulley and Toloui (2008) and Taylor (2008), except that we consider the possible advantages of a spread adjustment that is less than the size of the increase in credit spreads. (The proposal of these authors corresponds to the case $\phi_\omega = 1$; the classic Taylor rule corresponds to the opposite limiting case, $\phi_\omega = 0$.) We now omit the random term ϵ_t^m, as there is nothing desirable about unnecessary randomization of policy.[39]

In the previous section, we have discussed the economy's response to a variety of types of disturbances under this kind of policy rule, in the case that $\phi_\omega = 0$. We now consider the consequences of alternative values for $\phi_\omega > 0$, and compare the equilibrium responses to shocks under this kind of policy to those under Ramsey policy (i.e., an optimal policy commitment). Figures 6-11 present numerical responses in the case of several different types of exogenous disturbances, when the model is calibrated

[38]See Altissimo *et al.* (2005) for discussion of a numerical method that can be used to compute this welfare measure.

[39]In fact, in some models arbitrary randomization of monetary policy would raise welfare, as in the example of Dupor (2003). But we verify that under our numerical parameterization, the Lagrangian for our policy problem is locally convex, so that randomization is necessarily welfare-reducing (at least in the case of a small enough random term). See Benigno and Woodford (2008) for discussion of this issue, and the algebraic conditions that must be verified.

in the same way as in the previous section, for the case of a convex intermediation technology.[40]

Figure 6 shows the responses of endogenous variables to a "purely financial" disturbance — specifically, to an exogenous shift up in the schedule $\chi_t(b)$, of a size that would increase the credit spread by 4 percentage points (as an annualized rate) for a given volume of private credit. (Because of the contraction of credit that results, in equilibrium the shock only increases the credit spread by a little over one percentage point.[41]) In the case that policy is described by the baseline Taylor rule (1.21), such a disturbance leads not only to an increase in the credit spread and a contraction of aggregate credit, but also to a substantial fall in aggregate real activity and to a drop in the rate of inflation. (These responses are shown by the dashed lines in the figure.) This contraction of output is inefficient. Under an optimal monetary policy commitment (shown by the solid lines in the figure), output would decline much less, and only temporarily; indeed, output would be back to (and even slightly above) its normal level by the quarter following the shock, even though the financial disturbance persists for many quarters. (Here, as in all of our figures showing the effects of non-monetary shocks except Figure 10, the disturbance to the path of $\tilde{\chi}_t$ is assumed to be an AR(1) process with a coefficient of serial correlation of $\rho_\xi = 0.9$, so that the half-life of the disturbance is 6.6 quarters.) Nor would inflation be allowed to decrease as under the Taylor rule; indeed, initially it would rise slightly.

The figure also plots the equilibrium responses of the several endogenous variables under several variant monetary policy rules of the form (2.3). Responses are shown in the case of five different possible values of ϕ_ω, ranging between 0 and 1. We observe that adjusting the intercept of the Taylor rule in response to changes in the credit spread can indeed largely remedy the defects of the simple Taylor rule, in the case of a shock to the economy of this kind. And the optimal degree of adjustment is not too far from 100 percent (the case shown by the dashed lines with lighter-colored

[40]We discuss differences in our conclusions in the case of a linear intermediation technology subsequently.

[41]This is clearly a large shock, relative to what occurs with any frequency during normal periods; but increases in spreads even larger than this were observed in the fall of 2008. We do not here consider an even larger shock, in order to avoid having to deal with the consequences of the zero lower bound on nominal interest rates — a technical issue that becomes relevant only in the case of particularly large disturbances, though one that did indeed become relevant in the US and elsewhere as a result of the 2008 crisis.

Table 1: Optimal value of the spread-adjustment coefficient ϕ_ω in policy rule (2.3), in the case of a convex intermediation technology. Each column indicates a different type of disturbance, for which the policy rule is optimized; each row indicates a different possible degree of persistence for the disturbance.

	Z_t	μ_t^w	τ_t	G_t	b_t^g	$\bar{H}_t$	$\bar{C}_t^b$	$\bar{C}_t^s$	$\tilde{\chi}_t$	$\tilde{\Xi}_t$
$\rho_\xi = 0.00$	1.08	-7.89	-15.01	1.53	0.62	1.08	0.64	1.07	0.86	0.64
$\rho_\xi = 0.50$	1.35	-2.18	-4.42	2.22	0.71	1.35	0.60	0.72	0.84	0.72
$\rho_\xi = 0.90$	0.21	-0.12	-0.30	0.30	0.74	0.21	0.15	0.16	0.82	0.75
$\rho_\xi = 0.99$	-1.38	-1.44	-1.47	-1.37	0.65	-1.38	-1.39	-1.39	0.70	0.66

dots), as proposed by Taylor and by McCulley and Toloui. To be more precise, both inflation and output increase a little more under the 100 percent spread adjustment than they would under Ramsey policy; but the optimal responses of both variables are between the paths that would result from a 75 percent spread adjustment and the one that results from a 100 percent spread adjustment. If we optimize our welfare criterion over policy rules with alternative values of ϕ_ω, assuming that this type of disturbance is the only kind that ever occurs, the welfare maximum is reached when $\phi_\omega = 0.82$, as shown in Table 1.

It is interesting to observe in Figure 6 that, while a superior policy involves a reduction in the policy rate relative to what the unadjusted Taylor rule would prescribe, this does not mean that under such a policy the central bank actually cuts its interest rate target more sharply in equilibrium. The size of the fall in the policy rate (shown in the middle left panel) is about the same regardless of the value of ϕ_ω; but when ϕ_ω is near 1, output and inflation no longer have to decline in order to induce the central bank to accept an interest-rate cut of this size, and in equilibrium they do not decline. (In fact, the nominal policy rate does fall a little more, and since expected inflation does not fall, the *real* interest rates faced by both savers and borrowers fall more substantially when ϕ_ω is near 1.) The contraction of private credit in equilibrium is also virtually the same regardless of the value of ϕ_ω. Nonetheless, aggregate expenditure falls much less when ϕ_ω is positive; the expenditure of borrowers no longer has to be cut back so much in order to reduce their borrowing, because their labor income no longer falls in response to the shock, and there is an offsetting increase in the expenditure of savers.

The figure is very similar in the case of an exogenous shock to the marginal resource cost of intermediation (an exogenous increase in the multiplicative factor $\tilde{\Xi}_t$, not shown). As indicated in Table 1, in this case the optimal response coefficient is only slightly smaller, 0.75. The other comments about the shock to $\tilde{\chi}_t$ apply equally to this case. Moreover, while the dynamics of the equilibrium responses are different if one assumes a degree of persistence other than $\rho_\xi = 0.9$, we find — both in the case of disturbances that are less persistent than assumed in our baseline case, and in the case of disturbances that are more persistent — that our key conclusion is the same regardless of the assumed degree of persistence of the financial disturbance: a value of ϕ_ω that is positive and a large fraction of 1 maximizes welfare in the case of any individual disturbance of either of these two types. (Several different assumed values for ρ_ξ are considered on the different lines of Table 1.)

We also reach similar conclusions in the case of an exogenous disturbance to the level of the public debt, of the kind assumed in Figure 5. As shown in Figure 7, the effects of this kind of shock under the various spread-adjusted rules are quite similar to the effects of a purely financial disturbance (though with the opposite sign of the disturbance considered in Figure 6). Essentially, this disturbance matters for output and inflation determination only because of its effect on the supply of credit to private borrowers: because government borrowing crowds out private borrowing, equilibrium credit spreads fall (as was also shown for the "FF" case in Figure 5). This is also associated with increases in output and inflation that are inefficient, and would be prevented by an optimal monetary policy response (as shown by the solid lines in Figure 7). A spread-adjusted Taylor rule achieves something quite similar to optimal policy, especially for a spread adjustment on the order of $\phi_\omega = 0.75$. (Because the spread falls in response to this shock, the spread adjustment implies greater tightening of policy in response to the fiscal shock than would occur under the baseline Taylor rule, and this prevents output and inflation from increasing.) As shown in Table 1, the optimal spread adjustment would in fact be $\phi_\omega = 0.74$ in the case of a debt shock with a persistence of 0.9, and again this result is not too sensitive to the assumed degree of persistence of the disturbance.

However, our conclusions about the optimal spread adjustment are considerably more varied when we consider other kinds of disturbances. In the case of an endogenous credit spread, as assumed here, a spread adjustment in the Taylor rule affects the economy's equilibrium response to disturbances of all types, and not just disturbances originating in the financial sector, and the benefits of a spread adjustment are not the same regardless of the source of the variation in the equilibrium credit spread. In the case of the debt shock, this did not materially change the case for the desirability of the spread adjustment, but the same is not true of other types of disturbances that also affect the aggregate volume of lending and hence the equilibrium credit spread.

For example, Figure 8 considers again the consequences of a technology shock of the same kind as in Figure 4. In the case of this type of shock, the baseline Taylor rule is not too poor an approximation to optimal policy. In fact, in the absence of financial distortions (as discussed above), the baseline Taylor rule (1.21) would achieve a precisely optimal response to this type of shock: it would perfectly stabilize both inflation and the output gap (output would be allowed to rise to precisely the extent that the natural rate of output rises), as shown by the "NoFF" responses in Figure 4, and this would be optimal (as discussed in Benigno and Woodford, 2005). In our model with financial frictions, it is no longer quite true that this rule would completely stabilize inflation, though the inflation response is still quite small (again, as shown in Figure 4); nor is it any longer true that optimal policy would fully stabilize inflation, but here too the optimal departure from strict inflation targeting is fairly modest (as shown by the solid line in Figure 8). Given that the unadjusted Taylor rule is quite a good rule in this case, it should not surprise one to observe that a spread adjustment can easily do more harm than good. Because aggregate credit surges in response to a technological improvement, and the credit spread accordingly increases, a spread adjustment means a looser policy in response to such a shock, and except in the case of a very modest adjustment of this kind, the resulting inflationary boom would clearly be undesirable. In fact, Table 1 shows that in the case of a shock with persistence $\rho_\xi = 0.9$, as assumed in the figure, the optimal spread adjustment is only $\phi_\omega = 0.21$.

