Discussion Paper Series

Monetary Shocks and Central Bank Liquidity with Credit Market Imperfections

By

Pierre-Richard Agénor and Koray Alper

Centre for Growth and Business Cycle Research, Economic Studies,
University of Manchester, Manchester, M13 9PL, UK

August 2009
Number 120

Monetary Shocks and Central Bank Liquidity with Credit Market Imperfections

Pierre-Richard Agénor* and Koray Alper**

First complete draft: March 5, 2009
This version: December 28, 2009

Abstract

This paper analyzes the transmission process of monetary policy in a closed-economy New Keynesian model with monopolistic banking and a cost channel. Lending rates incorporate a risk premium, which depends on firms' net worth and cyclical output. The supply of bank loans is perfectly elastic at the prevailing commercial bank rate and so is the provision of central bank liquidity at the policy rate. The model is calibrated for a middle-income country. Numerical simulations show that credit market imperfections and sluggish adjustment of bank deposit rates may impart a substantial degree of persistence in the response of output and inflation to monetary shocks. With flexible wages, a relatively high elasticity of the risk premium with respect to cyclical output is required for a monetary contraction to lead to higher inflation.

JEL Classification Numbers: E44, E51, F41.

*Hallsworth Professor of International Macroeconomics and Development Economics, University of Manchester, United Kingdom, and Centre for Growth and Business Cycle Research; **Research Department, Central Bank of Turkey. We are grateful to George Bratsiotis for helpful comments on a previous draft. The views expressed in this paper are our own.

Contents

1 Introduction

Recent attempts in New Keynesian models to explain the high degree of persistence that characterizes the empirical response of aggregate output and inflation to monetary shocks has led to much emphasis on credit market imperfections.[1] Many of these models have followed in the tradition of Bernanke and Gertler (1989), Carlstrom and Fuerst (1997), and Bernanke, Gertler, and Gilchrist (2000), where agency costs—which arise endogenously—are the main source of credit market frictions and operate essentially through the cost of investment in physical capital. Contributions along these lines include Christiano, Eichenbaum, and Evans (2005), Faia and Monacelli (2007), Christiano, Motto, and Rostagno (2008), Christensen and Dib (2008), Morozumi (2008), De Graeve (2008), De Blas (2009), and Nolan and Thoenissen (2009). A key result of some of these models is that variations in borrowers' net worth (or collateral values) tend to magnify the impact of monetary shocks on prices and the supply side through a "financial accelerator" effect, and to impart a greater degree of inertia to the propagation process.[2] Another strand of this literature has focused on the impact of credit market imperfections on short-term borrowing costs—and thus, in the presence of a cost channel, on the behavior of prices and output. These contributions include Chowdhury, Hoffmann, and Schabert (2006), Ravenna and Walsh (2006), Rabanal (2007), Atta-Mensah and Dib (2008), Tillmann (2008), Hulsewig, Mayer, and Wollmershauser (2009), and Kaufmann and Scharler (2009).

This paper offers yet another contribution to the literature on New Keynesian models with credit market imperfections, but from a substantially different perspective. As in several of the papers cited above, the model that we propose allows monetary policy to generate a financial accelerator effect. Building on the static framework with monopolistic banks developed by Agénor and Montiel (2006, 2007, 2008*a*), it combines the cost and balance sheet channels of monetary policy with an explicit analysis of the link between collateralizable wealth and bank pricing behavior.[3] Because bor-

[1] See Wang and Wen (2006) and Agénor, Bratsiotis, and Pfajfar (2009), and the references therein, for an overview of the literature on output and inflation persistence. Agénor and Bayraktar (2008) provide evidence on the degree of inflation persistence in middle-income countries.

[2] Other contributions that account for financial frictions include Canzoneri et al. (2008) and Cúrdia and Woodford (2009). However, neither paper explicitly introduces default risk and net worth effects in their intermediation technology.

[3] The importance of the cost channel as a component of the monetary transmission

rowers' ability to repay is uncertain, lending is collateralized and borrowers' net worth affects the terms of credit through a risk premium that banks incorporate in lending rates. Moreover, at the (premium-inclusive) prevailing lending rate, the supply of funds by financial intermediaries is perfectly elastic. Thus, in contrast to models in the Kiyotaki-Moore tradition, net worth does not impose a (continuously binding) constraint on borrowing.[4]

As in some of the more recent contributions, we also assume that the central bank conducts monetary policy by fixing a short-term interest rate, using a Taylor-type rule. This assumption is well supported by the evidence. Indeed, central banks in both high- and middle-income countries typically implement short-term monetary policy according to a target for the overnight interest rate; to ensure that the actual interest rate remains close to target (or fluctuates only within a small band), the amount of liquidity that it provides in the market for overnight funds is adjusted endogenously, often through a standing facility. In contrast with most of the existing literature, we therefore account explicitly for the fact that the central bank's supply of liquidity is perfectly elastic at the target interest rate. As a result, banks are unconstrained in their lending operations—which, together with deposits and reserve requirements, determine residually their liquidity needs.

The central bank refinance rate represents the marginal cost of funds, upon which monopolistic banks set deposit rates; by contrast, the lending rate is set as a markup over the risk-free government bond rate, which represents the opportunity cost of lending. Because changes in bank borrowing affect the monetary base and the supply of currency, and the bond rate clears the currency market, changes in the refinance rate exert both direct and indirect effects on the structure of bank rates. In turn, changes in the bond rate and bank rates affect aggregate demand and supply. Put differently, in our model money affects the dynamics of real variables—even under the assumption of separability between consumption and monetary assets in household utility.[5] Thus, compared to the existing literature, which often considers

mechanism is now well documented, for both industrial and developing countries. See the references in Agénor, Bratsiotis, and Pfajfar (2009).

[4] Although the model does not account for endogenous credit rationing, it is compatible with *exogenous* rationing: it could be assumed for instance that small-scale firms, which operate in the informal sector (as is often the case in developing countries), are rationed out of the financial system entirely. See Beck and Demirguc-Kunt (2006) for a more detailed discussion and some evidence.

[5] Fundamentally, monetary aggregates matter for the model's dynamics because our

only a narrow spectrum of interest rates and ignores the implications of a perfectly elastic supply of central bank liquidity at the prevailing official rate, our setting offers a more complete perspective on interest rate determination and the transmission process of monetary policy.

The remainder of the paper is organized as follows. Section II presents the model. In addition to capturing the effect of net worth on default risk, the model incorporates a negative link between output fluctuations and the risk premium, in order to capture directly the fact that lending rate spreads move countercyclically. Section III describes the symmetric equilibrium, whereas Section IV briefly characterizes the steady-state solution and the log-linearization of the model. Section V describes the calibration. Section VI uses impulse response functions to study the dynamic effects of an increase in the central bank's refinance rate. Section VII performs a variety of sensitivity tests to gauge the robustness of the results obtained in this benchmark case. The last section provides a summary of the main results and considers some possible extensions of the analysis.

2 The Model

We consider a closed economy populated by five types of agents: households, intermediate goods-producing firms, a final-good-producing firm (or, equivalently, a retailer), a financial intermediary (a bank, for short), the government, and the central bank. There is a continuum of identical and infinitely-lived households, indexed by $h \in (0,1)$, and there is a continuum of intermediate good-producing firms, indexed by $j \in (0,1)$.

Households consume, hold financial assets, and supply labor to firms. Each household owns an intermediate good-producing firm and supplies labor only to that firm. They also own the economy's stock of physical capital; they rent it to firms and allow them to use it as collateral for bank borrowing. They choose the level of investment as part of their optimization problem. Thus, unlike models in the Bernanke-Gertler tradition, investment is financed entirely by private agents' own resources; there is no borrowing from the financial system. This assumption is consistent with the evidence for low- and middle-income countries, suggesting that a large share of private investment is financed by retained earnings, because financial institutions do

specification implies that the velocity of money is not constant.

not offer loans of a sufficiently long maturity to allow firms to physical capital accumulation through borrowing.[6]

Each intermediate good-producing firm produces (using both labor and capital) a perishable good that is sold on a monopolistically competitive market. The good can be used either for consumption or investment. Price adjustment is subject to quadratic costs, as in Rotemberg (1982). The final good-producing firm sells its output to households at a perfectly competitive price, whereas intermediate good-producing firms must borrow to pay wages in advance, that is, before production and sales have taken place.[7] Wages are fully flexible and adjust to clear the labor market.[8]

The bank is held collectively by all households and it supplies credit only to intermediate good-producing firms to finance their short-term working capital needs. Its supply of loans is perfectly elastic at the prevailing lending rate. It pays interest on household deposits and the liquidity that they borrow from the central bank. The maturity period of bank loans to firms and bank deposits by households is the same. In each period, loans are extended prior to production and paid off at the end of the period, after the sale of output. Households deposit funds in the bank prior to production and collect them at the end of the period, after the goods market closes. The central bank supplies liquidity elastically to the bank and sets its refinance rate in response to deviations of inflation to its target value and the growth rate of output.

2.1 Households

The objective of household $h \in (0,1)$ is to maximize

$$V_t^h = E_t \sum_{s=0}^{\infty} \beta^s U(C_{ht+s}, N_{ht+s}, x_{ht+s}), \tag{1}$$

[6] See Beck, Demirguc-Kunt, and Maksimovic (2008). In turn, constraints on the supply of medium- and long-term loans may be related to the same problems of contract enforcement that are discussed later, in the context of short-term loans to firms. Note also that in developing countries, stock markets play only a limited role as an alternative source of external finance.

[7] As in Atta-Mensah and Dib (2008) for instance, it could be assumed that the final good is used as material input in the production of intermediate goods and must be financed by bank borrowing as well.

[8] The assumption of complete wage flexibility at the aggregate level is a reasonable approximation for middle-income countries with a large informal sector; see Agénor (2006) for a detailed discussion.

where $U(\cdot)$ is an instantaneous utility function, C_{ht} consumption of the final good, N_{ht} working time, x_{ht} a composite index of real monetary assets, $N_{ht} = \int_0^1 N_{ht}^j dj$, with N_{ht}^j denoting the number of labor hours provided to the intermediate-good producing firm j, with $N_{ht} \in (0,1)$, and $\beta \in (0,1)$ is the discount factor. For simplicity, as noted earlier, $N_{ht}^j = 0$ for $h \neq j$. E_t is the expectation operator conditional on the information available in period t.

The instantaneous utility function takes the form

$$U(C_{ht}, N_{ht}, x_{ht}) = \frac{[C_{ht}]^{1-\sigma^{-1}}}{1-\sigma^{-1}} + \eta_N \ln(1 - N_{ht}) + \eta_x \ln x_{ht}, \tag{2}$$

where $\sigma > 0$ is the constant intertemporal elasticity of substitution in consumption and $\eta_N, \eta_x > 0$. We assume that it is the end-of-period composite stock of monetary assets that yields utility.

The composite monetary asset is generated by combining real cash balances, m_{ht}^H, and real bank deposits, d_{ht}, respectively (both at the beginning of period t), through a Cobb-Douglas function:

$$x_{ht} = (m_{ht}^H)^\nu d_{ht}^{1-\nu}, \tag{3}$$

where $\nu \in (0,1)$. Thus, both cash balances and bank deposits provide utility-enhancing transactions services.[9]

Nominal wealth of household h at the end of period t, A_{ht}, is given by

$$A_{ht} = M_{ht}^H + D_{ht} + B_{ht}^H + P_t K_{ht}, \tag{4}$$

where P_t is the price of the final good, $M_{ht}^H = P_t m_{ht}^H$ nominal cash holdings, $D_{ht} = P_t d_{ht}$ nominal bank deposits, B_{ht} holdings of one-period nominal government bonds, and K_{ht} the real stock of physical capital held by household h at the beginning of period t in firm $j = h$.

Each household h enters period t with K_{ht} real units of physical capital, and M_{ht-1}^H holdings of cash. It also collects principal plus interest on bank deposits at the rate contracted in $t-1$, $(1+i_{t-1}^D)D_{ht-1}$, where i_t^D is the interest rate on deposits, as well as principal and interest payments on maturing

[9] As in Christiano, Motto, and Rostagno (2008), we assume that the deposits that households receive as a counterpart to payment of their labor services (which occurs at the beginning of the period, as discussed later) arrive "an instant too late" to generate transactions services—and are therefore excluded from the definition of d_{ht} that appears in (3).

government bonds, $(1+i^B_{t-1})B^H_{ht-1}$, where i^B_{t-1} is the bond rate prevailing at $t-1$.

At the beginning of the period, each household chooses the levels of cash, deposits, and bonds, and M^H_{ht}, D_{ht}, and B^H_{ht}, and supplies labor and capital to its own intermediate goods-producing firm, for which it receives total real factor payment $r^K_t K_{ht} + \omega_t N_{ht}$, where r^K_t is the real rental price of capital and $\omega_t = W_t/P_t$ the economy-wide real wage (with W_t denoting the nominal wage, which is common across households). Agents adjust continuously their portfolios throughout the period, in response to changes in the marginal utility of consumption and relative rates of return.[10]

Each household h owns an intermediate good-producing firm and receives therefore all the profits made by that firm, J^I_{ht}.[11] In addition, each household holds a claim on the bank; consequently, it receives a fixed fraction $\varphi_h \in (0,1)$ of its profits, J^B_{ht}, with $\int_0^1 \varphi_h dh = 1$ and a total of $J^B_t = \int_0^1 J^B_{ht} dh$. It also pays a lump-sum tax, whose real value is T_{ht}. The household then purchases the final good for consumption and investment, in quantities C_{ht} and I_{ht}, respectively. Investment turns into capital available at the beginning of the next period, K_{ht+1}.