We reach a similar conclusion in the case of a shock to the path of government purchases G_t, as shown in Figure 9. Here again the unadjusted Taylor rule would fully stabilize inflation in the absence of financial frictions, and in a model with no steady-state distortions, this would be optimal (though it is not quite the optimal response even in a representative-household model, in the presence of steady-state distortions due to market power and/or taxes, as discussed by Benigno and Woodford, 2005); and this rule is not too different from optimal policy even in our model with credit frictions, though it would be desirable to reduce inflation slightly for a short period of time following such a shock (as shown by the solid line in the figure). Because government purchases crowd out the spending of type b households (the more interest-sensitive category of private spending) more than that of type s households, aggregate credit falls in response to such a shock, and hence the credit spread shrinks as well. A spread adjustment therefore tightens policy more in response to such a shock, and this can help to bring about the desired temporary reduction in inflation. But because the reduction in credit and in the spread in response to such a disturbance are relatively persistent, the spread adjustment keeps policy tight for much longer than is optimal; and as a consequence, any spread adjustment that is a large fraction of a full offset does more harm than good. Table 1 shows that in the case of a shock with persistence $\rho_\xi = 0.9$, as assumed in Figure 9, the optimal spread adjustment is again much less than half ($\phi_\omega = 0.30$).

Moreover, Table 1 makes it clear that the optimal spread adjustment in the case of either of these types of disturbances is quite sensitive to the degree of persistence of the disturbance. The optimal adjustment is 100 percent or even more, in the case that the disturbances are sufficiently transitory. But the optimal adjustment need not even be positive, and is not in the case of sufficiently persistent disturbances. For example, Figure 10 shows responses to a technology shock that is more persistent than the one assumed in Figure 8 ($\rho_\xi = 0.99$). In this case, the unadjusted Taylor rule results in more inflation in response to the productivity improvement than is optimal, mainly as a result of the adverse "cost-push" effect of the increase in the credit spread; a positive spread adjustment would result in even looser policy (as discussed above), and in this case would adjust policy in the wrong direction, even in the case of a modest spread adjustment. As shown in Table 1, the optimal spread adjustment in this case would actually be negative ($\phi_\omega = -1.47$), and the same would be true of a highly persistent disturbance to government purchases. Indeed, we obtain qualitatively similar conclusions for all of the disturbances that (i) do not create any tension between price stability and output-gap stabilization, in the case of an undistorted steady state, and (ii) do not primarily effect the economy through interference with financial intermediation:[42] in each case a substantial positive spread

[42]The shocks in this category are the $Z_t, G_t, \bar{H}_t, C_t^b$, and C_t^s shocks: all have substantial effects on equilibrium output even in the absence of all distortions, and all of these types of output fluctuations

adjustment would be optimal in the case of low enough persistence, while a strongly negative spread adjustment is instead optimal in the case of high enough persistence.

In the case of other types of disturbances, the optimal spread adjustment may be negative even in the case of less highly persistent shocks. Figure 11 shows equilibrium responses to an exogenous increase in the path of the tax rate τ_t, again for the case $\rho_\xi = 0.9$. Once again, the unadjusted Taylor rule does a good job of stabilizing inflation in response to the shock; in fact, since this type of disturbance has little effect on equilibrium credit and hence on the credit spread, the unadjusted Taylor rule is practically equivalent to a strict inflation target, even in the presence of financial frictions. But in the case of this type of shock, complete inflation stabilization is not optimal, even in the case of a representative household-model with no steady-state distortions, because of the "cost-push" effect of the shock: output must be contracted in order to maintain a constant inflation rate, and this output reduction is inefficient. Under an optimal policy, some inflation must be accepted in order to require less of a reduction in output relative to its efficient level (which does not fall like the flexible-price equilibrium level of output).

In this case, because there is little effect of the shock on the equilibrium credit spread, a spread adjustment cannot do much to cure the inefficiency of the baseline Taylor rule. But to the extent that a spread adjustment has an effect, it is a perverse one: since the spread declines slightly in response to this disturbance, the spread adjustment tightens policy more in response to the adverse fiscal shock, when it would actually be desirable to allow more inflation, as just explained. Table 1 shows that the optimal spread-adjustment coefficient is actually negative, and that this is true regardless of the degree of persistence of the shock, though the optimal size of the negative adjustment is quite sensitive to the persistence of the shock. (A coefficient $\phi_\omega = -.30$ is optimal in the case that $\rho_\xi = 0.9$, as assumed in the figure; but much larger negative coefficients are optimal in the case of tax shocks that are either more or less persistent than this.) Similar conclusions are obtained in the case of a disturbance to the size of the wage markup μ_t^w, and for similar reasons.

The fact that different sizes (or even signs) of spread adjustments are desirable in the case of different types of disturbances makes it difficult to draw a conclusion about the nature of the optimal spread adjustment, given that any actual economy will be

are consistent with the optimality of complete price stability, as explained for example in Woodford (2003, chap. 6, sec. 3).

Table 2: Welfare consequences of increasing ϕ_ω, in the case of different disturbances. Each column indicates a different type of disturbance, while each row corresponds to a given degree of spread adjustment.

	Z_t	μ_t^w	τ_t	G_t	b_t^g	$\bar{H}_t$	$\bar{C}_t^b$	$\bar{C}_t^s$	$\tilde{\chi}_t$	$\tilde{\Xi}_t$
No persistence ($\rho_\xi = 0$)										
$\phi_\omega = 0.25$	0.4	-0.8	-1.4	4.0	26.9	0.4	22.5	9.9	38.4	27.7
$\phi_\omega = 0.50$	0.7	-1.6	-2.9	7.7	40.8	0.7	35.0	17.2	65.0	42.5
$\phi_\omega = 0.75$	0.9	-2.6	-4.5	11.0	40.4	0.9	35.8	22.0	78.4	43.1
$\phi_\omega = 1.00$	1.0	-3.7	-6.3	13.6	24.2	1.0	23.2	24.1	77.1	27.7
Persistence ($\rho_\xi = 0.9$)										
$\phi_\omega = 0.25$	0.2	-0.7	-1.1	2.5	55.1	0.2	1.0	2.4	61.6	55.5
$\phi_\omega = 0.50$	-0.3	-2.1	-3.0	1.3	89.5	-0.3	-10.0	-13.8	102.9	90.3
$\phi_\omega = 0.75$	-1.6	-4.3	-5.5	-3.8	101.1	-1.6	-33.6	-49.4	121.9	102.3
$\phi_\omega = 1.00$	-3.7	-7.2	-8.9	-13.1	87.6	-3.7	-70.6	-105.8	116.2	89.4

subject to disturbances of many types. It is necessary to balance the considerations that arise in the case of each individual type of disturbance. When doing this, it is important to consider not only the optimal spread adjustment in the case of a given type of disturbance, but also the size of the change in welfare achieved by a spread adjustment in each case. Table 2 reports the welfare change (relative to the baseline Taylor rule) for each of the types of shocks, for each of several different possible sizes of spread adjustment (the same four values of ϕ_ω considered in the figures). The first part of the table shows results for the case of disturbances with zero persistence, the second part for the case of disturbances with $\rho = 0.9$. In the case of each type of disturbance, the amplitude of the shock is normalized so that the standard deviation of fluctuations in output around trend will be one percentage point, in the case that that disturbance is the only kind that exists.

When considering the overall advantage of a given increase in the spread adjustment, it is necessary to consider the implications of a single contemplated change in the policy rule for the way in which the economy will respond to *all* of the different types of disturbances to which it is subject at different times. It is possible to determine this, however, by looking across a given row of the table. For example, suppose that in a given economy, 50 percent of output fluctuations (relative to trend) are due to productivity shocks, 25 percent are due to variations in the spending opportunities of credit-dependent (type b) households, and 25 percent are due to credit spread variations resulting from shocks to the default rate. Suppose furthermore that each of the three types of disturbances that occur have serial correlation coefficient $\rho = 0.9$ (so that the second part of Table 2 applies), and that the three disturbances are independent of one another (so that we can simply sum the contributions of the three disturbances to our quadratic loss function).[43] Then a change in the value of ϕ_ω will raise welfare if and only if raises $W^{tot} = 0.5W_Z + 0.25W_{Cb} + 0.25W_{\tilde{\chi}}$, where W_Z is the welfare measure reported in the Z_t column of Table 2, W_{Cb} is the welfare measure reported in the $\bar{C}_t^b$ column, and so on.

For example, in the case of an increase in ϕ_ω from 0.25 to 0.50, the table indicates that $W_{\tilde{\chi}}$ increases, while W_Z and W_{Cb} both fall. However, the increase in $W_{\tilde{\chi}}$ is larger than the declines in either of the other two quantities. If we use the weights just proposed, W^{tot} increases by a net amount of 7.4, so that the increase in the spread adjustment would be beneficial in welfare terms, despite the fact that it leads to a less optimal response to two of the types of disturbances.[44] Instead, in the case of increase in ϕ_ω from 0.50 to 0.75, the net change in W^{tot} is negative (-7.7), so that the increase would reduce welfare, even though $W_{\tilde{\chi}}$ still increases. Thus under this assumption about the relative importance of different shocks, we would conclude that a partial spread adjustment of $\phi_\omega = 0.50$ would be best among the alternatives in the table.

While the results of this calculation depend on what we assume about the relative importance of different sources of aggregate fluctuations in real activity, we can offer some (cautious) generalizations even without undertaking to estimate the relative importances of the different disturbances in the context of a macroeconometric model. We observe that the variations in the spread adjustment do not make a great difference for welfare except in the case of two types of shocks: shocks that affect the economy

[43]Of course, there is no reason why these disturbances are necessarily distributed independently of one another. For example, the preferences of type b households and of type s households need not fluctuate independently of one another. But to deal with this possibility, we would need additional information beyond that reported in Table 2. In effect, we would have to consider additional types of disturbances besides those reported in the table: a disturbance that raises $\bar{C}_t^b$ and $\bar{C}_t^s$ in the same proportion, a disturbance that raises τ_t by half the amount of the increase in G_t, and so on.

[44]This assumes, of course, that only policy rules within the restricted family (2.3) are considered.

by interfering with credit flows (the $\tilde{\chi}_t, \tilde{\Xi}_t$, and b_t^g shocks) on the one hand, and shocks to private spending opportunities[45] (the $\bar{C}_t^b$ and $\bar{C}_t^s$ shocks) on the other. If *either* intermediation shocks (of whatever degree of persistence) or expenditure shocks that are sufficiently transitory are responsible for any substantial fraction of aggregate variability, then a positive spread adjustment is likely to improve welfare, but the optimal adjustment is in general well below a 100 percent adjustment. The only important qualification to this conclusion is in the case that relatively *persistent* expenditure shocks are also quite important. If shocks of this type are sufficiently important relative to shocks in the other category, the desirable size of the spread adjustment is reduced, although, as in the numerical example just considered, a partial spread adjustment on the order of 50 percent could easily still be justified.[46]

The considerations involved in judging the optimal spread adjustment are simpler in some respects in the case that we assume a linear intermediation technology (along with our maintained assumption in the above calculations that $\chi_t(b)$ is linear). In this case, the credit spread is an exogenous process, so that a spread adjustment to the Taylor rule has no consequences (in our log-linear approximation) for the economy's response to disturbances other than purely financial disturbances (shocks to $\tilde{\chi}_t$ or to $\tilde{\Xi}_t$, the two determinants of the credit spread). Moreover, the consequences of a spread adjustment are quite similar in the case of these two types of financial disturbances; so it might seem that we should be able to choose the spread adjustment so as to

[45]Note that in the context of our model, where consumption spending and investment spending are not distinguished, these disturbances may be taken to represent variations in opportunities for profitable investment spending, and not just opportunities for consumer expenditure.

[46]The relative robustness of our conclusions to alternative hypotheses about the relative importance of alternative disturbances depends importantly on the fact that our baseline Taylor rule (1.21) includes adjustments for variations in the natural rate of output and in the natural rate of interest, which allows the rule to respond relatively well to a variety of types of non-financial disturbances. If we were instead to use as our baseline case a Taylor rule in which the natural rate of interest is assumed to be a constant and the natural rate of output is assumed to be a deterministic trend (as in many calculations of "Taylor rules" in practice), then equilibrium responses to many real disturbances would be quite inefficient under such a rule, even in a model without financial frictions. Moreover, there is no general pattern in the way the consequences of a spread adjustment would compare to the way in which the Taylor rule would need to be adjusted to correct for the shifts in the natural rates, in the case of different types of disturbances. As a result, our conclusions about the effects of a spread adjustment would vary much more depending on the types of disturbances judged to be most important. See the technical appendix for details of our results for this case.

Table 3: Optimal value of the spread-adjustment coefficient ϕ_ω in policy rule (2.3), as in Table 1, but for the case of a linear intermediation technology.

	$\tilde{\chi}_t$	$\tilde{\Xi}_t$
$\rho_\xi = 0.00$	1.84	1.30
$\rho_\xi = 0.50$	1.62	1.40
$\rho_\xi = 0.90$	0.26	0.28
$\rho_\xi = 0.99$	-2.43	-2.36

optimize the response to a single type of shock. However, as shown in Table 3, the optimal spread adjustment is quite different depending on the degree of persistence of the financial disturbances. It is positive and even greater than 1, in the case of either type of disturbance, if the degree of persistence is $\rho_\xi = 0.5$ or less. But the optimal degree of spread adjustment is much smaller (on the order of 0.25, for either type of disturbance) if instead we assume $\rho_\xi = 0.9$. In the case of even more persistent financial disturbances, the optimal spread adjustment changes sign. If, for example, we assume $\rho_\xi = 0.99$, the optimal spread adjustment is more negative than -2, for either type of disturbance.

Hence our conclusions about the optimal spread adjustment are actually less robust in this case to alternative assumptions about the relative importance of different shocks, since the result differs greatly depending on the relative importance of financial shocks of differing degrees of persistence. (There is no reason, of course, to assume that all financial disturbances are of any one degree of persistence.) However, despite the attention given to the case of a linear intermediation technology in our previous work (Cúrdia and Woodford, 2009), because of the possibility of obtaining analytical results for this case, we are inclined toward the view that it is more realistic to assume significant capacity constraints in lending (meaning substantial convexity of the cost function). For this reason, our conclusions for the convex case may be of more practical relevance.

Whether this is the case or not, our results indicate that the same size of spread adjustment is not desirable regardless of the nature of the disturbances that are responsible for the change in credit spreads. This is an important reason for the superiority of an alternative approach to the problem, in which the central bank's policy commitment is formulated in terms of a target criterion that its interest-rate instrument is adjusted to achieve, rather than in terms of a Taylor-type instrument rule for the policy rate. We consider the advantages of a particular type of "flexible inflation targeting rule" in Cúrdia and Woodford (2009), and show that in the case of a linear intermediation technology, this rule would imply a larger spread adjustment in the case of less persistent financial disturbances. We discuss this alternative further in the conclusion.

2.3 Responding to Variations in Aggregate Credit

Some have suggested that because of imperfections in financial intermediation, it is more important for central banks to monitor and respond to variations in the volume of bank lending than would be the case if the "frictionless" financial markets of Arrow-Debreu theory were more nearly descriptive of reality. A common recommendation in this vein is that monetary policy should be used to help to stabilize aggregate private credit, by tightening policy when credit is observed to grow unusually strongly and loosening policy when credit is observed to contract. For example, Christiano *et al.* (2007) propose that a Taylor rule that is adjusted in response to variations in aggregate credit may represent an improvement upon an unadjusted Taylor rule.

In order to consider the possible advantages of such an adjustment, we now propose to replace (1.21) by a rule of the form

$$\hat{\imath}_t^d = r_t^n + \phi_\pi \pi_t + \phi_y(\hat{Y}_t - \hat{Y}_t^n) + \phi_b \hat{b}_t, \tag{2.4}$$

for some coefficient ϕ_b, the sign of which we shall not prejudge. (Christiano *et al.*, like most proponents of credit-based policies, argue for the desirability of a positive coefficient.) Figure 12 illustrates the consequences of alternative degrees of response (of either sign) to credit variations, in the case of the same kind of increase in government debt as in Figures 5 and 7, again in an economy with a convex intermediation technology, and with ϕ_π and ϕ_y set at the Taylor values.

Because in the case of a convex intermediation technology (and in the absence of "purely financial" disturbances) the credit spread ω_t is a monotonic function of the aggregate volume of private credit b_t (and in our log-linear approximation, $\hat{\omega}_t$ is a *linear* function of $\hat{b}_t$), any rule of the form (2.4) is actually *equivalent* to a particular rule of the form (2.3), as far as our model's predictions about the responses to all

Table 4: Optimal value of the response coefficient ϕ_b in policy rule (2.4), for the same set of possible disturbances as in Table 1, and a convex intermediation technology.

	Z_t	μ_t^w	τ_t	G_t	b_t^g	$\bar{H}_t$	$\bar{C}_t^b$	$\bar{C}_t^s$	$\tilde{\chi}_t$	$\tilde{\Xi}_t$
$\rho_\xi = 0.00$	-1.08	7.89	15.01	-1.53	-0.62	-1.08	-0.64	-1.07	1.14	0.97
$\rho_\xi = 0.50$	-1.35	2.18	4.42	-2.22	-0.71	-1.35	-0.60	-0.72	0.42	0.40
$\rho_\xi = 0.90$	-0.21	0.12	0.30	-0.30	-0.74	-0.21	-0.15	-0.16	0.06	0.06
$\rho_\xi = 0.99$	1.38	1.44	1.47	1.37	-0.65	1.38	1.39	1.39	0.00	0.00

non-financial shocks (shocks that do not shift the equilibrium relation between ω_t and b_t) are concerned. Under our calibration, a rule of the form (2.4) with a coefficient ϕ_b is equivalent to a rule of the form (2.3) with coefficient $\phi_\omega = -\phi_b$. Hence the results shown in Figure 12 (at least for the two cases with $\phi_b < 0$) are actually the same as those in Figure 7 (for the corresponding values of $\phi_\omega > 0$). As noted before, the optimal spread adjustment in this case is positive (and a substantial fraction of 1); it follows that the optimal value of ϕ_b for this kind of shock is *negative* (in fact, -0.74, as reported in Table 4). The baseline Taylor rule accommodates this type of disturbance to too great an extent, allowing inflation and output to increase more than they would under an optimal policy. But this type of shock reduces private credit (government borrowing crowds out private borrowing), so a positive value of ϕ_b would mean an even looser policy in response to the shock, making the equilibrium responses even farther from optimal policy.