The end-of-period budget constraint facing household h is thus

$$\Delta M^H_{ht} + \Delta D_{ht} + \Delta B^H_{ht} = P_t(r^K_t K_{ht} + \omega_t N_{ht} - T_{ht}) \tag{5}$$

$$+ i^D_{t-1} D_{ht-1} + i^B_{t-1} B^H_{ht-1} + J^I_{ht} + \varphi_h J^B_{ht} - P_t(C_{ht} + I_{ht}).$$

The stock of capital at the beginning of period $t+1$ is given by

$$K_{ht+1} = (1-\delta)K_{ht} + I_{ht} - \Gamma(K_{ht+1}, K_{ht}), \tag{6}$$

where $\delta \in (0,1)$ is a constant rate of depreciation and $\Gamma(K_{ht+1}, K_{ht})$ is a capital adjustment cost function specified in standard fashion as

$$\Gamma(K_{ht+1}, K_{ht}) = \frac{\Theta}{2}\left(\frac{K_{ht+1}}{K_{ht}} - 1\right)^2 K_{ht}, \tag{7}$$

where $\Theta > 0$ is the adjustment cost parameter.

[10] In limited participation models, as for instance in De Blas (2009), households are assumed to deposit funds in the bank *before* they enter the goods market and cannot adjust them until the next period.

[11] As noted below, the final good-producing firm makes zero profits.

Each household maximizes lifetime utility with respect to C_{ht}, N_{ht}, m_{ht}^H, d_{ht}, $b_{ht}^H = B_{ht}^H/P_t$, and K_{ht+1} taking as given i_t^D, i_t^B, P_t, and T_{ht}.[12] Let $\pi_{t+1} = (P_{t+1} - P_t)/P_t$ denote the inflation rate; as shown in Appendix A, maximizing (1) subject to (2)-(7) yields the following solutions:

$$C_{ht}^{-1/\sigma} = \beta E_t \left[(C_{ht+1})^{-1/\sigma} \frac{\left(1 + i_t^B\right)}{(1 + \pi_{t+1})} \right], \tag{8}$$

$$N_{ht} = 1 - \frac{\eta_N (C_{ht})^{1/\sigma}}{\omega_t}, \tag{9}$$

$$m_{ht}^H = \frac{\eta_x \nu (C_{ht})^{1/\sigma} (1 + i_t^B)}{i_t^B}, \tag{10}$$

$$d_{ht} = \frac{\eta_x (1 - \nu)(C_{ht})^{1/\sigma} (1 + i_t^B)}{i_t^B - i_t^D}, \tag{11}$$

$$-\lambda_t [1 + \Theta(\frac{K_{ht+1}}{K_{ht}} - 1)] + \beta E_t \left\{ \lambda_{t+1} \left[r_{t+1}^K + 1 - \delta - \frac{\Theta}{2} (\frac{K_{ht+2}^2 - K_{ht+1}^2}{K_{ht+1}^2}) \right] \right\} = 0, \tag{12}$$

together with the transversality conditions

$$\lim_{s \to \infty} E_{t+s} \lambda_{t+s} \beta^s (\frac{z_{ht+s}}{P_{t+s}}) = 0, \quad \text{for } z = m^H, K. \tag{13}$$

Equation (8) is the standard Euler equation.[13] Equation (9) relates labor supply positively to the real wage and negatively to consumption. Equation (10) relates the real demand for cash positively with consumption and negatively with the opportunity cost of holding money, measured by the interest rate on government bonds. Similarly, equation (11) relates the real demand for deposits positively with consumption and the deposit rate, and negatively with the bond rate. With a nonnegativity restriction on d_{ht}, this equation implies that $i_t^B > i_t^D$, $\forall t$. Intuitively, although both assets can be used to transfer wealth across periods, deposits (unlike bonds) yield utility and households are willing to accept a lower rate of return on them.

[12] The demand for bonds can be derived residually from the stock constraint (4), given that wealth is predetermined at any given moment in time.

[13] Because there is only a single final good, there is no "second stage" derivation of demand functions.

2.2 Final Good-Producing Firm

The final good, Y_t, is divided between private consumption, government consumption, and investment. It is produced by assembling a continuum of imperfectly substitutable intermediate goods Y_{jt}, with $j \in (0,1)$:

$$Y_t = \left\{ \int_0^1 [Y_{jt}]^{(\theta-1)/\theta} dj \right\}^{\theta/(\theta-1)}, \tag{14}$$

where $\theta > 1$ is the elasticity of demand for each intermediate good.[14]

The final good-producing firm behaves competitively. Given the final-good price P_t and the intermediate-goods prices P_{jt}, it chooses the quantities of intermediate goods, Y_{jt}, that maximize its profits. Using (14), the maximization problem of the final good-producing firm is thus

$$Y_{jt} = \arg\max P_t \left\{ \int_0^1 [Y_{jt}]^{(\theta-1)/\theta} dj \right\}^{\theta/(\theta-1)} - \int_0^1 P_{jt} Y_{jt} dj.$$

The first-order conditions yield

$$Y_{jt} = \left(\frac{P_{jt}}{P_t}\right)^{-\theta} Y_t, \quad \forall j \in (0,1). \tag{15}$$

Imposing a zero-profit condition leads to the following final good price:

$$P_t = \left\{ \int_0^1 (P_{jt})^{1-\theta} dj \right\}^{1/(1-\theta)}. \tag{16}$$

2.3 Intermediate Good-Producing Firms

All intermediate good-producing firms face the same technology, which involves constant returns in labor and capital:

$$Y_{jt} = A_t N_{jt}^{1-\alpha} K_{jt}^{\alpha}, \tag{17}$$

where N_{jt} is household $h = j$ labor hours, $\alpha \in (0,1)$, and A_t a serially uncorrelated common technology shock.[15]

[14] The restriction $\theta > 1$ ensures that the firm's markup in the steady state, equal (as shown later) to $\theta/(\theta-1)$, is positive.

[15] We abstract from the role of land in the production process—an important fixed input in many developing countries. As shown in other studies, introducing land would help to reduce the volatility of output and increase its degree of persistence, by limiting substitution effects across production inputs.

Wages must be paid in advance.[16] To do so, firm j borrows the amount L_{jt}^F from the bank at the beginning of the period. The amount borrowed is therefore such that

$$L_{jt}^F \geq P_t \omega_t N_{jt}, \tag{18}$$

for all $t \geq 0$. Repayment of loans occurs at the end of the period, at the gross nominal rate $(1 + i_{jt}^L)$, where i_{jt}^L is the lending rate faced by firm j. With (18) holding with equality, total costs of firm j in period t consist therefore of wages and interest payments, $(1 + i_{jt}^L) P_t \omega_t N_{jt}$.

Nominal price stickiness is introduced along the lines of Rotemberg (1982), namely, by assuming that intermediate good-producing firms incur a cost (measured in terms of aggregate output) in adjusting prices, of the form

$$PAC_t^j = \frac{\phi_F}{2} (\frac{P_{jt}}{\tilde{\pi}^G P_{jt-1}} - 1)^2 Y_t, \tag{19}$$

where $\phi_F \geq 0$ is the adjustment cost parameter (or, equivalently, the degree of price stickiness), $\tilde{\pi}^G = 1 + \tilde{\pi}$ is the gross steady-state inflation rate, and Y_t is aggregate output, defined in (14). Full price flexibility obtains therefore for $\phi_F = 0$.[17]

Intermediate goods-producing firms are competitive in factor markets. Each firm j solves the unit cost minimization problem defined as

$$N_{jt}, K_{jt} = \arg\min (1 + i_{jt}^L) \omega_t N_{jt} + r_t^K K_{jt},$$

subject to $Y_{jt} = 1$. As shown in Appendix A, the first-order conditions equate the marginal products of capital and labor to their relative prices, r_t^K and $(1 + i_{jt}^L)\omega_t$, respectively, implying that the capital-labor ratio is

$$\frac{K_{jt}}{N_{jt}} = (\frac{\alpha}{1 - \alpha}) [\frac{(1 + i_{jt}^L)\omega_t}{r_t^K}]. \tag{20}$$

Because firms also incurs a financing cost for the payment of wages, the marginal cost of labor includes also borrowing costs, $i_{jt}^L \omega_t$. As derived also

[16] In Christiano, Motto, and Rostagno (2008), intermediate good-producing firms must also finance a fraction of their capital services in advance. As in their paper, it could also be assumed that only a fraction of labor services must be paid in advance.

[17] As in Ireland (2001), a second quadratic term related to the *rate of change* of the firm's price relative to average lagged inflation could be added, to impart more rigigity in price behavior. We abstract from this possibility, given that our focus is on highlighting the role of inertia stemming from credit market imperfections.

in Appendix A, unit real marginal cost is

$$mc_{jt} = \frac{\left[(1+i_{jt}^{L})\omega_t\right]^{1-\alpha}(r_t^K)^{\alpha}}{\alpha^{\alpha}(1-\alpha)^{1-\alpha}}. \tag{21}$$

Although cost minimization is a static problem, the presence of nominal rigidities, in the form of price adjustment costs, introduces a dynamic dimension into the representative firm's price optimization problem. The reason is that price adjustment costs depend not only on the lagged value of prices but also on future (expected) prices. In this case, each firm chooses a sequence of prices P_{jt} so as to maximize the discounted real value of all its current and future real profits:

$$\{P_{jt+s}\}_{s=0}^{\infty} = \arg\max E_t \sum_{s=0}^{\infty} \beta^s \lambda_{t+s}(\frac{\Pi_{jt+s}^F}{P_{t+s}}), \tag{22}$$

where nominal profits at period t, Π_{jt}^F, are defined as

$$\Pi_{jt}^F = P_{jt}Y_{jt} - P_t mc_t Y_{jt} - PAC_t^j. \tag{23}$$

Because firms are owned by households (to whom they transfer their profits), we assume in standard fashion that the firm's discount factor for period-$t+s$ profits in (22) is $\beta^s\lambda_{t+s}$, where λ_{t+s} is the marginal utility value (in terms of consumption) of an additional currency unit of profits at $t+s$; this value is the same $\forall h$.

Substituting (15) and (19) in (23), and taking $\{mc_{t+s}, P_{t+s}, Y_{t+s}\}_{s=0}^{\infty}$ as given, the first-order condition for this maximization problem is:

$$(1-\theta)\lambda_t(\frac{P_{jt}}{P_t})^{-\theta}\frac{Y_t}{P_t} + \theta\lambda_t(\frac{P_{jt}}{P_t})^{-\theta-1}\frac{mc_{jt}Y_t}{P_t} - \lambda_t\phi_F\left\{(\frac{P_{jt}}{\tilde{\pi}^G P_{jt-1}} - 1)\frac{Y_t}{\tilde{\pi}^G P_{jt-1}}\right\} \tag{24}$$

$$+\beta\phi_F E_t\left\{\lambda_{t+1}(\frac{P_{jt+1}}{\tilde{\pi}^G P_{jt}} - 1)Y_{t+1}(\frac{P_{jt+1}}{\tilde{\pi}^G P_{jt}^2})\right\} = 0,$$

which essentially requires that at the optimum, a small change in prices must have a zero effect on the present discounted value of profits. Condition (24) describes the adjustment process of the nominal price P_{jt}. When prices are fully flexible ($\phi_F = 0$), the optimization problem boils down to the simple markup rule:

$$P_{jt} = \frac{\theta}{\theta-1} mc_{jt} P_t, \tag{25}$$

which shows that the real price is a markup over the real marginal cost. In the symmetric equilibrium, where $P_{jt} = P_t$ for all j, the real marginal cost is thus the reciprocal of the markup, $mc_t = (\theta - 1)/\theta$.

2.4 Financial Intermediation

At the beginning of each period t, the bank receives deposits $D_t = \int_0^1 D_{ht} dh$ from households.[18] All funds are used to finance loans to intermediate good-producing firms, which in turn use them to pay labor in advance. Thus, total lending, L_t^F, is equal to

$$L_t^F = \int_0^1 L_{jt}^F dj = P_t \omega_t N_t, \tag{26}$$

where $N_t = \int_0^1 N_{jt} dj = \int_0^1 N_{ht} dh$.

The bank holds required reserves at the central bank, RR_t. Upon receiving household deposits, and given L_t^F and RR_t, the bank borrows from the central bank, L_t^B, to fund any shortfall in deposits. At the end of the period, it repays the central bank, at the interest rate i_t^R, which we refer to as the refinance rate.[19]

The bank's balance sheet is thus[20]

$$L_t^F + RR_t = D_t + L_t^B. \tag{27}$$

Reserves held at the central bank do not pay interest. They are determined by:

$$RR_t = \mu D_t, \tag{28}$$

where $\mu \in (0, 1)$ is the reserve requirement ratio.

Using (28), and given that L_t^F and D_t are determined by private agents' behavior, the balance sheet constraint (27) can be used to determine bor-

[18] As noted earlier, and unlike limited-participation models, households may change their level of deposits after shocks are realized.

[19] All these variables are measured in nominal terms.