Table 4 reports the optimal value of ϕ_b in the rule (2.4), in the case of each of the types of individual disturbances considered in Table 1, using the same format as the earlier table.[47] The results for disturbances other than $\tilde{\chi}_t$ and $\tilde{\Xi}_t$ all follow directly from the results in Table 1. As before, we find that both the sign and magnitude of the optimal response coefficient depends on which types of disturbances one is

[47] The coefficients in the table indicate the desired increase in the policy rate target, expressed in percentage points per year, per percentage point increase in real aggregate credit. Thus $\phi_b = 1.14$ means that a one percent greater volume of aggregate credit raises the operating target for the policy rate by 1.14 percentage points per year, in the absence of any change in inflation or output. If, in equation (2.4), $\hat{\imath}_t^d$ and π_t are understood to be quarterly rates, then the coefficient on $\hat{b}_t$ in that equation should be written as $\phi_b/4$.

concerned with. But in particular, to the extent that our previous results showed that a positive spread adjustment would often be beneficial (even in the case of non-financial disturbances) — in particular, the optimal spread adjustment was positive, not only in the case of the government debt shock, but in the case of all of the real non-financial disturbances that are not "cost-push" shocks, as long as those disturbances are not extremely persistent — this would correspond to a preference for a *negative* value of ϕ_b, rather than a positive value as assumed in most discussion of this proposal.

However, the results in Table 1 according to which it is desirable for ϕ_ω to be positive in the case of "purely financial" disturbances do *not* imply that it is optimal for ϕ_b to be negative, since these disturbances shift the equilibrium relation between aggregate credit and the credit spread. In fact, Table 4 shows that the optimal ϕ_b in the case of either of the two types of purely financial disturbances is at least slightly positive. As in our discussion of the spread adjustment, we find that it is desirable to loosen policy in response to a shock that increases $\omega_t(\bar{b})$, to a greater extent than would occur under the unadjusted Taylor rule; but because credit *contracts* in response to such a disturbance (at the same time that the credit spread increases), this is achieved by setting $\phi_b > 0$. Nonetheless, the table shows that except when the disruption of financial intermediation is quite transitory, the optimal response coefficient is relatively small. Figure 13 shows how alternative sizes of responses to aggregate credit change the equilibrium responses to an increase in the default rate with persistence $\rho = 0.9$, the same kind of disturbance considered in Figure 6. One sees that responses to credit of *either* sign make the economy's equilibrium response farther from what would occur under optimal policy, when the responses are of moderate size (the sizes of response that would be optimal in the case of many other types of disturbance). The optimal response to variation in aggregate credit is positive in this case, but quite small ($\phi_b = 0.06$).

On the whole, in our view, it is even harder to find a policy within the class (2.4) that is reasonably good regardless of the type of disturbance affecting the economy than it is to find a robust rule within the class (2.3). In the case of the spread-adjusted rules, we obtained fairly consistent conclusions about the more desirable rules in the case of both types of financial disturbances and the government-debt shocks, regardless of the persistence of disturbances; and these were the only kind of disturbances for which the spread adjustment had a significant effect on welfare

Table 5: Optimal value of the response coefficient ϕ_b in policy rule (2.4), for the same set of possible disturbances as in Table 5, but a linear intermediation technology.

	Z_t	μ_t^w	τ_t	G_t	b_t^g	$\bar{H}_t$	$\bar{C}_t^b$	$\bar{C}_t^s$	$\tilde{\chi}_t$	$\tilde{\Xi}_t$
$\rho_\xi = 0.00$	-0.01	0.01	0.02	-0.01	0.00	-0.01	0.00	0.00	0.00	0.00
$\rho_\xi = 0.50$	0.00	0.00	0.01	-0.01	0.00	0.00	0.00	0.00	0.00	0.00
$\rho_\xi = 0.90$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$\rho_\xi = 0.99$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(if we set aside the case of highly persistent private expenditure shocks). But with the credit-adjusted rules, the sign of the optimal response is opposite between the financial disturbances and the government debt shocks; and the magnitude of the optimal credit adjustment is very different in the case of financial disturbances with different degrees of persistence. Hence it is harder to make a case that *any* adjustment in response to variations in aggregate private credit would clearly be desirable.

In the case of a linear intermediation technology, instead, rules in the family (2.4) are no longer equivalent to any rules in the family (2.3) in the case of non-financial disturbances. One might think that in this case there could be an advantage of a credit-adjustment rule relative to the spread-adjusted Taylor rules: whereas a spread adjustment cannot improve upon the rule's response to non-financial disturbances, a credit adjustment might. However, a credit adjustment turns out to lower welfare, regardless of the sign of the response, in almost all cases. Table 5 reports the optimal value of ϕ_b for each of the types of disturbance considered in Table 4, but for the case of the linear technology ($\eta = 1$). The optimal coefficient is close to zero in *all* cases. The reason is that, with no endogenous variation in the credit spread, the baseline Taylor rule is already relatively close to representing optimal policy in the case of the non-financial disturbances. But since the volume of credit is affected by the disturbances, a credit adjustment would mean departing from the baseline Taylor rule, which is not necessary. The spread adjustment, which in this economy will modify the Taylor rule *only* in the case of purely financial disturbances, is therefore a more desirable type of modification of the baseline rule.

3 Conclusion

We have considered two possible ways in which the standard Taylor rule might be modified to include a response to financial conditions: by adding a response to variations in a credit spread, as proposed by McCulley and Toloui (2008) and Taylor (2008); or by adding a response to a measure of aggregate private credit, as proposed by Christiano *et al.* (2007) among others. According to the model that we have used to analyze this issue, either type of adjustment, if of an appropriate magnitude, can improve equilibrium responses to disturbances originating in the financial sector. (In the case of the spread adjustment, this would require that the policy rate be reduced, relative to what the standard Taylor rule would prescribe, when credit spreads are larger than normal; in the case of a credit response, it would require that the policy rate be reduced when the volume of credit is smaller than normal.) However, even if this is the only kind of disturbance with which we must be concerned, the optimal degree of spread adjustment is likely to be less than a 100 percent offset for the increase in credit spreads; and the optimal degree of response to a reduction in credit will be much less strong than would be required to fully stabilize aggregate credit at some target level.

Neither type of simple proportional adjustment is ideal, however, since the time path of the distortions that one would like to offset is in general not the same as the dynamic response of either of these two indicators to the disturbance. In the model of Cúrdia and Woodford (2009), the most important perturbations of the model structural relations due to credit frictions are direct functions of the path of the credit spread ω_t; but many of the additional terms involve the marginal-utility gap Ω_t (which, to a linear approximation, is a forward-looking moving average of the credit spread) rather than the contemporaneous credit spread alone. The dynamic response of aggregate credit is even less similar to that of the distortions. At the time of a financial disturbance, credit contracts while the distortions (measured either by ω_t or Ω_t) increase; but subsequently, as the underlying disturbance (the shift in the functions $\Xi_t(b)$ or $\chi_t(b)$) dissipates but its effects persist, a lower volume of credit will be associated with *lower* values of both ω_t and Ω_t.

Simple proposals of this kind are even less adequate once one considers their consequences for the economy's responses to other kinds of disturbances besides purely financial ones. Disturbances of all sorts should cause endogenous variation in the volume of private credit, but the response coefficient ϕ_b that would represent the best modification of a standard Taylor rule is quite different in the case of different types of disturbances; in particular, in many cases, it would be better for monetary policy to be loosened when credit *expands* (rather than when it contracts) as a consequence of a non-financial disturbance, though the optimal sign of ϕ_b is positive in the case of most financial disturbances. In the case that the credit spread is endogenous (as in the "convex intermediation technology" case treated above), disturbances of all sorts cause credit spreads to vary as well, and a spread adjustment would also have implications for the economy's response to each of these disturbances. The tension between what is desirable in the case of different types of disturbances is somewhat less acute in this case, as a positive value for ϕ_ω is preferred in the case of many non-financial disturbances as in the case of the purely financial disturbances; but there are considerable differences in the size of adjustment that is best in the case of different types of disturbances.

A superior approach to either kind of simple rule, at least in principle, is to adjust the policy instrument so as to imply economic projections for inflation and real activity that are consistent with a *target criterion,* as discussed in Cúrdia and Woodford (2009). Assuming that the model used to produce these projections takes correct account of the implications of financial conditions for aggregate demand and supply, this will imply a response to changing financial conditions in the way that the central bank sets its target for the policy rate. But the response that is called for is not a simple proportional response to any single measure of financial conditions. A forecast-targeting central bank will properly take account of many credit spreads rather than just one; it will take account of whether changes in credit spreads indicate disruptions of the financial sector as opposed to endogenous responses to developments elsewhere in the economy; and it will calibrate its response depending on its best guess about the likely persistence of disturbances on a particular occasion. Of course, the degree to which such an approach should be expected to improve upon a simple rule depends on the quantity and quality of information available for use in the construction of projections; and the use of a more complex (and inevitably more judgmental) approach creates greater challenges with regard to transparency and accountability. Nonetheless, the advantages of such an approach seem to us even more salient under the more complex circumstances associated with financial market disruptions.

References

[1] Altissimo, Filippo, Vasco Cúrdia, and Diego Rodriguez Palenzuela, "Linear-Quadratic Approximation to Optimal Policy: An Algorithm and Two Applications," paper presented at the conference "Quantitative Analysis of Stabilization Policies," Columbia University, September 2005.

[2] Benigno, Pierpaolo, and Michael Woodford, "Inflation Stabilization And Welfare: The Case Of A Distorted Steady State," *Journal of the European Economic Association*, 3: 1185-1236 (2005).

[3] Benigno, Pierpaolo, and Michael Woodford, "Linear-Quadratic Approximation of Optimal Policy Problems," NBER working paper no. 12672, revised August 2008.

[4] Christiano, Lawrence J., Cosmin Ilut, Roberto Motto, and Massimo Rostagno, "Monetary Policy and Stock-Market Boom-Bust Cycles," unpublished, Northwestern University, March 2007.

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

[6] Cúrdia, Vasco, and Michael Woodford, "Credit Frictions and Optimal Monetary Policy," unpublished, Columbia University, May 2009.

[7] Den Haan, Wouter, Steven W. Sumner, and Guy Yamashiro, "Bank Loan Components and the Time-Varying Effects of Monetary Policy Shocks," CEPR discussion paper no. 4724, November 2004.

[8] Dupor, William (2003), "Optimal Random Monetary Policy with Nominal Rigidity," *Journal of Economic Theory*, 112 (1): 66-78.

[9] Gerali, Andrea, Stefano Neri, Luca Sessa, and Federico M. Signoretti, "Credit and Banking in a DSGE Model," unpublished, Banca d'Italia, June 2008.

[10] Goodfriend, Marvin, and Robert G. King, "The New Neoclassical Synthesis and the Role of Monetary Policy," *NBER Macroeconomics Annual* 12: 231-283 (1997).

[11] Goodfriend, Marvin, and Bennett T. McCallum, "Banking and Interest Rates in Monetary Policy Analysis: A Quantitative Exploration," *Journal of Monetary Economics* 54: 1480-1507 (2007).

[12] Lown, Cara S., and Donald P. Morgan, "Credit Effects in the Monetary Mechanism," Federal Reserve Bank of New York *Economic Policy Review* 8(1): 217-235 (2002).

[13] McCulley, Paul, and Ramin Toloui, "Chasing the Neutral Rate Down: Financial Conditions, Monetary Policy, and the Taylor Rule," *Global Central Bank Focus*, PIMCO, February 20, 2008.

[14] Mehra, Rajnish, Facundo Piguillem, and Edward C. Prescott, "Intermediated Quantities and Returns," Research Dept. Staff Report no. 405, Federal Reserve Bank of Minneapolis, revised August 2008.

[15] Meyer, Laurence H., and Brian P. Sack, "Updated Monetary Policy Rules: Why Don't They Explain Recent Monetary Policy?" *Monetary Policy Insights*, Macroeconomic Advisors, March 7, 2008.

[16] Mishkin, Frederic S., "Monetary Policy Flexibility, Risk Management and Financial Disruptions," speech delivered on January 11, 2008.

[17] Rotemberg, Julio J., and Michael Woodford, "An Optimization-Based Econometric Framework for the Evaluation of Monetary Policy," *NBER Macroeconomics Annual* 12: 297-346 (1997).

[18] Svensson, Lars E.O., "Inflation Targeting as a Monetary Policy Rule," *Journal of Monetary Economics* 43: 607-654 (1999).

[19] Svensson, Lars E.O., "What Is Wrong with Taylor Rules? Using Judgment in Monetary Policy through Targeting Rules," *Journal of Economic Literature* 41: 426-477 (2003).

[20] Svensson, Lars E.O., and Michael Woodford, "Implementing Optimal Policy through Inflation-Forecast Targeting," in B.S. Bernanke and M. Woodford, eds., *The Inflation Targeting Debate*, Chicago: University of Chicago Press, 2005.

[21] Taylor, John B., “Discretion versus Policy Rules in Practice,” *Carnegie-Rochester Conference Series on Public Policy* 39: 195-214 (1993).

[22] Taylor, John B., “Housing and Monetary Policy,” in *Housing, Housing Finance, and Monetary Policy,* Federal Reserve Bank of Kansas City, 2007.

[23] Taylor, John B., “Monetary Policy and the State of the Economy,” testimony before the Committee on Financial Services, U.S. House of Representatives, February 26, 2008.

[24] Taylor, John B., and John C. Williams, “A Black Swan in the Money Market,” unpublished, Stanford University, revised April 2008a.

[25] Taylor, John B., and John C. Williams, “Further Results on a Black Swan in the Money Market,” unpublished, Stanford University, May 2008b.

[26] Woodford, Michael, *Interest and Prices: Foundations of a Theory of Monetary Policy,* Princeton: Princeton University Press, 2003.

[27] Woodford, Michael, “The Case for Forecast Targeting as a Monetary Policy Strategy,” *Journal of Economic Perspectives,* Fall 2007, pp. 3-24

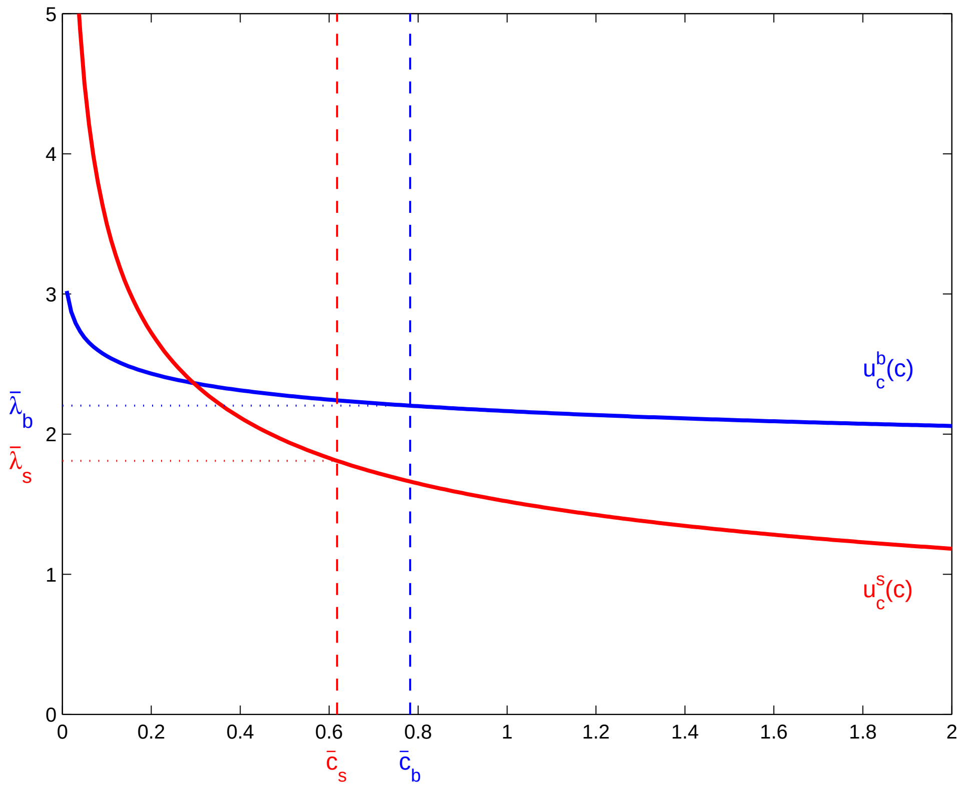

Figure 1: Marginal utilities of consumption for households of the two types. The values $\bar{c}^s$ and $\bar{c}^b$ indicate steady-state consumption levels of the two types, and $\bar{\lambda}^s$ and $\bar{\lambda}^b$ their corresponding steady-state marginal utilities.

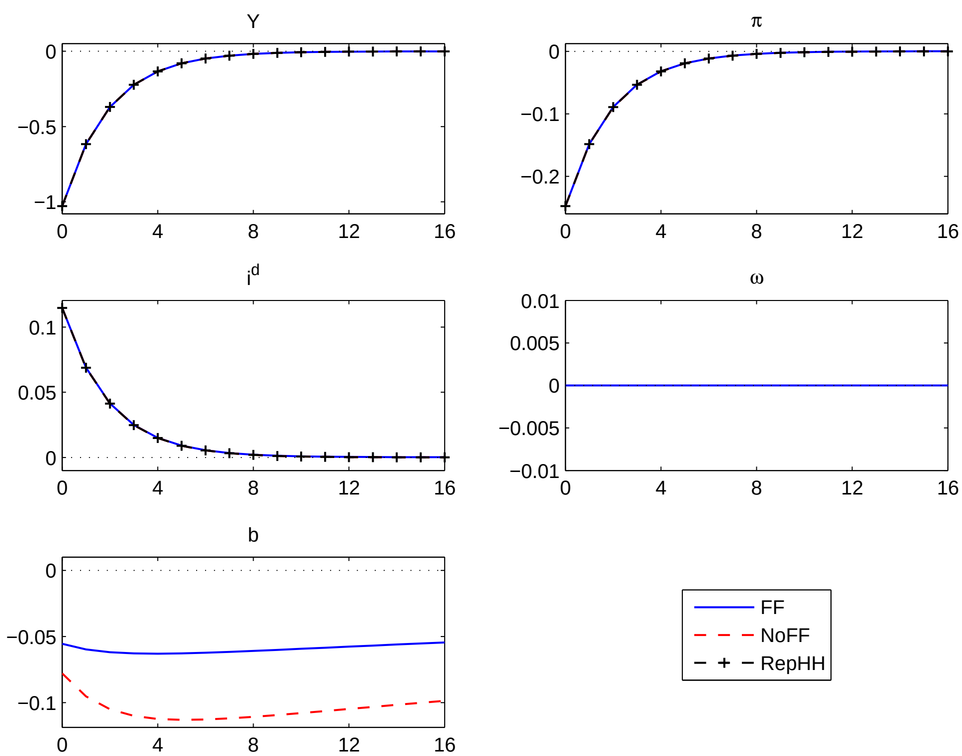

Figure 2: Impulse responses to a 1 percent (annualized) shock to ϵ_t^m, in three different models with a linear intermediation technology.