[20] In equilibrium, firms always pay the (premium-inclusive) borrowing rate demanded by the lender; as a result, the bank has no incentive to hold government debt. See the discussion below.

rowing from the central bank:[21]

$$L_t^B = L_t^F - (1-\mu)D_t. \tag{29}$$

The bank sets both deposit and lending rates. Regarding the former, we assume that deposits and loans from the central bank are perfect substitutes (at the margin) for funding loans. The bank therefore sets the desired interest rate on deposits, $i_t^{D,d}$, equal to the marginal cost of funds, the refinance rate, corrected for the (implicit) cost of holding reserve requirements:[22]

$$i_t^{D,d} = (1-\mu)i_t^R. \tag{30}$$

To capture in a simple and tractable way limited pass-through of policy rates to bank deposit rates, without explicitly introducing microfoundations, we assume that the actual deposit rate is adjusted only partially to the desired rate:[23]

$$\Delta i_t^D = \zeta_D(i_t^{D,d} - i_{t-1}^D), \tag{31}$$

where $\zeta_D > 0$ is the speed of adjustment. Thus, the pass-through effect is complete only in the long run.

Consider now the desired lending rate charged to each intermediate good-producing firm, $i_{jt}^{L,d}$. Although we do not model it explicitly, lending to firms is subject to default risk. The bank therefore charges a premium above and beyond the opportunity cost of lending, given here by the risk-free government bond rate:

$$i_{jt}^{L,d} = (1+i_t^B)(1+\Phi_{jt}^L) - 1, \tag{32}$$

where $\Phi_{jt}^L > 0$ is the risk premium. In turn, the premium is taken to depend on both "micro" and "macro" factors:

$$\Phi_{jt}^L = \Phi_0^L(\frac{\kappa P_t K_{jt}}{L_{jt}})^{-\phi_1}(\frac{Y_t}{\tilde{Y}})^{-\phi_2}, \tag{33}$$

[21] Strictly speaking, (27) should be written as $L_t^B = \max[0, L_t^F - (1-\mu)D_t]$, given that there is no reason for the bank to borrow if it collects sufficient funds from households. We assume in what follows that $L_t^B > 0\ \forall t$. This condition always holds in the simulations that we report later.

[22] The deposit rate is directly specified to be uniform across households, given that neither μ nor i_t^R depend on h.

[23] Evidence of limited interest rate pass-through is robust for both industrial and developing countries; see for instance Berstein and Fuentes (2005), Sorensen and Werner (2006), Scharler (2008), and Wong (2008). As noted by Scharler (2008) and Kaufmann and Scharler (2009), limited pass-through may be interpreted either as an implicit contract between financial institutions and their customers that arises as a consequence of long-term relationships, or as a consequence of intermediation costs.

where $\kappa \in (0,1)$, $\Phi_0^L > 0$, $\phi_1, \phi_2 \geq 0$, and $\tilde{Y}$ is the steady-state level of aggregate output. The first term represents the collateral-loan ratio, which is given by a fraction κ of the value of firm j's capital stock, $P_t K_{jt}$, in proportion to its borrowing. Thus, higher collateral, or lower borrowing, implies a lower risk premium. The second term captures the effect of aggregate cyclical factors; in periods of high levels of activity, profits and cash flows tend to improve, incentives to default diminish, and the risk premium tends to fall. Put differently, the cost of borrowing is lower during cyclical upturns—a potentially important source of amplification of monetary policy shocks. There is some evidence that risk premia in banking may also depend on inflation in developing countries, as documented by Chirwa and Mlachila (2004) for Malawi, and Beck and Hesse (2009) for Uganda, for instance; we abstract from that extension, given the positive correlation between inflation and changes in output.[24]

Note that equations (30) and (32) can both be derived from a simple profit maximization problem for the bank, as in Agénor and Montiel (2008*a*). In that case, the risk premium would be directly related to the repayment probability. Moreover, although we use in both cases a "quasi-reduced form" for these variables, the impact of collateralizable net worth on borrowing costs can be explicitly derived as in Agénor and Aizenman (1998), under the assumption that producers of intermediate goods face uniformly distributed supply shocks.[25]

Again, to account for rigidity in interest rate setting, we assume that the actual lending rate adjusts gradually over time to the desired rate:

$$\Delta i_{jt}^L = \zeta_L^j (i_{jt}^{L,d} - i_{jt-1}^L), \tag{34}$$

where $\zeta_L^j > 0$ is the speed of adjustment.

[24]Note also that we do not account for the fact that an improvement in firms' (past) profits could reduce (current) borrowing needs; this could be captured by assuming that constraint (18) is replaced by $L_{jt}^F = P_t \omega_t N_{jt} - \zeta \Pi_{jt-1}^F$, where $\zeta \in (0,1)$. However, this creates significant technical complications in solving the intermediate firm's optimization problem.

[25]Note also that using (18), holding with equality, and (20), we have $\kappa P_t K_{jt}/L_{jt} = \kappa \omega_t^{-1}(K_{jt}/N_{jt}) = \kappa\alpha(1-\alpha)^{-1}(1+i_{jt}^L)/r_t^K$, so that in equilibrium movements in the collateral-loan ratio mirrors movements in the gross lending rate relative to the rental rate. By contrast, if firms were to borrow only to rent capital in advance, at the same interest rate i_{jt}^L, then $L_{jt} = r_t^K P_t K_{jt}$ and $\kappa P_t K_{jt}/L_{jt} = \kappa/r_t^K$. In practice, firms borrow for both reasons; but in line with most of the literature, we focus only on loans to finance labor costs.

At the end of the period, as noted earlier, the bank pays interest on deposits and repays with interest loans received from the central bank. Assuming no operating costs (no labor is used), the bank's net profits are therefore given by

$$J_t^B = (1 + i_t^L)L_t^F - (1 + i_t^D)D_t - (1 + i_t^R)L_t^B, \tag{35}$$

which are distributed in equal proportions to the bank's owners, that is, households.

2.5 Central Bank

The central bank's assets consist of holdings of government bonds, B_t^C, loans to the commercial bank, L_t^B, whereas its liabilities consist of currency supplied to households and firms, M_t^s, and required reserves, RR_t; the latter two make up the monetary base. The balance sheet of the central bank is thus given by

$$B_t^C + L_t^B = M_t^s + RR_t. \tag{36}$$

Using (28) to eliminate required reserves, (36) yields

$$M_t^s = B_t^C + L_t^B - \mu D_t. \tag{37}$$

Any net income made on loans to the commercial bank by the central bank is transferred to the government at the end of each period.

Monetary policy is operated by fixing the refinance rate, i_t^R, and providing liquidity (at the discretion of the bank) through a standing facility.[26] In turn, the refinance rate is assumed determined by a Taylor-type policy rule, of the form:

$$i_t^R = \chi i_{t-1}^R + (1 - \chi)[\tilde{r} + \pi_t + \varepsilon_1(\pi_t - \pi^T) + \varepsilon_2 \Delta \ln Y_t] + \epsilon_t, \tag{38}$$

where $\tilde{r}$ is the steady-state value of the *net* real interest rate on bonds, $\pi^T \geq 0$ the central bank's inflation target, $\chi \in (0, 1)$ a coefficient measuring the degree of interest rate smoothing, and $\varepsilon_1, \varepsilon_2 > 0$ the relative weights on inflation deviations from target and output growth, respectively, and ϵ_t a serially correlated shock with constant variance. Thus, as in Liu (2006) for instance, we will examine the properties of the model using a "speed limit"

[26] Access to central bank funds through standing facilities often occurs in practice at increasing penalty rates. For simplicity, we abstract from threshold effects.

policy, rather than a more traditional Taylor rule in terms of the output gap.[27]

2.6 Government

The government purchases the final good and issues nominal riskless one-period bonds, which are held by the central bank and households.[28] Its budget constraint is given by

$$B_t = (1 + i^B_{t-1})B_{t-1} + P_t(G_t - T_t) - i^R_t L^B_t - i^B_{t-1}B^C_{t-1}, \tag{39}$$

where $B_t = B^C_t + B^H_t$ is the end-of-period stock of government bonds, G_t real government spending on the final good, and T_t real lump-sum tax revenues. The final terms, $i^R_t L^B_t$ and $i^B_{t-1}B^C_{t-1}$, come from our assumption that all net income that the central bank makes (from its lending to the commercial bank and its holdings of government bonds) is transferred to the government at the end of each period.

Government purchases are assumed to be a constant fraction of output of the final good:

$$G_t = \psi Y_t, \tag{40}$$

where $\psi \in (0, 1)$.[29]

3 Symmetric Equilibrium

In what follows we will assume that the government maintains budget balance by adjusting lump-sum taxes, while keeping the overall stock of bonds constant at $\bar{B}$, and that the central bank also keeps its stock of bonds constant at $\bar{B}^C$. Private holdings of government bonds are thus equal to $\bar{B} - \bar{B}^C$.

[27] Nonlinear terms could also be introduced to account for asymmetric effects of inflation and the output gap on policy decisions. See for instance Surico (2007), who finds evidence of an asymmetric preference regarding output in the behavior of the European Central Bank. For middle-income countries, however, the evidence is mixed; see Moura and Carvalho (2009).

[28] If Ricardian equivalence was assumed to hold, it would be redundant to allow the government to issue debt.

[29] Instead of assuming that government spending involves simply an unproductive use of resources, it could be viewed as affecting either the utility of households or the productivity of firms.

In a symmetric equilibrium, all households are identical and all firms producing intermediate goods are identical. Thus, $D_{ht} = D_t$, $I_{ht} = I_t$, $K_{jt} = K_t$, $N_{jt} = N_t$, $Y_{jt} = Y_t$, $P_{jt} = P_t$, for all $h, j \in (0, 1)$. All firms also produce the same output, all households supply the same amount of labour hours, and prices are the same across firms. By implication, the lending rate is also the same across borrowers, $i^L_{jt} = i^L_t$, and $\Phi^L_{jt} = \Phi^L_t$, $\forall j$. From (19) and (23), real profits of a representative intermediate-good firm are thus given by $(1 - mc_t)Y_t - 0.5\phi_F[1/(1 + \tilde{\pi}) - 1]^2$. In the steady state, inflation is constant at $\tilde{\pi}$.

Equilibrium conditions must also be satisfied for the credit, deposit, goods, and cash markets.[30] Because the supply of loans by the bank, and the supply of deposits by households, are perfectly elastic at the prevailing interest rates, the markets for loans and deposits always clear. For equilibrium in the goods markets we require that production be equal to aggregate demand, that is, using (19),[31]

$$Y_t = C_t + G_t + I_t + \frac{\phi_F}{2}(\frac{1 + \pi_t}{1 + \tilde{\pi}} - 1)^2 Y_t, \tag{41}$$

where $C_t = \int_0^1 C_{ht} dh$, and $I_t = \int_0^1 I_{jt} dj$, or equivalently, from (6),

$$I_t = K_{t+1} - (1 - \delta)K_t + \Gamma(K_{t+1}, K_t). \tag{42}$$

Combining (40), (41), and (42), the aggregate resource constraint then takes the form

$$\left\{1 - \psi - \frac{\phi_F}{2}(\frac{1 + \pi_t}{1 + \tilde{\pi}} - 1)^2\right\} Y_t = C_t + K_{t+1} - (1 - \delta)K_t + \Gamma(K_{t+1}, K_t). \tag{43}$$

The equilibrium condition of the market for cash is given by

$$M^s_t = M^H_t + M^F_t,$$

where M^s_t is defined in (37) and $M^F_t = \int_0^1 M^F_{j,t} dj$ denotes firms' total holdings of cash. Suppose that bank loans to firms are made only in the form of cash;

[30] By Walras' Law, the equilibrium condition of the market for government bonds can be eliminated.

[31] Implicit in (41) is the assumption that bank monitoring (in case of default) does not entail real costs.

we therefore have $L_t^F = M_t^F$.[32] The equilibrium condition of the market for currency is thus given by $M_t^s = M_t^H + L_t^F$, that is, using (37),

$$L_t^B + B_t^C - \mu D_t = M_t^H + L_t^F.$$

Using (29) to eliminate L_t^B in the above expression yields

$$M_t^H + D_t = \bar{B}^C, \tag{44}$$

which implies that $dM_t^H = -dD_t$.

Using (10) and (11) and aggregating, condition (44) becomes

$$\frac{\bar{B}^C}{P_t} = \eta_x (C_t)^{1/\sigma} (1 + i_t^B) \left\{ \frac{\nu}{i_t^B} + \frac{(1-\nu)}{i_t^B - i_t^D} \right\}, \tag{45}$$

which can be solved for i_t^B:

$$i_t^B = i^B(C_t, \frac{\bar{B}^C}{P_t}; i_t^D) > i_t^D. \tag{46}$$

The equilibrium bond rate depends therefore on private consumption, expected inflation, the bank deposit rate, and the real value of other central bank assets. The spread $i^B - i_t^D$ (that is, the opportunity cost for households of holding deposits instead of bonds) is also positive in equilibrium, ensuring from (11) that indeed $d_t > 0 \ \forall t$.

Finally, note that condition (20) can be rewritten as

$$W_t = P_t(\frac{1-\alpha}{\alpha})\frac{r_t^K K_t}{(1 + i_t^L) N_t}, \tag{47}$$

which determines the equilibrium nominal wage.

4 Steady State and Log-Linearization

The steady state of the model is derived in Appendix B. As shown there, the steady-state inflation rate is equal to its target value ($\tilde{\pi} = \pi^T$) and

[32] From the balance sheet equation (27), the bank holds no cash in vault. Thus, following an increase in the supply of loans, the bank immediately gets the cash that it needs from the central bank, in exchange for an increase in its liabilities, L_t^B. It can be verified that the equilibrium condition (44) remains the same if instead the counterpart to bank loans is—as in Christiano, Motto, and Rostagno (2008), for instance—deposits held by firms.

the steady-state value of the refinance rate is equal to $\tilde{i}^R = \tilde{r}^K + \tilde{\pi}$. Price adjustment costs (just like capital adjustment costs) are zero in the steady state. We will focus in what follows on the case where the inflation target is $\pi^T = 0$. In standard fashion, the steady-state value of the marginal cost is given by $(\theta - 1)/\theta$.