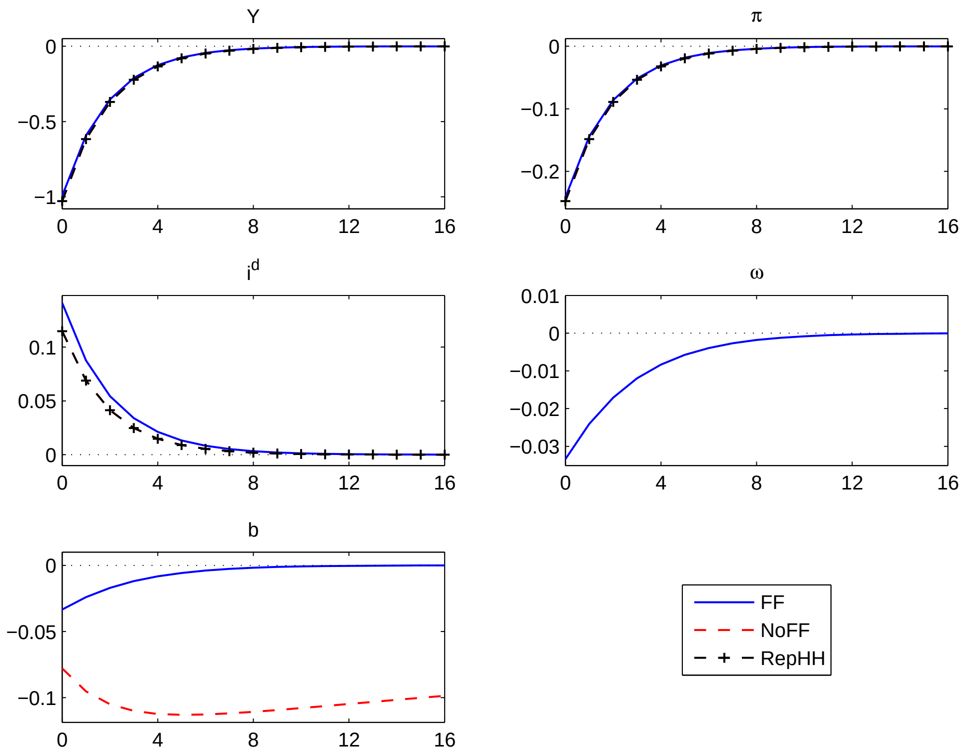

Figure 3: Impulse responses to a 1 percent (annualized) shock to ϵ_t^m, in three different models with a convex intermediation technology.

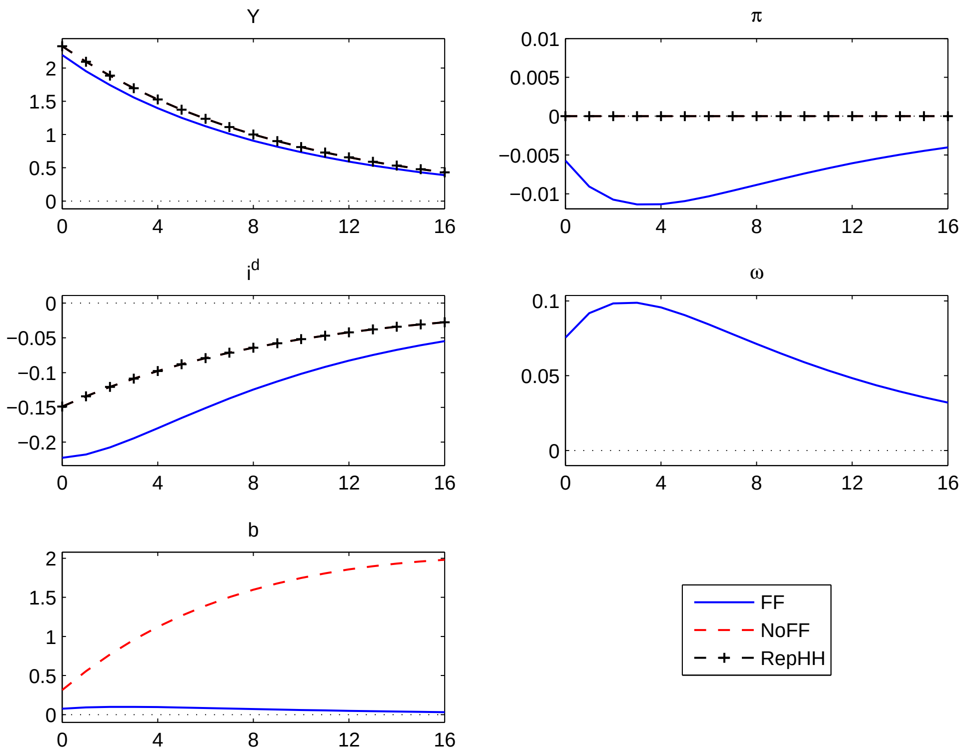

Figure 4: Impulse responses to a 1 percent shock to Z_t, in three different models with a convex intermediation technology.

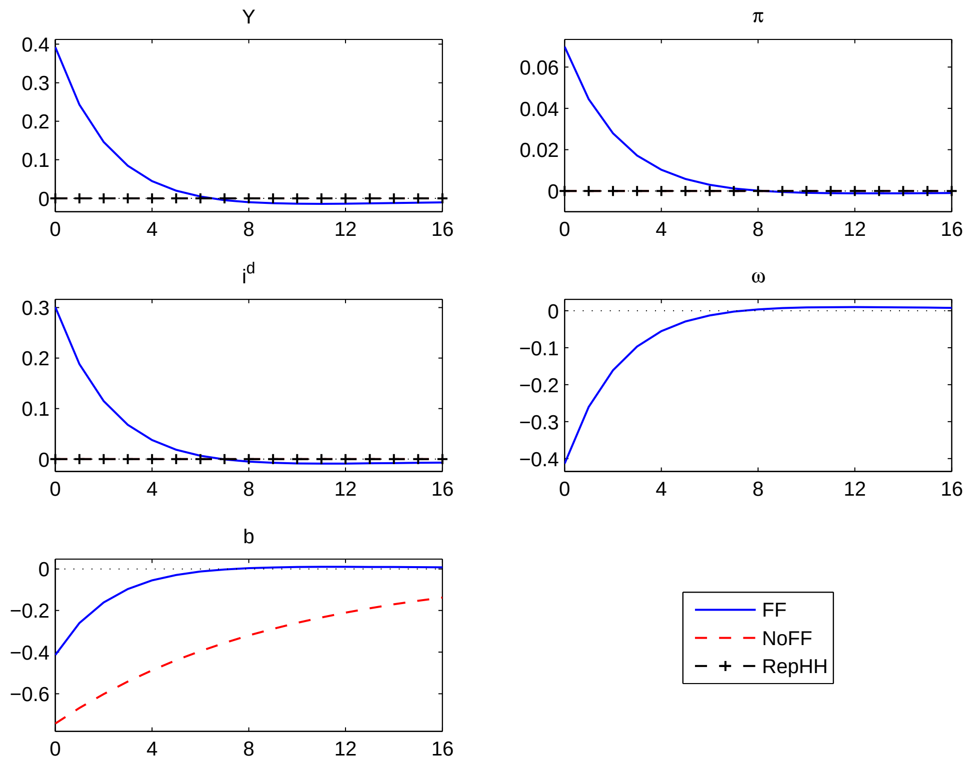

Figure 5: Impulse responses to a shock to b_t^g equal to 1 percent of annual steady-state output, in three different models with a convex intermediation technology.

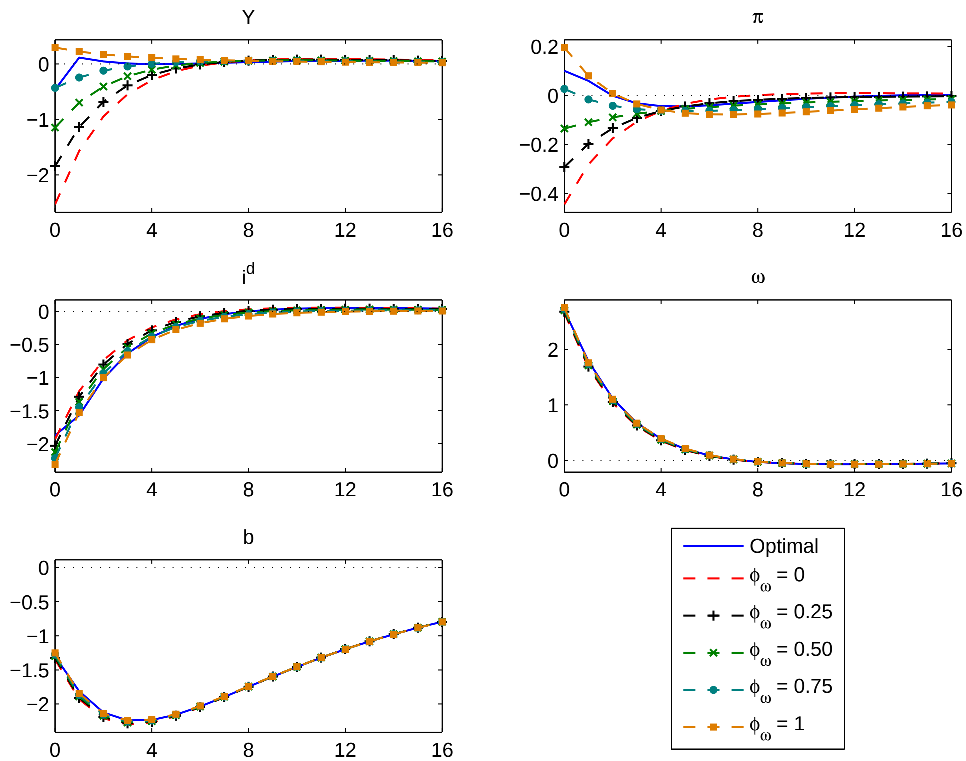

Figure 6: Impulse responses to a shock to $\tilde{\chi}_t$ that increases $\omega_t(\bar{b})$ initially by 4 percentage points (annualized), under alternative degrees of spread adjustment.

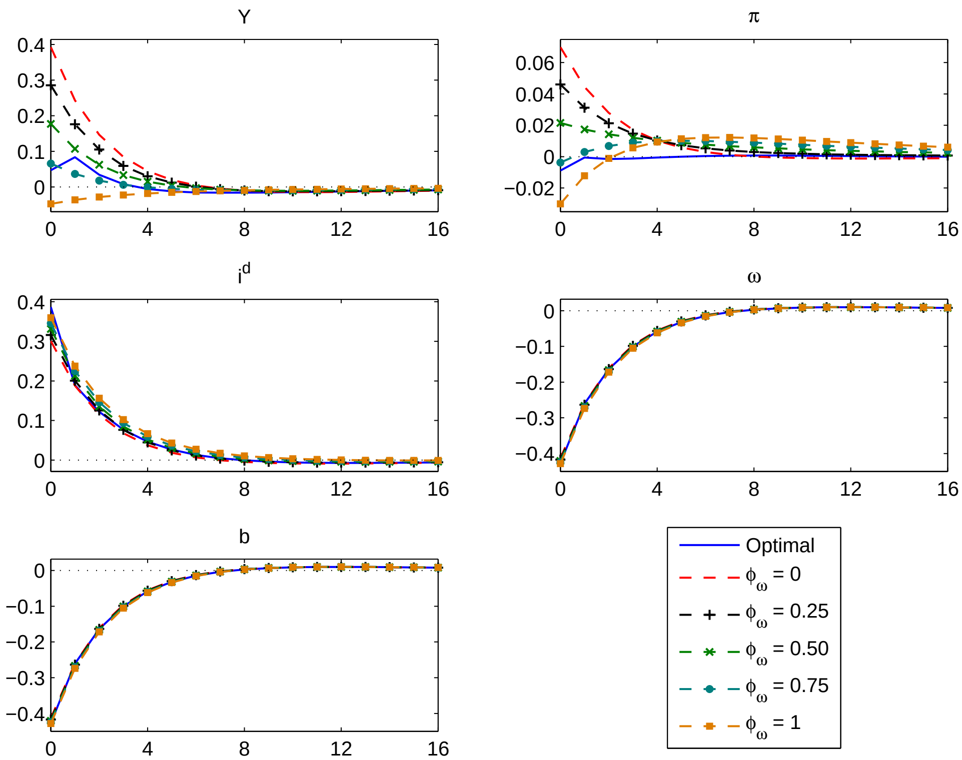

Figure 7: Impulse responses to a shock to b_t^g equal to 1 percent of annual steady-state output, under alternative degrees of spread adjustment.

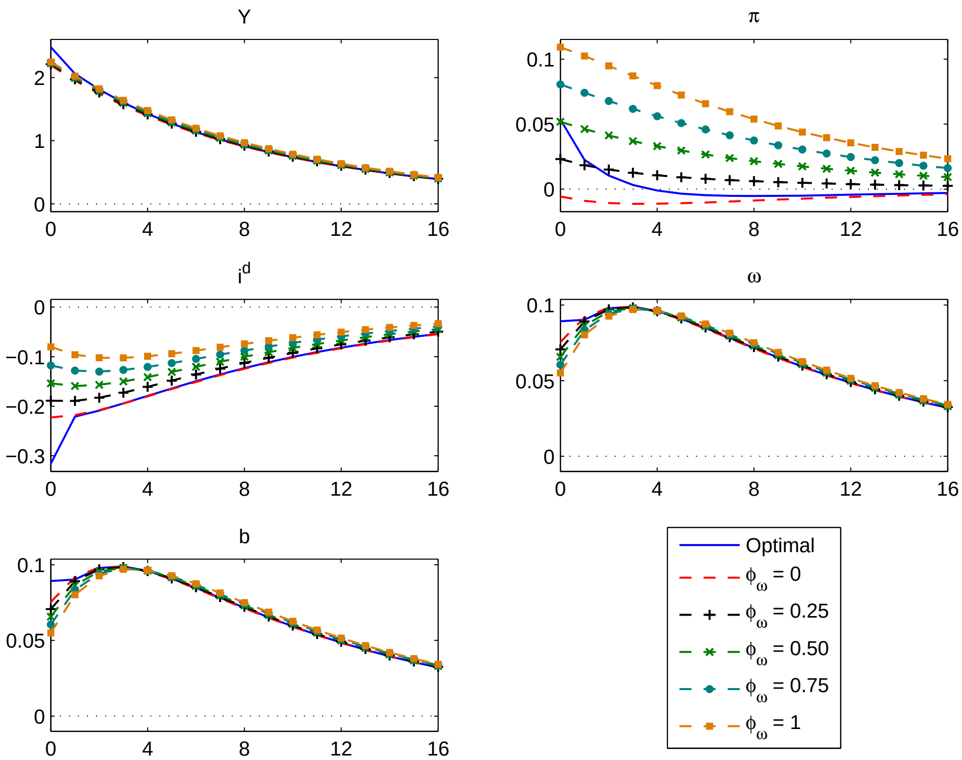

Figure 8: Impulse responses to a 1 percent shock to Z_t, with persistence $\rho = 0.9$, under alternative degrees of spread adjustment.

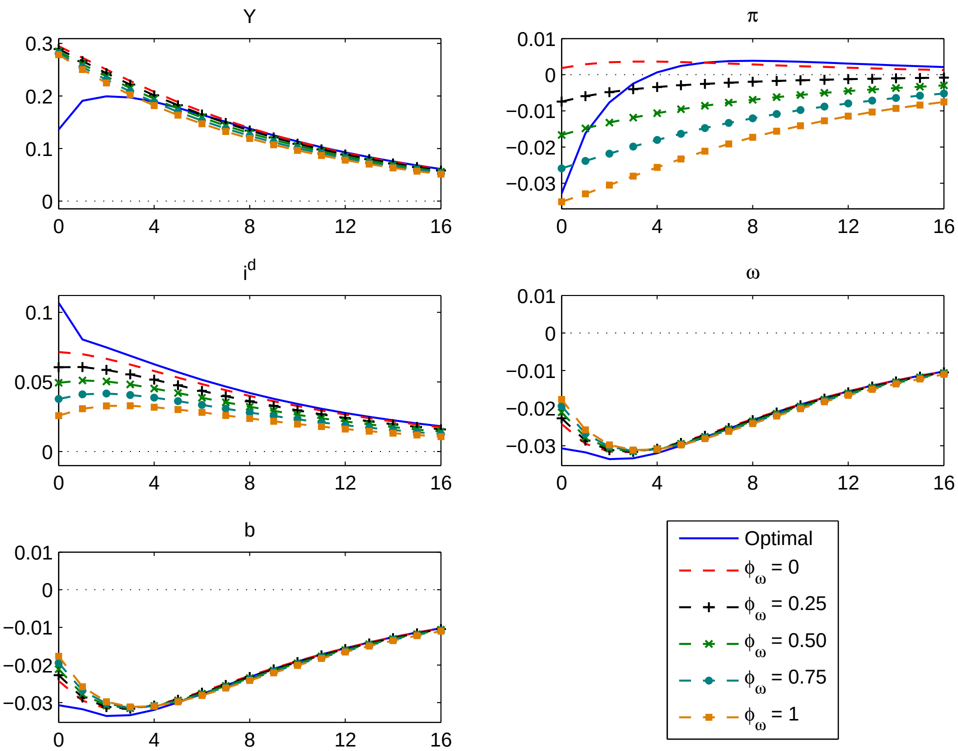

Figure 9: Impulse responses to a shock to G_t equal to 1 percent of annual steady-state output, under alternative degrees of spread adjustment.