In addition to standard results, steady-state interest rates with zero inflation are given by

$$\tilde{i}^B = \tilde{i}^R = \frac{1}{\beta} - 1, \quad \tilde{r}^K = \frac{1}{\beta} - (1 - \delta),$$

$$\tilde{i}^D = (1 - \mu)\tilde{i}^R, \quad \tilde{i}^L = \tilde{i}^B + \Phi_0^L (\frac{\kappa \tilde{P} \tilde{K}}{\tilde{L}^F})^{-\phi_1},$$

from which it can be shown that

$$\tilde{i}^B - \tilde{i}^D = \frac{\mu}{\beta} > 0.$$

Note that the equality of $\tilde{i}^B$ and $\tilde{i}^R$ means that the bank has no incentive to borrow from the central bank (which it can always do, given the perfectly elastic supply of liquidity) to buy risk-free government bonds. In addition, because loans are risky and incorporate a premium, $\tilde{i}^L > \tilde{i}^B$; the bank always prefers to lend instead of holding bonds.[33] The bank therefore has no reason to hold government bonds in the steady state. This result justifies why, in specifying the bank's balance sheet in (27), we excluded bond holdings at the outset. Note also with no reserve requirement ($\mu = 0$), the deposit rate is equal to the refinance rate, and thus $\tilde{i}^B = \tilde{i}^D$.

Excluding mc_t (which can be written in terms of r_t^K and ω_t) the model consists of 15 endogenous variables and 15 equations. To analyze how the economy responds to monetary shocks we solve it by log-linearization around a nonstochastic, zero-inflation steady state. The log-linearized equations are summarized in Appendix B. In particular, log-linearizing condition (24)

[33] In the model, there is no distinction between actual and expected loan rates; and given that there is no default in equilibrium, the two rates are equal. If we were to account explicitly for the probability of default on loans ($q \in (0, 1)$, say), an arbitrage equation of the type $\tilde{q}\tilde{i}^L + (1 - \tilde{q})\tilde{z} = \tilde{i}^B$, where $\tilde{z}$ is the steady-state value of the rate of return on loans in case of default (related to the value of collateral that can be seized), would hold.

yields the familiar form of the New Keynesian Phillips curve (see for instance Galí (2008)):

$$\pi_t = (\frac{\theta - 1}{\phi_F})\widehat{mc}_t + \beta E_t \pi_{t+1}, \tag{48}$$

where $\widehat{mc}_t$ is the log-deviation of mc_t from its steady-state level. Now, however, deviations in the real marginal cost are given by

$$\widehat{mc}_t = (1-\alpha)(\hat{\imath}_t^L + \hat{\omega}_t) + (\frac{\alpha + \alpha\beta\delta}{1 + \beta\delta - \beta})\hat{r}_t^K, \tag{49}$$

where $\hat{\imath}_t^L$ and $\hat{r}_t^K$ denote percentage point deviations of the lending rate and the rental rate of capital from their steady-state levels, and $\hat{\omega}_t$ the log-deviation of the real wage.

Thus, because the marginal cost depends on the lending rate in addition to factor prices, persistence in borrowing costs (through collateral effects on the premium or cyclical factors) may translate into persistence in both inflation and output.[34] However, whether the presence of the cost channel translates into greater inertia associated with policy shocks (changes in the refinance rate) depends on the degree of pass-through to bank rates.

5 Calibration

We calibrate our model as much as possible for a "typical" middle-income country, using a benchmark set of parameters summarized in Table 1.[35] We will also consider in this section alternative values for one of the key parameters characterizing the credit market (the elasticity of the risk premium with respect to collateral) and will report more extensive sensitivity analysis in the next section. Time frequency is annual.

Consider first the parameters characterizing household behavior. The discount factor β is set at 0.95, which corresponds to an annual real interest rate of 5 percent. This value is substantially higher than the average used in

[34] As a result, we abstract entirely from persistence stemming from bckward-looking indexation, that is, the possibility that firms that cannot adjust their prices optimally do so mechanically with respect to lagged inflation, as for instance in Christiano, Eichenbaum, and Evans (2005).

[35] See Tovar (2008) for a discussion of the difficulties posed by the econometric estimation of New Keynesian models in developing countries. When parameters are not available for middle-income countries, we use conventional estimates for industrial countries.

the literature on industrial countries, but it reflects the fact that real interest rates tend indeed be higher in developing countries. The intertemporal elasticity of substitution, σ, is taken to be 0.6, consistent with the average value estimated by Ogaki, Ostry, and Reinhart (1996) for upper middle-income countries. The value used for the preference parameter for leisure, η_N, is set at 1.5, the same value as in Atta-Mensah and Dib (2008), among others. We set η_x, the preference parameter for composite monetary assets, also at 1.5. The share parameter in the index of money holdings, ν, which corresponds to the relative share of cash in narrow money, is set at 0.2. Both η_x and ν are based on recent estimates of M2-GDP and cash-deposit ratios for Turkey. There is little information on appropriate values of the adjustment cost parameter for investment, Θ, for middle-income countries; as in Atta-Mensah and Dib (2008), we set it at 8.6.

Second, consider the production side. The share of capital in output of intermediate goods, $1-\alpha$, is set at 0.35, a value consistent with a number of empirical estimates for developing countries, such as Cole and Neumayer (2006, p. 925). The elasticity of demand for intermediate goods, θ, is set at 10, which gives a steady-state value markup rate $\theta/(\theta-1)$ equal to 11.1 percent. For the adjustment cost parameter for prices, ϕ_F, we use a value of 74.5, which is the average of the values used by Ireland (2001).[36] For the capital depreciation rate, we use an estimate of 6.0 percent, which is consistent with those reported by Bu (2006) for middle-income countries. The share of government spending in output, ψ, is set at 20 percent.

Third, consider the parameters characterizing bank behavior. We assume that the effective collateral-loan ratio, κ, is 0.2—a relatively low value, in line with the practice observed in many developing countries of demanding a face value of collateral that exceeds by an order of magnitude the value of the loan itself (see World Bank (2005, Chapter 5)). The elasticity of the risk premium with respect to collateral, ϕ_1, is set at 0.05. Given that there is not much guidance from the literature, this is a sensible approach. The elasticity of the risk premium with respect to cyclical output is set in the base case at $\phi_2 = 0.9$; we also consider later alternative values of 0.5 and 1.3. The speed of adjustment for deposit and lending rates, ζ_D and ζ_L, are both set at unity in the benchmark case; alternative values are considered subsequently.

[36] As showed by Keen and Wang (2007), this corresponds to an average of 13.5 months (or 4.5 quarters) between reoptimization under Calvo pricing—a value well consistent with the evidence.

Finally, consider the parameters characterizing central bank policy and behavior. We assume that the reserve requirement rate μ is relatively low, at 10 percent. We abstract from *direct* interest rate smoothing and therefore set $\chi = 0$. The response of the refinance rate to inflation deviations from target and to output growth are set at conventional values for Taylor-type rules in middle-income countries, $\varepsilon_1 = 1.5$ and $\varepsilon_2 = 0.2$.[37] The random shock to the policy rate follows a first-order autoregressive process with a degree of persistence $\rho_\epsilon = 0.4$ and a standard deviation $\sigma_\epsilon = 0.01$.[38]

6 Benchmark Experiment

Our benchmark experiment is to consider the behavior of the model following a temporary, one percentage point increase in the refinance rate, using the base parameter values reported earlier; these entail, in particular, instantaneous adjustment in deposit and lending rates, in response to changes in the policy rate. Figure 1 shows the impulse response functions of some of the main variables.

The first effect of this shock is a proportional increase in the deposit rate. In turn, the increase in the deposit rate brings about higher demand for bank deposits. The reduction in the demand for cash (given the increase in its opportunity cost) is not sufficient to fully offset the effect of the increase in the demand for deposits. Because the central bank's bond holdings, which determine total monetary assets (defined as cash plus deposits) held by households, are fixed in nominal terms, equilibrium in asset markets requires either an increase in the real value of the central bank's holdings of bonds or a reduction in the demand for monetary assets. Adjustment in the demand for monetary assets is brought about through changes in two variables, namely, the interest rate on government bonds (which clears the currency market) and the price of the final good (which operates only indirectly). Increases in the bond rate induce a portfolio shift away from monetary assets toward bonds, whereas a decrease in the price level raises the real value of household holdings of monetary assets.

[37] See, for instance, Moura and Carvalho (2009). By comparison, Liu (2006) estimated values of $\chi = 0.7$, $\phi_1 = 1.4$, and $\phi_2 = 0.4$ for New Zealand.

[38] As illustrated by Rudebusch (2006), a nonzero autoregresive coefficient for the interest rate shock is a substitute for persistence stemming directly from the central bank's policy response.

Higher returns on financial assets curb consumption (through intertemporal substitution) and the demand for physical capital. Thus, aggregate demand decline. The drop in consumption induces households to supply more labor, which puts downward pressure on real wages. However, this does not necessarily translate into a fall in the *effective* cost of labor. The reason is that the actual cost of labor for firms (or total wage payments) depends not only on real wages (and thus indirectly on the labor supply decisions of households) but also on the bank lending rate, which increases as a result of a higher bond rate.

In fact, the lending rate rises by more than the bond rate. This is because the risk premium, which depends on the output gap and the collateral-to-debt ratio, increases as well. Although the collateral-to-debt ratio rises as a result of a fall in working capital needs, thereby putting downward pressure on the premium, the contraction in output tends to raise it. Given our calibration, the latter effect dominates and the risk premium therefore increases. Consequently, the effective cost of labor decreases by less than the decrease in the real wage.

Given the parameter configuration chosen, the figure shows that the behavior of the effective cost of labor, through which we expect financial frictions to affect the supply side of the economy, does not differ drastically from the behavior of the real wage. This is because the change in the lending rate is about 0.4 percentage points, whereas the change in the real wage is more than 1 percentage point. As can be also inferred from the figures, there is substantial inertia in the behavior of output and inflation; it takes five periods (years) for the effect of the shock to dissipate. Bank rates take even more time to return to their baseline values. Gradual adjustment is due not only to persistence in the policy rate but also, and most importantly, to the fact that the risk premium displays inertia (as a result of collateral and cyclical effects) and that interactions between the real and financial sectors are modeled in a more detailed manner, by considering explicitly the determination and dynamics of the bond rate.

7 Sensitivity Analysis

To assess the robustness of the previous results, we consider the response of the economy to the same shock but under alternative scenarios. We begin by examining different elasticities of the risk premium with respect to the

collateral ratio and to cyclical output. We next consider the case where the pass-through of policy rates into bank rates is gradual, instead of instantaneous, and examine the extent to which smoothing of retail interest rates affects the degree of persistence of macroeconomic variables. Finally, we modify the model to study the case where household utility is not separable across consumption and monetary assets—a modification that in principle imparts a greater role to monetary aggregates in the monetary transmission mechanism.

7.1 Risk Premium Elasticities

In the first experiment, we assume that the risk premium is constant, so that $\phi_1 = \phi_2 = 0$ in the log-linearized system. The purpose of this scenario is to examine to what extent credit market frictions (for a given degree of price rigidity and gradual capital accumulation) affect the degree of persistence of macroeconomic variables in response to policy shocks.

The results of this alternative scenario are shown in Figure 2, together with those pertaining to the benchmark case. They show indeed that the endogeneity of the risk premium in the benchmark case imparts a greater degree of inertia to all variables in response to the monetary shock—including, in particular, output and inflation. These results are consistent with those obtained in several of the studies cited in the introduction (including, in particular, Faia and Monacelli (2007) and Christiano, Motto, and Rostagno (2008)), where credit market imperfections are modeled in very different ways.

In the second experiment, the elasticity of the risk premium with respect to output deviations, ϕ_2, is lowered to 0.5 and raised to a relatively high value of 1.3, from the benchmark value of 0.9. The results of these alternative simulations, together with those of the benchmark scenario, are shown in Figure 3. Deposit and bond rates in this alternative scenario do not depart much from their benchmark values, but the lending rate is now significantly lower (with $\phi_2 = 0.5$) or higher (with $\phi_2 = 1.3$). Indeed, in the latter case, a higher elasticity of the premium with respect to output deviations leads to a larger increase in the lending rate, following the hike in the official rate and the resulting contraction in output. As a result, the effective marginal cost of labor, total marginal costs and inflation are all higher along the convergence path, whereas output is lower—although not significantly so. Thus, a higher sensitivity of the risk premium to changes in output strengthens the

accelerator effect associated with financial frictions. In fact, with $\phi_2 = 1.3$, the effective marginal cost of labor *increases* immediately—indicating that the "cost push" effect of the higher lending rate dominates the downward movement in wages. The existence of the cost channel leads not only to an adverse effect of the lending rate on aggregate supply through its impact on the effective marginal cost of labor, but also to a *rise* in inflation. A monetary contraction leads therefore to a perverse response in prices, as predicted by simpler New Keynesian models that emphasize the role of the cost channel in the monetary transmission mechanism (see Chowdhury, Hoffmann, and Schabert (2006), Ravenna and Walsh (2006), Tillmann (2008), and Kaufmann and Scharler (2009)).

It is also worth noting what happens to the differential between the deposit and bond rates in the two scenarios. The stronger the accelerator effect associated with the risk premium, the weaker is the effect of the policy rate on inflation. Given the endogeneity of the official interest rate, the magnitude of the response of the policy rate to its own shock depends negatively on the magnitude of the effect of the shock on inflation. Hence, the response of the policy rate is stronger when the elasticity of the risk premium to output is higher. This helps also to explain why the increase in the lending rate is relatively large, with $\phi_2 = 1.3$, compared to the benchmark case.

7.2 Gradual Interest Rate Pass-through

In the foregoing analysis, interest rate pass-through was assumed to be instantaneous and complete, so that $\zeta_D = \zeta_L = 1$. We now consider the case where the pass-through of policy rates to deposit and lending rates occurs gradually. In the first scenario, we assume that the lending rate adjusts to its desired level instantaneously, whereas the deposit rate adjusts gradually. In the second scenario, the lending rate adjusts gradually while the deposit rate adjusts to its desired level instantaneously. Results in both cases are shown in Figure 4, together with those corresponding to the benchmark case.

7.2.1 Sluggish Deposit Rates

Consider first the case where there is a gradual pass-through only in the deposit rate, so that $\zeta_D = 0.3$ and $\zeta_L = 1$. This is consistent with the evidence provided by Berstein and Fuentes (2005) for Chile and Ozdemir

(2009) for Turkey. Ozdemir, in particular, found that deposit rates are less flexible than lending rates in the short run.

In the model, the policy rate affects the bond rate (and, by implication, the lending rate) through its impact on the deposit rate. A slower response of the deposit rate to changes in the refinance rate mitigates the shift away from cash by households, and dampens the reduction in the demand for currency, compared to the benchmark case; it implies therefore a smaller increase in the bond rate to restore equilibrium in the currency market. Gradual adjustment in the deposit rate translates into gradual adjustment in the bond rate. Consequently, the lending rate is now also lower than in the benchmark case. The lower cost of borrowing, in turn, implies that the effective cost of labor goes up by less, implying lower marginal production costs than in the benchmark case. Inflation is therefore lower compared with the benchmark experiment.

Regarding output, however, the alternative scenario does not exhibit a consistently higher level compared with the benchmark scenario, given that marginal costs are systematically lower; in fact, after the second period, the level of output in the alternative scenario is lower than in the benchmark case. In the benchmark experiment, a higher bond rate induces households to substitute future consumption for present consumption and raises labor supply, which in turn decreases the marginal cost of labor by inducing a fall in real wages. Because the initial increase in the bond rate is much less significant in the alternative scenario, intertemporal substitution effects are less significant; as a result, the fall in real wages is mitigated. This explains why, as shown in Figure 4, effective marginal costs and output under the alternative scenario fall by less than under the benchmark case. In subsequent periods, the situation is reversed because gradual pass-through of policy rates to deposit rates imparts a more protracted behavior to all variables in the adjustment process. Thus, despite a stronger initial fall, consumption and output converge faster in the benchmark case.

7.2.2 Sluggish Lending Rates

Consider now the opposite case where there is limited pass-through of the lending rate, so that $\zeta_D = 1$ and $\zeta_L = 0.3$. This is consistent with the evidence reviewed by Wong (2008), which suggests that the pass-through to deposit rates in some developing countries appears to be more rapid than the pass-through to lending rates.

As illustrated in Figure 4, the lending rate displays a smoother path under this scenario, whereas the deposit and bond rates do not diverge significantly from their benchmark paths. In the first two periods following the shock, the lending rate is lower compared to the benchmark case; but due to rapid convergence of the lending rate in the benchmark scenario, this situation is reversed in subsequent periods. For the periods during which the lending rate remains below its benchmark values, inflation is also slightly lower and output higher in the alternative scenario, as a result of the existence of cost channel. But in general, the slow adjustment of the lending rate does not lead to results that differ significantly from the benchmark scenario. This is due to the fact that, given our calibration (namely, the sensitivity of the premium with respect to its various determinants), changes in the effective marginal cost of labor are mainly driven by changes in real wages.

While the deposit and bond rates are higher in the benchmark case in the first period, the reverse occurs after the second period. This arises from the pattern of the lending rate in the two scenarios. In the first two periods, the lending rate is lower in the alternative scenario, which pushes inflation down as a result of the cost channel. Owing to the Taylor-type rule, the policy rate is also lower in those periods. After the second period, the lending rate in the alternative scenario remains above its benchmark value, implying that inflation is higher again in the latter case, due to the cost push effect. Hence, from the second period on, the refinance rate becomes higher in the alternative scenario. The behavior of the deposit and bond rates mimics the path of the policy rate.

To summarize, as firms use external funds solely for the purpose of financing their working capital needs, the lending rate only affects the supply side. At the same time, given our parameter configuration, movements in the effective cost of labor is to a large extent driven by developments in real wages. Gradual adjustment in the lending rate further mitigates the role of that variable on effective labor costs—and therefore on output. At the same time, changes in the bond rate affect directly and significantly the demand side. Gradual adjustment in that rate to changes in the refinance rate affects aggregate demand. Although slow adjustment in either rate imparts greater inertia to the lending rate, only sluggish adjustment in the deposit rate leads to greater persistence in inflation and output. Our results therefore differ substantially from some of the existing New Keynesian studies introducing limited pass-through effects in loan rates, such as those of Hulsewig, Mayer, and Wollmershauser (2009) and Gerali et al. (2009). In particular, the

"attenuator effect" emphasized by Gerali et al. (2009) operates only under specific circumstances.

7.3 Nonseparable Household Utility

The specification of the instantaneous utility function in (2) assumed separability between consumption and monetary assets. Although there seems to be some empirical evidence to support this specification, there has been much debate in recent years about the implications of nonseparability for the conduct of monetary policy (see Christiano, Motto, and Rostagno (2007) and Woodford (2008)). In addition, for middle-income countries, where the menu of financial assets is more limited than in industrial countries, there is good intuitive reason to believe that the separability assumption may not be appropriate.[39] In our model, as discussed earlier, close interactions between the real and financial sectors occur even under separability; nevertheless, as a final sensitivity test, we examine the behavior of the model under nonseparability between private spending and monetary aggregates in utility.[40]

Suppose that the instantaneous utility function takes now the nonseparable form

$$U(\cdot) = \frac{\{\Lambda C_{ht}^{-\tau} + (1-\Lambda)[(m_{ht}^{H})^{\nu} d_{ht}^{1-\nu}]^{-\tau}\}^{-(1-\sigma^{-1})/\tau}}{1-\sigma^{-1}} + \eta_N \ln(1-N_{ht}), \quad (50)$$

where $\Lambda \in (0,1)$, $-1 \leq \tau \leq \infty$, and $\sigma_{CS} = 1/(1+\tau)$ is the intratemporal elasticity of substitution between consumption and the composite monetary aggregate.[41] As in Ireland (2004), the nonseparability assumption implies that real monetary assets may affect aggregate demand directly, thereby opening up another channel through which money can impact on inflation and output persistence. Unlike Ireland (2004), however, real balances do not enter in the New Keynesian Phillips curve (48), given the use here of Rotemberg pricing.

[39] Jones and Stracca (2006, 2008) found some empirical support for the assumption of additive separability between consumption real money balances for the Euro area over the period 1991-2005 and for the United Kingdom over the period 1999-2007. However, as far as we know there is no comparable evidence for middle-income developing countries.

[40] The same issue arises in a "shopping cost" model with respect to the transactions technology; see for instance McCallum (2001).

[41] Money and consumption are therefore gross complements as in most of the literature. Atta-Mensah and Dib (2008) and Christensen and Dib (2008) use a similar specification with $\sigma = 1$, whereas Christiano, Motto, and Rostagno (2008) assume $\sigma_{CS} = 1$.

The first-order conditions with respect to N_{ht} and K_{ht+1}, (9) and (12), remain the same, whereas those with respect to C_t, m_{ht}^H and d_{ht} are presented in Appendix A. The absence of additive separability between consumption and real monetary balances implies that the latter enter in the Euler equation. Thus, the marginal rate of substitution between current and future consumption now depends on current and future holdings of monetary assets. The new steady-state solutions are given in Appendix B and the new log-linearized equations in Appendix C.

We simulate the model again with these new equations, setting $\Lambda = 0.9$, keeping $\sigma = 0.6$, and using two values for the intratemporal substitution of elasticity for consumption and holdings of monetary assets: $\sigma_{CS} = 0.06$ and $\sigma_{CS} = 0.9$. The first corresponds to the value estimated by Christensen and Dib (2008, p. 164), whereas the second is the value imposed by Christiano, Motto, and Rostagno (2008). Lower values for σ_{CS} imply a smaller degree of intratemporal substitutability between consumption and monetary assets.

The results associated with a one percentage point increase in the refinance rate are illustrated in Figures 5 and 6. Before describing the results, it is worth recalling that in the model nominal holdings of monetary assets (cash plus deposits) of households are fixed, as long as the Central bank's holdings of government bonds are fixed (see (44)). Thus, changes in households' holdings of monetary assets in real terms stem only from price level movements.

The results of the two simulations differ not only in quantitative terms but in qualitative terms as well. A shock to the refinance rate is mechanically and directly transmitted to the deposit rate, hence, for this variable the effects are almost the same.[42] However, the bond rate evolves in opposite directions. The path of output generated with the higher σ_{CS} value yields results that are qualitatively similar to those obtained with the additively separable utility case: the bond rate increases, consumption and output fall, and inflation abates. However, results obtained with lower σ_{CS} are at odds with the conventional story. The bond rate and inflation fall, despite the increase in consumption and output. As discussed previously, the negative correlation between inflation and output can be explained by the cost channel effect. Because the lending rate and the bond rate are closely related, the fall in the cost of external funds reduces the marginal cost of labor despite

[42] Slight differences stem from feedback effects to the policy rate, resulting from the Taylor-type rule.

the increase in output.[43] The difficult question here is what explains the negative correlation observed between the deposit rate and the bond rate.

A possible explanation for this unusual result is as follows. Higher deposit rates induce households to hold more monetary assets (given that the increase in deposits exceeds the drop in cash holdings), but this also stimulates spending by increasing the marginal utility of consumption. A lower value of σ_{CS} implies a lower degree of substitutability between consumption and monetary assets, hence the effect of real balances on the marginal utility of consumption is stronger as τ [or σ_{CS}?] increases. At the same time, an increase in both consumption and demand for monetary assets tends to reduce the demand for bonds, implying that the bond rate goes up. In turn, this would tend to reduce consumption and money demand. However, under this scenario prices would be increasing, which would lead to a contraction in real monetary balances and further reduce the demand for bonds. Equilibrium is satisfied at a point where the bond rate is lower than its steady-state value. The lending rate follows the bond rate, and falls as well. Thus, although consumption is higher, lower prices increase households' real monetary balances—thereby restoring equilibrium in the bond market, despite the lower bond rate.[44]

8 Summary and Extensions

The purpose of this paper was to analyzes the transmission process of monetary policy in a closed-economy, New Keynesian model with credit market imperfections and a cost channel. In the model, which dwells on Agénor and Montiel (2006, 2007, 2008*a*), the instrument of monetary policy is the administered rate at which the central bank provides liquidity to commercial banks. Monetary policy therefore operates exclusively through the banking system, which then intermediates directly monetary impulses to the real

[43] In the absence of the cost channel, the increase in output should raise the marginal cost of labor because households would supply more labor only if real wages go up, to compensate for the marginal disutility of working.

[44] We have also performed some simulations with values of σ_{CS} lying in between the values we have reported above. A general observation was that the policy rate is quite a bit less effective on inflation when money and consumption are additively non-separable in the utility function. This is mainly because the fact that a lower price level resulting from the higher policy rate increases households' real cash balances, which in turn increase the marginal utility of consumption and thus stimulate (all else equal) private spending.

economy, as a result of a link between short-term working capital needs and bank loans. Banks set deposit rates on the basis of the central bank policy rate, adjusted for the required reserve ratio. In addition, and in an important departure from the existing literature, we explicitly accounted for the fact that the central bank's supply of liquidity to banks is perfectly elastic at the prevailing policy rate. As a result, changes in bank borrowing affect the supply of currency, which (together with the demand for cash) determines the equilibrium bond rate. Because the lending rate is set as a markup over the risk-free bond rate (which represents the opportunity cost of lending), changes in the refinance rate exert both direct and indirect effects on the structure of bank rates. The markup is a risk premium that depends both on net worth and the cyclical position of the economy. The latter effect was introduced to capture the well-documented fact that asset quality tends to deteriorate, and default risk to increase, during periods of weak economic activity. Finally, we also assumed that adjustment of actual bank rates to their desired levels occur gradually. By considering a broad spectrum of interest rates and how they are formed, our setting offers a more comprehensive description of the monetary transmission mechanism.

The model was calibrated (for the most part, given data limitations) for a middle-income country. Our numerical experiments showed that credit market frictions, combined with price rigidity and gradual capital accumulation, may generate a high degree of persistence in the response of output and inflation to monetary shocks. Moreover, financial frictions were shown to substantially amplify the effects of monetary shocks, and also to reinforce the stabilizing or destabilizing effects of interest rate rules on both output and inflation. Sensitivity analysis showed that credit market frictions do generate more persistence in output and inflation in response to monetary policy shocks. This is consistent with the evidence reported in other studies where credit market imperfections are modeled in different ways. With flexible wages, a relatively high elasticity of the risk premium with respect to cyclical output is required for a monetary contraction to lead to higher inflation. In addition, we found that although slow adjustment in either rate imparts greater inertia to the lending rate, only sluggish adjustment in the deposit rate leads to greater persistence in inflation and output.