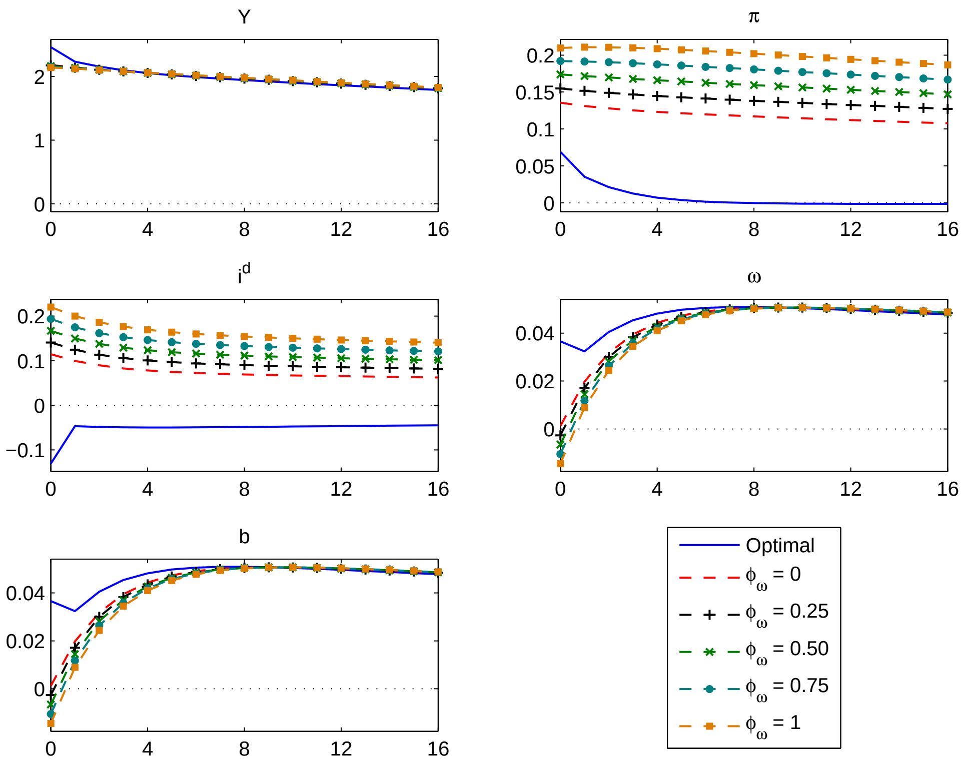

Figure 10: Impulse responses to a 1 percent shock to Z_t, with persistence $\rho = 0.99$, under alternative degrees of spread adjustment.

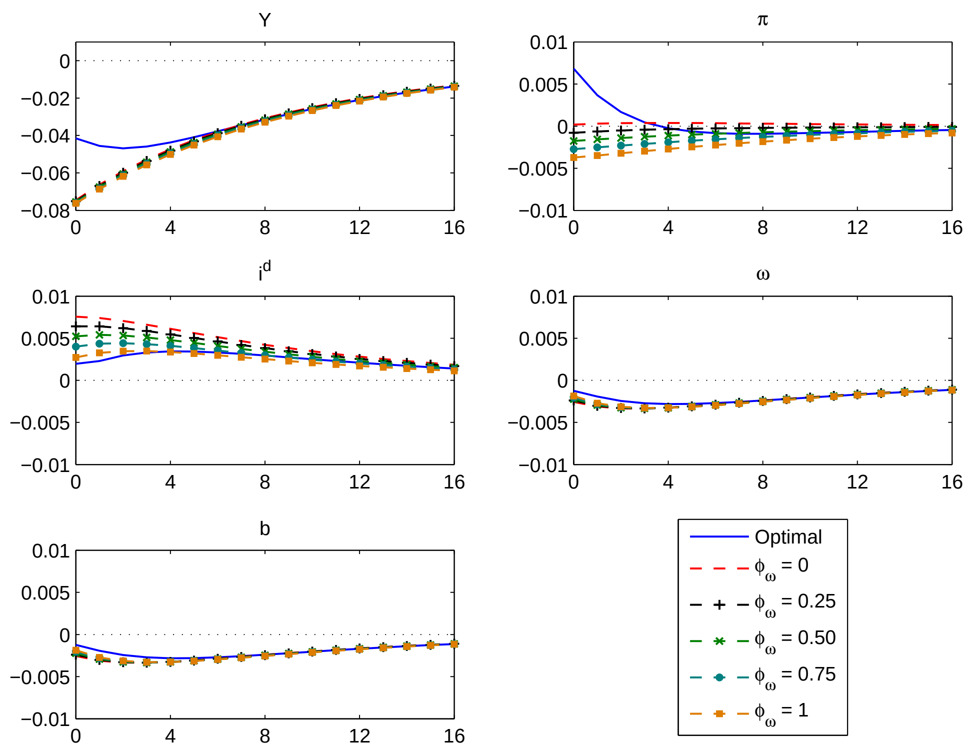

Figure 11: Impulse responses to a 1 percent shock to τ_t, under alternative degrees of spread adjustment.

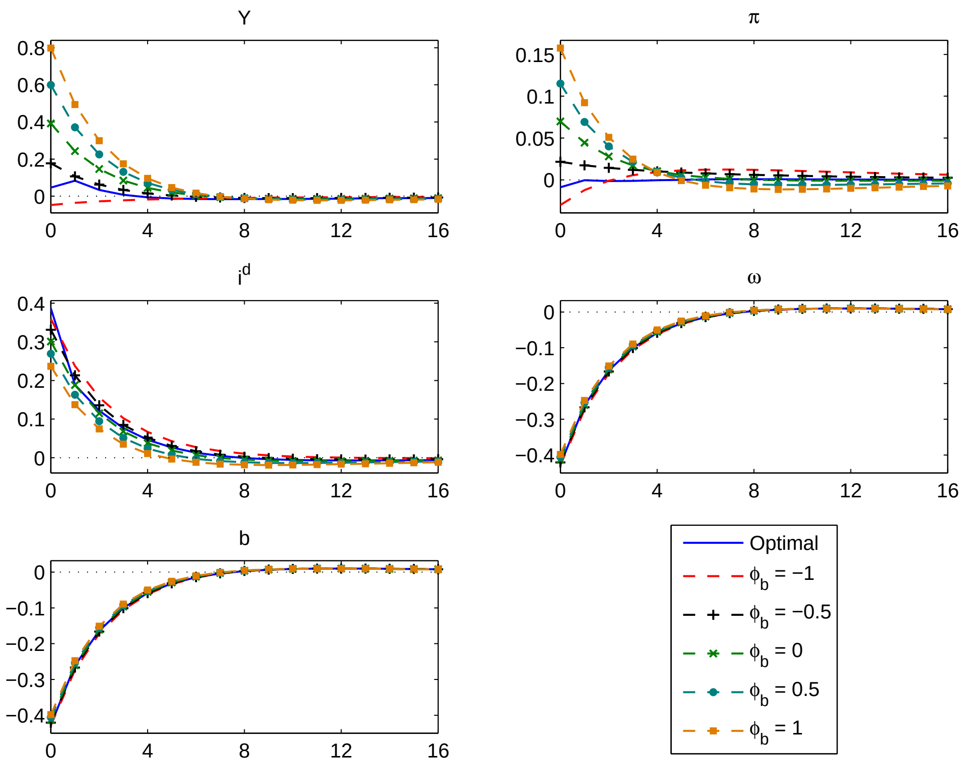

Figure 12: Impulse responses to a shock to b_t^g equal to 1 percent of annual steady-state output, under alternative degrees of response to aggregate credit, in the case of a convex intermediation technology.

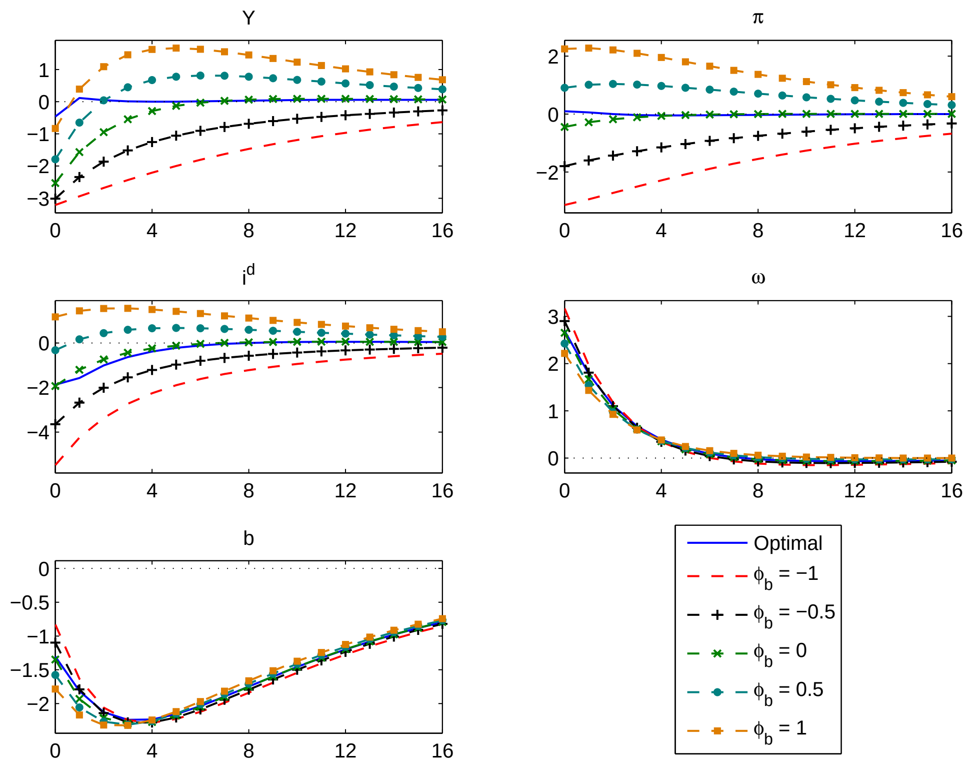

Figure 13: Impulse responses to a shock to $\tilde{\chi}_t$ that increases $\omega_t(\bar{b})$ initially by 4 percentage points (annualized), under alternative degrees of response to aggregate credit, in the case of a convex intermediation technology.