Finally, we also examined the case where the household's utility function is nonseparable in consumption and real holdings of monetary assets—a matter of much debate in the current literature on monetary policy (see Christiano, Motto, and Rostagno (2007) and Woodford (2008)). We found

that the results are quite sensitive to parameter values for the intratemporal elasticity of substitution between consumption and money.

Our model can be extended in several directions. First, the analysis could be extended by assuming, as in Goodfriend and McCallum (2007) and Canzoneri et al. (2008), that banking activity is costly. This would introduce an additional (possibly endogenous) markup in the formation of the deposit and lending rates. Second, it could be assumed that banks have a target level of reserves (or base money), set as a fixed fraction of deposits. This "precautionary" demand for reserves (above and beyond required reserves) could be motivated by the desire to meet the flow of (stochastic) claims on their deposit liabilities. If, in addition, we assume that banks borrow from the central bank only to satisfy that target, holdings of government bonds could then be introduced as the residual variable in banks' balance sheet. However, if central bank liquidity remains the adjustment variable, our analysis would not be much affected, as long as the precautionary demand for reserves remains stable.

Third, we could introduce asymmetric information problems associated with investment, along the lines of Bernanke et al. (1999). This could be done most transparently by adding capital producers, as in Christensen and Dib (2008) and Christiano, Motto, and Rostagno (2008), among others. This would allow us also to introduce a term structure of interest rates, by distinguishing short-term interest rates (on working capital needs) and long-term interest rates (on investment), both incorporating a risk premium with possibly different determinants. Fourth, the model could be extended to include Non-Ricardian consumers, as for instance in Coenen and Straub (2005).

Finally, a housing sector could be introduced, and the role of land as collateral examined, as for instance in Gerali et al. (2009). Goodhart and Hoffman (2008) found that house prices have had a significant impact on credit in industrialized countries, particularly since the mid-1980s; there is some evidence that this is also the case for developing countries, although data are harder to come by. This link between house prices and credit may arise via the impact of housing wealth on credit demand and collateral effects on credit supply. Indeed, in addition to their conventional wealth effect, house prices exert a collateral effect stemming from the fact that houses are commonly used as collateral for loans because they are immobile and cannot therefore be easily put out of a creditor's reach. As a consequence, higher house prices may not only induce homeowners to spend and borrow more, but they may also enable them to do so by enhancing their borrowing

capacity. The increase in the value of collateralizable property and land may also affect the ability of firms (particularly smaller ones, for which housing is often the main pledgeable asset) to borrow and invest. There is indeed some evidence suggesting that a large value of bank loans to small firms in developing countries are secured by real estate.

At the same time, however, an increase in house prices may have a negative income effect on tenants who have to pay higher rents, and on prospective first-time buyers who now have to save more to buy a home. If spending and saving behavior are the same across these different groups; the net income effect at the aggregate level may be negligible. Otherwise, higher house prices may prove to be contractionary.

Appendix A
Solutions to Optimization Problems

This Appendix presents solutions to the optimization problems of household, the final good firm, and intermediate good-producing firms.

To solve the household's maximization problem, first, divide both sides of the flow budget constraint (5) by P_t and multiply and divide $t-1$ dated nominal variables by P_{t-1}; we can then express the constraint in real terms:

$$P_t(r_t^K K_{ht} + \omega_t N_{ht} - T_{ht}) + (\frac{P_{t-1}}{P_t})m_{ht-1}^H + (1+i_{t-1}^D)(\frac{P_{t-1}}{P_t})d_{ht-1} \qquad \text{(A1)}$$

$$+(1+i_{t-1}^B)(\frac{P_{t-1}}{P_t})b_{ht-1}^H + \frac{J_{ht}^I}{P_t} + \varphi_h\frac{J_{ht}^B}{P_t} - C_{ht} - I_{ht} - (m_{ht}^H + d_{ht} + b_{ht}^H) = 0.$$

Next, using (6) and (7), write investment as

$$I_{ht} = K_{ht+1} - (1-\delta)K_{ht} + \frac{\Theta}{2}(\frac{K_{ht+1}}{K_{ht}} - 1)^2 K_{ht}. \qquad \text{(A2)}$$

Substituting (3) in the utility function (2), and (A2) in (A1), the Lagrangian can be written as

$$\mathbf{L}^H = E_t\sum_{s=0}^{\infty}\beta^s\left\{\frac{[C_{ht+s}]^{1-\sigma^{-1}}}{1-\sigma^{-1}} + \eta_N\ln(1-N_{ht+s}) + \eta_x\ln[(m_{ht+s}^H)^\nu d_{ht+s}^{1-\nu}]\right. \qquad \text{(A3)}$$

$$+\lambda_{t+s}\left[[r_{t+s}^K K_{ht+s} + \omega_{t+s}N_{ht+s} - T_{ht+s} + \frac{m_{ht+s-1}P_{t+s-1}}{P_{t+s}}\right.$$

$$+(1+i_{t+s-1}^D)\frac{d_{ht+s-1}P_{t+s-1}}{P_{t+s}} + (1+i_{t+s-1}^B)\frac{b_{ht+s-1}P_{t+s-1}}{P_{t+s}} + \frac{J_{ht+s}^I}{P_{t+s}} + \varphi_h\frac{J_{ht+s}^B}{P_{t+s}} - C_{ht+s}$$

$$-(m_{ht+s}^H + d_{ht+s} + b_{ht+s}^H)$$

$$\left.\left. - \left(K_{ht+s+1} - (1-\delta)K_{ht+s} + \frac{\Theta}{2}(\frac{K_{ht+s+1}}{K_{ht+s}} - 1)^2 K_{ht+s}\right)\right]\right\}.$$

Each household maximizes lifetime utility with respect to C_{ht}, N_{ht}, b_{ht}^H, m_{ht}^H, d_{ht} and K_{ht+1}, taking as given i_t^D, i_t^B, P_t, and T_{ht}. Using the definition $\pi_{t+1} = (P_{t+1} - P_t)/P_t$ for the inflation rate, so that $P_{t+1}/P_t = 1 + \pi_{t+1}$, maximizing (A3) yields the following first-order conditions:

$${C_{ht}}^{-1/\sigma} - \lambda_t = 0, \qquad \text{(A4)}$$

$$\frac{\eta_N}{1-N_{ht}} - \lambda_t \omega_t = 0, \tag{A5}$$

$$-\lambda_t + \beta E_t \left\{ \lambda_{t+1} (\frac{1+i_t^B}{1+\pi_{t+1}}) \right\} = 0, \tag{A6}$$

$$\frac{\eta_x \nu}{m_{ht}^H} - \lambda_t + \beta E_t (\frac{\lambda_{t+1}}{1+\pi_{t+1}}) = 0, \tag{A7}$$

$$\frac{\eta_x (1-\nu)}{d_{ht}} - \lambda_t + \beta E_t \left\{ \lambda_{t+1} (\frac{1+i_t^D}{1+\pi_{t+1}}) \right\} = 0, \tag{A8}$$

$$-\lambda_t [1 + \Theta(\frac{K_{ht+1}}{K_{ht}} - 1)] + \beta E_t \left\{ \lambda_{t+1} \left[r_{t+1}^K + 1 - \delta - Q(\frac{K_{ht+2}}{K_{ht+1}}) \right] \right\} = 0, \tag{A9}$$

where

$$Q(\cdot) = [\frac{\Theta}{2}(\frac{K_{ht+2}}{K_{ht+1}} - 1)^2 K_{ht+1}]' = \frac{\Theta}{2} \left\{ (\frac{K_{ht+2}}{K_{ht+1}} - 1)^2 - 2(\frac{K_{ht+2}}{K_{ht+1}} - 1) \frac{K_{ht+2}}{K_{ht+1}} \right\},$$

together with the transversality conditions

$$\lim_{s \to \infty} E_{t+s} \beta^s \lambda_{t+s} (\frac{z_{ht+s}}{P_{t+s}}) = 0, \quad \text{for } z = m^H, K. \tag{A10}$$

The first-order conditions for bonds and cash are fairly standard. The condition for deposit demand, d_{ht}, looks similar to the condition for cash demand as deposits also yield utility, the only difference being that deposits have a nominal return. The first-order condition for capital goods differs from the familiar condition only due to the capital adjustment costs. Here, returns to capital include capital adjustment costs as well.[45]

By using (A6), condition (A4) can be written as

$$E_t [\frac{(C_{ht+1})^{1/\sigma}}{C_{ht}^{1/\sigma}}] = \beta E_t (\frac{1+i_t^B}{1+\pi_{t+1}}), \tag{A11}$$

[45] Specifically, in (A9) the return to capital also includes the term $\Theta(K_{ht+2}^2 - K_{ht+1}^2)/2K_{ht+1}^2$, which is due to capital adjustment costs. The intuition behind adding this term to the return to capital is as follows: if the optimal level of capital at time $t+2$ is higher than the desired level at time $t+1$, that is $K_{ht+2}^* > K_{ht+1}$, then inceasing the capital stock has the benefit of decreasing adjustment costs, as this cost is quadratic in K_t.

which is the usual Euler equation. Substituting (A4) in (A5) yields $1/(1 - N_{ht}) = \eta_N^{-1}\omega_t(C_{ht})^{-1/\sigma}$, so that the supply of labor can be expressed as

$$N_{ht} = 1 - \frac{\eta_N(C_{ht})^{1/\sigma}}{\omega_t}. \tag{A12}$$

Condition (A6) can be rewritten as

$$\beta E_t(\frac{\lambda_{t+1}}{1+\pi_{t+1}}) = \frac{\lambda_t}{1+i_t^B}. \tag{A13}$$

Substituting this expression in (A7) yields

$$\frac{\eta_x\nu}{m_{ht}^H} = \lambda_t(1 - \frac{1}{1+i_t^B}) = \lambda_t(\frac{i_t^B}{1+i_t^B}),$$

which, using (A4), can be rearranged to show that the demand for real cash balances is a function of current consumption and the bond rate:

$$m_{ht}^H = \frac{\eta_x\nu(C_{ht})^{1/\sigma}(1+i_t^B)}{i_t^B}. \tag{A14}$$

Similarly, substituting (A13) in (A8), yields

$$\frac{\eta_x(1-\nu)}{d_{ht}} = \lambda_t[1 - (\frac{1+i_t^D}{1+i_t^B})] = \lambda_t(\frac{i_t^B - i_t^D}{1+i_t^B}),$$

which can be rearranged, using (A4), to yield the demand for bank deposits:

$$d_{ht} = \frac{\eta_x(1-\nu)(C_{ht})^{1/\sigma}(1+i_t^B)}{i_t^B - i_t^D}. \tag{A15}$$

Equation (A9) can be rearranged as follows. From the definition of $Q(K_{ht+2}/K_{ht+1})$ given above,

$$Q(\frac{K_{ht+2}}{K_{ht+1}}) = \frac{\Theta}{2}(\frac{K_{ht+2}}{K_{ht+1}} - 1)\left\{\frac{K_{ht+2}}{K_{ht+1}} - 1 - 2\frac{K_{ht+2}}{K_{ht+1}}\right\},$$

or equivalently

$$Q(\frac{K_{ht+2}}{K_{ht+1}}) = -\frac{\Theta}{2}(\frac{K_{ht+2}}{K_{ht+1}} - 1)(\frac{K_{ht+2}}{K_{ht+1}} + 1).$$

Factorizing the last two terms yields

$$Q(\frac{K_{ht+2}}{K_{ht+1}}) = -\frac{\Theta}{2}(\frac{K_{ht+2}^2}{K_{ht+1}^2} - 1) = -\frac{\Theta}{2}(\frac{K_{ht+2}^2 - K_{ht+1}^2}{K_{ht+1}^2}).$$

Substituting this result in (A9) yields

$$-\lambda_t[1 + \Theta(\frac{K_{ht+1}}{K_{ht}} - 1)] + \beta E_t \left\{ \lambda_{t+1} \left[r_{t+1}^K + 1 - \delta - \frac{\Theta}{2}(\frac{\Delta K_{ht+2}^2}{K_{ht+1}^2}) \right] \right\} = 0, \tag{A16}$$

where $\Delta K_{ht+2}^2 = K_{ht+2}^2 - K_{ht+1}^2$.

Applying the product rule for two independent random variables, equation (A6) can be rewritten as

$$E_t(\frac{1 + i_t^B}{1 + \pi_{t+1}}) = \frac{\lambda_t}{\beta E_t \lambda_{t+1}}. \tag{A17}$$

By using (A16) and (A17), one can express the implied relation between the nominal rate of return on bonds, expected inflation, and the real rate of return on capital, that is, the Fisher relation:

$$E_t(\frac{1 + i_t^B}{1 + \pi_{t+1}}) = E_t \left\{ \left[\Theta(\frac{K_{ht+1}}{K_{ht}} - 1) + 1 \right]^{-1} \left[r_{t+1}^K + 1 - \delta - \frac{\Theta}{2}(\frac{\Delta K_{ht+2}^2}{K_{ht+1}^2}) \right] \right\}. \tag{A18}$$

The left-hand side of this expression is the expected real return on bonds, whereas the left-hand side is the expected marginal return of investing in physical capital.[46] With $\Theta = 0$, this expression takes the simpler form

$$E_t(\frac{1 + i_t^B}{1 + \pi_{t+1}}) = 1 - \delta + E_t r_{t+1}^K.$$

Consider now the final good-producing firm. Solving the profit maximization problem or cost minimization problem of the final good producer provides two important pieces of information; the aggregate price level and the demand for each intermediate good. The profit maximization problem of the final good-producing firm is given by

$$\max_{Y_{jt}} P_t \left\{ \int_0^1 [Y_{jt}]^{(\theta-1)/\theta} dj \right\}^{\theta/(\theta-1)} - \int_0^1 P_{jt} Y_{jt} dj.$$

[46] Due to capital adjustment costs, increasing the capital stock by one unit requires investing more than one unit; that is why we have the first expression in squared brackets (with an exponent of minus unity) on the right-hand side of this expression.

The first-order condition with respect to Y_{jt} yields

$$P_t \left\{ \int_0^1 [Y_{jt}]^{(\theta-1)/\theta} dj \right\}^{1/(\theta-1)} {Y_{jt}}^{-1/\theta} - P_{jt} = 0. \tag{A19}$$

Using the fact that $\left\{ \int_0^1 [Y_{jt}]^{(\theta-1)/\theta} dj \right\}^{1/(\theta-1)} = Y_t^{1/\theta}$, (A19) can be written as

$$Y_{jt} = (\frac{P_{jt}}{P_t})^{-\theta} Y_t, \quad \forall j \in (0,1). \tag{A20}$$

The price of the final good can be obtained by substituting out for Y_{jt} using (A20) in the final good production function, (14):

$$P_t = \left\{ \int_0^1 (P_{jt})^{1-\theta} dj \right\}^{1/(1-\theta)}. \tag{A21}$$

Finally, consider intermediate good-producing firms. As each firm operates with a constant returns to scale technology, total production costs can be obtained by simply multiplying the unit cost with the quantity produced, Y_{jt}. In turn, the unit cost can be found by solving the firm's cost minimization problem.

Assuming that each firm j operates under perfect competition in markets for both inputs, the unit cost minimization problem can be defined as

$$\min_{N_{jt}, K_{jt}} (1 + i_{jt}^L) \omega_t N_{jt} + r_t^K K_{jt}, \tag{A22}$$

subject to (17) with $Y_{jt} = 1$.

The Lagrangian function for this problem can be written as

$$\mathbf{L}^{FC} = (1 + i_{jt}^L) \omega_t N_{jt} + r_t^K K_{jt} + \xi_t (1 - A_t K_{jt}^{\alpha} N_{jt}^{1-\alpha}),$$

where ξ_t is the Lagrange multiplier. The first-order conditions yield

$$\alpha \frac{Y_{jt}}{K_{jt}} \xi_t = r_t^K, \tag{A23}$$

$$(1 - \alpha) \frac{Y_{jt}}{N_{jt}} \xi_t = (1 + i_{jt}^L) \omega_t. \tag{A24}$$

These conditions equate the marginal product of capital and labor to their relative price.

Combining (A23) and (A24) implies that N_{jt} can be written as a function of K_{jt}, ω_t, and r_t^K:

$$N_{jt} = (\frac{1-\alpha}{\alpha})[\frac{r_t^K}{(1+i_{jt}^L)\omega_t}]K_{jt}.$$

Substituting this result in the constraint $1 - A_t K_{jt}^{\alpha} N_{jt}^{1-\alpha} = 0$, K_{jt} (and so N_{jt}) can then be written as a function of r_t^K and ω_t:

$$K_{jt} = A_t^{-1}(\frac{\alpha}{1-\alpha})^{1-\alpha}[\frac{(1+i_{jt}^L)\omega_t}{r_t^K}]^{1-\alpha}.$$

Plugging this term back in the N_{jt} equation above yields therefore

$$N_{jt} = A_t^{-1}(\frac{\alpha}{1-\alpha})^{-\alpha}[\frac{(1+i_{jt}^L)\omega_t}{r_t^K}]^{-\alpha}. \tag{A25}$$

Combining the last two equations yields the capital-labor ratio:

$$\frac{K_{jt}}{N_{jt}} = (\frac{\alpha}{1-\alpha})[\frac{(1+i_{jt}^L)\omega_t}{r_t^K}]. \tag{A26}$$

Although the real wage and rental cost of capital are economy-wide costs, the capital-labor ratio may in principle differ across intermediate goods firms because they face a different marginal cost on bank borrowing.

The unit real marginal cost is[47]

$$mc_{jt} = \frac{(1+i_{jt}^L)\omega_t N_{jt} + r_t^K K_{jt}}{Y_{jt}} = (1+i_{jt}^L)\omega_t(\frac{K_{jt}}{N_{jt}})^{-\alpha} + r_t^K(\frac{K_{jt}}{N_{jt}})^{1-\alpha},$$

that is, using (A26),

$$mc_{jt} = (\frac{\alpha}{1-\alpha})^{-\alpha}[(1+i_{jt}^L)\omega_t]^{1-\alpha}(r_t^K)^{\alpha} + (\frac{\alpha}{1-\alpha})^{1-\alpha}[(1+i_{jt}^L)\omega_t]^{1-\alpha}(r_t^K)^{\alpha},$$

or

$$mc_{jt} = (\frac{\alpha}{1-\alpha})^{-\alpha}[(1+i_{jt}^L)\omega_t]^{1-\alpha}(r_t^K)^{\alpha}(1+\frac{\alpha}{1-\alpha}),$$

which gives the unit real marginal cost as

$$mc_{jt} = \frac{\left[(1+i_{jt}^L)\omega_t\right]^{1-\alpha}(r_t^K)^{\alpha}}{\alpha^{\alpha}(1-\alpha)^{1-\alpha}}. \tag{A27}$$

Multiplying this expression with the quantity produced yields total production costs, $mc_{jt}Y_{jt}$.[48]

[47] Adding (A23) and (A24) yields $[(1-\alpha)+\alpha]\xi_t = \xi_t = [(1+i_{jt}^L)\omega_t N_{jt} + r_t^K K_{jt}]/Y_{jt}$; thus, ξ_t is also equal to the unit real marginal cost

[48] Thus, the marginal cost equals the average cost.

Substituting for PAC_t^j from (19) and using (A27), the profit function (23) can be rewritten as

$$\Pi_{jt}^F = P_{jt}Y_{jt} - P_t mc_{jt}Y_{jt} - \frac{\phi_F}{2}(\frac{P_{jt}}{\tilde{\pi}^G P_{jt-1}} - 1)^2 P_t Y_t. \tag{A28}$$

In contrast to the cost minimization problem, which is static, the profit maximization problem involves solving a dynamic problem due to price adjustment costs. Here, how prices are adjusted affect not only current-period profits but also future profits. Hence, each firm maximizes the intertemporal profit function (22), with respect to the price of the firm's good, P_{jt}:

$$\max_{P_{jt}} E_t \sum_{s=0}^{\infty} \beta^s \lambda_{t+s} (\frac{\Pi_{jt+s}^F}{P_{t+s}}).$$

In solving this problem, there is one constraint arising from the requirement that the supply of intermediate good j, Y_{jt}, must be equal to the demand for that good, as derived in (A20). Substituting out for Y_{jt} in (A28) using (A20), the maximization problem becomes an unconstrained problem:

$$\max_{P_{jt}} E_t \sum_{s=0}^{\infty} \beta^s \lambda_{t+s} \left\{ (\frac{P_{jt+s}}{P_{t+s}})^{1-\theta} Y_{t+s} - mc_{jt+s}(\frac{P_{jt+s}}{P_{t+s}})^{-\theta} Y_{t+s} \right. \tag{A29}$$

$$\left. -\frac{\phi_F}{2}(\frac{P_{jt+s}}{\tilde{\pi}^G P_{jt+s-1}} - 1)^2 Y_{t+s} \right\}.$$

Taking P_{t+s} and Y_{t+s} as given, the first-order condition with respect to P_{jt} yields

$$(1-\theta)\lambda_t(\frac{P_{jt}}{P_t})^{-\theta}(\frac{Y_t}{P_t}) + \theta\lambda_t(\frac{P_{jt}}{P_t})^{-\theta-1}\frac{mc_{jt}Y_t}{P_t} \tag{A30}$$

$$-\lambda_t\phi_F \left\{ (\frac{P_{jt}}{\tilde{\pi}^G P_{jt-1}} - 1)\frac{Y_t}{\tilde{\pi} P_{jt-1}} \right\} + \beta\phi_F E_t \left\{ \lambda_{t+1}(\frac{P_{jt+1}}{\tilde{\pi}^G P_{jt}} - 1)(\frac{P_{jt+1}}{\tilde{\pi}^G P_{jt}^2})Y_{t+1} \right\} = 0.$$

The markup ratio in the absence of price adjustment costs is obtained by setting $\phi_F = 0$ in (A30):

$$P_{jt} = \frac{\theta}{\theta - 1} mc_{jt} P_t. \tag{A31}$$

In the symmetric equilibrium, where $P_{jt} = P_t$ and $K_{jt} = K_t$ for all j, equation (A30) becomes

$$(1-\theta)\lambda_t(\frac{Y_t}{P_t}) + \theta\lambda_t\frac{mc_tY_t}{P_t} - \lambda_t\phi_F\left\{(\frac{1+\pi_t}{1+\tilde{\pi}}-1)\frac{1+\pi_t}{1+\tilde{\pi}}(\frac{Y_t}{P_t})\right\}$$

$$+\beta\phi_F E_t\left\{\lambda_{t+1}(\frac{1+\pi_{t+1}}{1+\tilde{\pi}}-1)(\frac{1+\pi_{t+1}}{1+\tilde{\pi}})(\frac{Y_t}{P_t})(\frac{Y_{t+1}}{Y_t})\right\} = 0,$$

or equivalently

$$(1-\theta) + \theta mc_t - \phi_F(\frac{1+\pi_t}{1+\tilde{\pi}}-1)(\frac{\pi_t}{\tilde{\pi}}) \tag{A32}$$

$$+\beta\phi_F E_t\left\{\frac{\lambda_{t+1}}{\lambda_t}(\frac{1+\pi_{t+1}}{1+\tilde{\pi}}-1)(\frac{1+\pi_{t+1}}{1+\tilde{\pi}})(\frac{Y_{t+1}}{Y_t})\right\} = 0.$$

With nonseparable utility function as in (50), the first-order conditions (A4), (A7) and (A8) are replaced by

$$\Lambda C_{ht}^{-\tau-1}H_t^{\frac{-(1-\sigma^{-1})/\tau-1}{(1-\sigma^{-1})/\tau}} - \lambda_t = 0, \tag{A33}$$

$$\frac{\nu}{m_t^H}(1-\Lambda)[(m_{ht}^H)^\nu d_{ht}^{1-\nu}]^{-\tau}H_t^{\frac{-(1-\sigma^{-1})/\tau-1}{(1-\sigma^{-1})/\tau}} - \lambda_t + \beta E_t(\frac{\lambda_{t+1}}{1+\pi_{t+1}}) = 0, \tag{A34}$$

$$(\frac{1-\nu}{d_{ht}})(1-\Lambda)[(m_{ht}^H)^\nu d_{ht}^{1-\nu}]^{-\tau}H_t^{\frac{-(1-\sigma^{-1})/\tau-1}{(1-\sigma^{-1})/\tau}} - \lambda_t + \beta E_t\left\{\lambda_{t+1}(\frac{1+i_t^D}{1+\pi_{t+1}})\right\} = 0, \tag{A35}$$

where $H_t = \left\{\Lambda {C_{ht}}^{-\tau} + (1-\Lambda)[(m_{ht}^H)^\nu d_{ht}^{1-\nu}]^{-\tau}\right\}^{-(1-\sigma^{-1})/\tau}$. Eliminating λ_t, equations (A34) and (A35) become

$$(\frac{1-\Lambda}{\Lambda})\frac{\nu}{m_{ht}^H}[(m_{ht}^H)^\nu d_{ht}^{1-\nu}]^{-\tau}C_{ht}^{1+\tau} = 1 - \frac{1}{1+i_t^B} = \frac{i_t^B}{1+i_t^B}, \tag{A36}$$

$$(\frac{1-\Lambda}{\Lambda})(\frac{1-\nu}{d_{ht}})[(m_{ht}^H)^\nu d_{ht}^{1-\nu}]^{-\tau}C_{ht}^{1+\tau} = 1 - (\frac{1+i_t^D}{1+i_t^B}) = \frac{i_t^B - i_t^D}{1+i_t^B}, \tag{A37}$$

which replace (A14) and (A15).

Appendix B
Steady-State Solution

Given the parameter values, the steady-state values of all endogenous variables (denoted by tildes) are calculated by dropping all time subscripts from the relevant equations. Endogenous variables would converge to these values if the system is not disturbed by shocks.

From (38), with $\Delta \ln \tilde{Y} = 0$,

$$\tilde{i}^R = \tilde{r} + \tilde{\pi} + \varepsilon_1(\tilde{\pi} - \pi^T). \tag{B1}$$

We require inflation to be equal to its target value in the steady state:

$$\tilde{\pi} = \pi^T. \tag{B2}$$

Substituting this result in (B1) yields therefore the steady-state value of the refinance rate:

$$\tilde{i}^R = \tilde{r} + \tilde{\pi}. \tag{B3}$$

We will focus in what follows on the case where the inflation target is $\pi^T = 0$. Thus, the steady state is characterized by zero inflation, $\tilde{\pi} = 0$.

The steady-state value of the bond rate is determined by (8) or (A17),

$$\frac{1 + \tilde{i}^B}{1 + \tilde{\pi}} = 1 + \tilde{r} = \frac{1}{\beta}, \tag{B4}$$

that is, with $\tilde{\pi} = 0$,

$$\tilde{i}^B = \tilde{r} = \beta^{-1} - 1. \tag{B5}$$

From (7),

$$\Gamma(\tilde{K}, \tilde{K}) = \frac{\Theta}{2}(\frac{\tilde{K}}{\tilde{K}} - 1)^2 \tilde{K} = 0, \tag{B6}$$

which shows that in the steady state capital adjustment costs Γ are zero. Thus, from (6),

$$\tilde{I} = \delta \tilde{K}. \tag{B7}$$

Substituting (B6) in (12) or (A16) yields the steady-state relationship,

$$-1 + \beta(\tilde{r}^K + 1 - \delta) = 0,$$

which gives the steady-state value of the rate of return to physical capital:

$$\tilde{r}^K = \frac{1}{\beta} - (1-\delta). \tag{B8}$$

From (30), the steady-state value of the desired (and actual) deposit rate is

$$\tilde{i}^D = (1-\mu)\tilde{i}^R. \tag{B9}$$

Setting $Y_{t-1} = \tilde{Y}$ in (32) and using (33), the desired (and actual) lending rate is given by

$$\tilde{i}^L = (1+\tilde{i}^B)[1+\Phi_0^L(\frac{\kappa\tilde{P}\tilde{K}}{\tilde{L}^F})^{-\phi_1}] - 1. \tag{B10}$$

From (10) and (11) or (A14) and (A15), the household's demand for real cash balances and bank deposits are

$$\tilde{m}^H = \frac{\eta_x \nu \tilde{C}^{1/\sigma}(1+\tilde{i}^B)}{\tilde{i}^B}, \tag{B11}$$

$$\tilde{d} = \frac{\eta_x(1-\nu)\tilde{C}^{1/\sigma}(1+\tilde{i}^B)}{\tilde{i}^B - \tilde{i}^D}, \tag{B12}$$

or equivalently, using (B3), (B4), (B8), and (B9) with $\tilde{\pi} = 0$,

$$\tilde{m}^H = \frac{\eta_x \nu \tilde{C}^{1/\sigma}}{1-\beta}, \tag{B13}$$

$$\tilde{d} = \frac{\eta_x(1-\nu)\tilde{C}^{1/\sigma}}{(1-\beta)\mu}. \tag{B14}$$

From (9) or (A12), the steady-state value of labor supply is

$$\tilde{N} = 1 - \frac{\eta_N \tilde{C}^{1/\sigma}}{\tilde{\omega}}. \tag{B15}$$

From (17), steady-state output of intermediate goods is given by

$$\tilde{Y} = A\tilde{K}^{\alpha}\tilde{N}^{1-\alpha}. \tag{B16}$$

The marginal productivity conditions yield

$$\tilde{r}^K = \alpha(\frac{\tilde{K}}{\tilde{Y}})^{-1}(\frac{\theta-1}{\theta}), \qquad \tilde{\omega} = (\frac{1-\alpha}{\alpha})\frac{\tilde{r}^K\tilde{K}}{(1+\tilde{i}^L)\tilde{N}}.$$

These equations can be combined to give the capital-labor ratio (see (A26)), whose steady-state value is

$$\frac{\tilde{K}}{\tilde{N}} = (\frac{\alpha}{1-\alpha})[\frac{(1+\tilde{i}^L)\tilde{\omega}}{\tilde{r}^K}].$$

Substituting (B4), (B8), and (B10) in this expression, and solving for $\tilde{\omega}$ with $\tilde{\pi} = 0$ yields the steady-state real wage as

$$\tilde{\omega} = \left(\frac{1-\alpha}{\alpha}\right) \frac{\tilde{K}(\beta^{-1} - 1 + \delta)}{\tilde{N}\left[\beta^{-1} + \Phi_0^L(\kappa \tilde{P}\tilde{K}/\tilde{L}^F)^{-\phi_1}\right]}. \tag{B17}$$

The steady-state level of borrowing from the bank is thus

$$\tilde{L}^F = \tilde{N}\tilde{\omega}\tilde{P}. \tag{B18}$$

From (19), and with $\tilde{\pi} = 0$, price adjustment costs are zero in the steady state ($PAC = 0$). From the price adjustment equation (24) or (A32),

$$(1-\theta) + \theta\widetilde{mc} - \phi_F(\frac{\tilde{\pi}}{\tilde{\pi}} - 1)(\frac{\tilde{\pi}}{\tilde{\pi}}) + \beta\phi_F\frac{\tilde{\lambda}}{\tilde{\lambda}}(\frac{\tilde{\pi}}{\tilde{\pi}} - 1)(\frac{\tilde{\pi}}{\tilde{\pi}})(\frac{\tilde{Y}}{\tilde{Y}}) = 0,$$

which can be solved for the steady-state value of the marginal cost:

$$\widetilde{mc} = \frac{\theta - 1}{\theta}. \tag{B19}$$

From (27), the steady-state level of the bank's borrowing from the central bank is

$$\tilde{L}^B = \tilde{L}^F - (1-\mu)\tilde{d}\tilde{P}. \tag{B20}$$

The steady-state equilibrium condition of the goods market, equation (41), yields $\tilde{Y} = \tilde{C} + \tilde{G} + \tilde{I}$, which can be rearranged, together with (B7) and (40), to give

$$(1-\psi)\tilde{Y} = \tilde{C} + \delta\tilde{K}. \tag{B21}$$

From (45), the equilibrium condition of the market for cash yields

$$\frac{\bar{B}^C}{\tilde{P}} = \eta_X\tilde{C}^{1/\sigma}(1+\tilde{i}^B)(\frac{\nu}{\tilde{i}^B} + \frac{1-\nu}{\tilde{i}^B - \tilde{i}^D}),$$

which can rearranged as, using (B3), (B4), (B8), and (B9), and with $\tilde{\pi} = 0$,

$$\frac{\bar{B}^C}{\tilde{P}} = \frac{\eta_X \tilde{C}^{1/\sigma}}{1-\beta}(\nu + \frac{1-\nu}{\mu}). \tag{B22}$$

This equation can be solved for $\tilde{P}$. Given that the overall stock of bonds is also constant, household holdings of government bonds are given by, as noted in the text:

$$\bar{B}^H = \bar{B} - \bar{B}^C. \tag{B23}$$

From (39) and (40), the steady-state value of lump-sum taxes is thus

$$\tilde{T} = \psi \tilde{Y} + \tilde{\imath}^B(\bar{B} - \bar{B}^C) - \tilde{\imath}^R \tilde{L}^B. \tag{B24}$$

With nonseparable utility function as in (50), equations (B11) and (B12) are replaced by, using (A36) and (A37),

$$(\frac{1-\Lambda}{\Lambda})\frac{\nu}{\tilde{m}^H}[(\tilde{m}^H)^\nu \tilde{d}^{1-\nu}]^{-\tau}\tilde{C}^{1+\tau} = \frac{\tilde{\imath}^B}{1+\tilde{\imath}^B}, \tag{B25}$$

$$(\frac{1-\Lambda}{\Lambda})(\frac{1-\nu}{\tilde{d}})[(\tilde{m}^H)^\nu \tilde{d}^{1-\nu}]^{-\tau}\tilde{C}^{1+\tau} = \frac{\tilde{\imath}^B - \tilde{\imath}^D}{1+\tilde{\imath}^B}, \tag{B26}$$

whereas the labor supply equation (B15) is replaced by

$$\tilde{N} - 1 + \eta_N \left(\frac{1}{\Lambda\tilde{\omega}}\right)\tilde{C}^{1+\tau}\left\{\Lambda\tilde{C}^{-\tau} + (1-\Lambda)[(\tilde{m}^H)^\nu \tilde{d}^{1-\nu}]^{-\tau}\right\}^{\frac{1-\sigma^{-1}}{\tau}-1}.$$

Appendix C
Log-Linearized System

Based on the results of Appendix A, the log-linearized equations of the model are presented below. Variables with a hat denote percentage point deviations of the related variables for interest rates and inflation, and log-deviations for the others, from steady-state levels.[49]

From the first-order conditions from household optimization, equations (8) and (10) or (A11) and (A14), private consumption is driven by

$$E_t\hat{C}_{t+1} = \hat{C}_t + \sigma(\hat{\imath}_t^B - E_t\pi_{t+1}), \tag{C1}$$

where π_{t+1} is defined as

$$E_t\pi_{t+1} = E_t\hat{P}_{t+1} - \hat{P}_t. \tag{C2}$$

Note that the steady-state inflation rate (as discussed in Appendix B) is set to zero; so changes in inflation with respect to its steady-state level is simply the inflation rate itself.

The demand for cash is

$$\hat{m}_t^H\tilde{m}^H = \frac{\eta_x\nu(\tilde{C})^{1/\sigma}}{1-\beta}[\frac{\hat{C}_t}{\sigma} - (\frac{\beta}{1-\beta})\hat{\imath}_t^B]. \tag{C3}$$

By using the steady-state value of cash balances from (B13), equation (C3) can be written as

$$\hat{m}_t^H = \frac{\hat{C}_t}{\sigma} - (\frac{\beta}{1-\beta})\hat{\imath}_t^B. \tag{C4}$$

From (A15) and (B14), the demand for deposits is

$$\hat{d}_t = \frac{\hat{C}_t}{\sigma} + \left[\beta^{-1} - (\beta^{-1}-1)\mu\right]\hat{\imath}_t^D - \left(\beta^{-1}-1\right)\hat{\imath}_t^B. \tag{C5}$$

The Fisher equation, defined in (A18), yields

$$(1+\beta\delta)E_t\hat{r}_{t+1}^K + \beta\Theta(E_t\hat{K}_{t+2} - E_t\hat{K}_{t+1}) - \Theta(E_t\hat{K}_{t+1} - \hat{K}_t) - \hat{\imath}_t^B + E_t\pi_{t+1} = 0, \tag{C6}$$

[49] Interest rates are log-linearized around the corresponding gross interest rates, and net interest rates are used as approximations of the logarithm of gross interest rates.

which can be used to determine $\hat{r}_t^K$.

From (A12), labor supply is

$$\tilde{N}\hat{N}_t = \frac{\eta_N \tilde{C}^{1/\sigma}}{\tilde{\omega}}\hat{\omega}_t - \frac{\eta_N \tilde{C}^{1/\sigma}\hat{C}_t}{\sigma\tilde{\omega}},$$

that is, using (B15),

$$\hat{N}_t = (\frac{\eta_N \tilde{C}^{1/\sigma}}{\tilde{\omega} - \eta_N \tilde{C}^{1/\sigma}})(\hat{\omega}_t - \frac{\hat{C}_t}{\sigma}). \tag{C7}$$

From (A26), labor demand can be derived as

$$\hat{N}_t = \hat{K}_t - \hat{\imath}_t^L - \hat{\omega}_t + (\frac{1+\beta\delta}{1+\beta\delta-\beta})\hat{r}_t^K. \tag{C8}$$

A log-linear approximation around the steady state of the price adjustment equation (A32) yields

$$\pi_t = (\frac{\theta-1}{\phi_F})\widehat{mc}_t + \beta E_t \pi_{t+1}. \tag{C9}$$

The marginal cost itself is a function of not only of factor prices ω_t and r_t^K but also of the lending rate. Using (A27) yields

$$\widehat{mc}_t = (1-\alpha)(\hat{\imath}_t^L + \hat{\omega}_t) + (\frac{\alpha+\alpha\beta\delta}{1+\beta\delta-\beta})\hat{r}_t^K. \tag{C10}$$

From the production function (17), output of intermediate goods is

$$\hat{Y}_t = \alpha\hat{K}_t + (1-\alpha)\hat{N}_t. \tag{C11}$$

From (30) and (B9), the desired bank deposit rate is given by

$$\hat{\imath}_t^{D,d} = \frac{(1-\mu)}{1-(1-\beta)\mu}\hat{\imath}_t^R. \tag{C12}$$

Given the fact that in the steady state the actual and desired deposit rates would be equal, (31) can be expressed in terms of deviations from the steady state:

$$\Delta\hat{\imath}_t^D = \zeta_D(\hat{\imath}_t^{D,d} - \hat{\imath}_{t-1}^D). \tag{C13}$$

From (32), the desired lending rate is a function of lagged output, and the lagged value of firms' capital:

$$\hat{i}_t^{L,d} = \frac{1}{\tilde{i}^L}\left\{\frac{1}{\beta}\hat{i}_t^B + \Phi_0^L(\frac{\kappa\tilde{P}\tilde{K}}{\tilde{L}^F})^{-\phi_1}\left[\phi_1(\hat{L}_t^F - \hat{K}_t - \hat{P}_t) - \phi_2\hat{Y}_{t-1}\right]\right\}. \quad \text{(C14)}$$

Similar to deposit rates, (34) can be expressed in terms of deviations from the steady state:

$$\Delta\hat{i}_{jt}^L = \zeta_L(\hat{i}_{jt}^{L,d} - \hat{i}_{jt-1}^L). \quad \text{(C15)}$$

From (38), the Central bank policy rate is determined by

$$\hat{i}_t^R = \chi\hat{i}_{t-1}^R + \varepsilon_1\hat{\pi}_t + \varepsilon_2\hat{Y}_t. \quad \text{(C16)}$$

Firms' demand for credit is, from (18),

$$\hat{L}_t^F = \hat{N}_t + \hat{\omega}_t + \hat{P}_t. \quad \text{(C17)}$$

From (29), the bank's borrowing from the Central bank is

$$\hat{L}_t^B = \frac{1}{\tilde{L}^B}\left[\tilde{L}^F\hat{L}_t^F - (1-\mu)(\tilde{P}\tilde{d}\hat{d}_t + \tilde{d}\tilde{P}\hat{P}_t)\right]. \quad \text{(C18)}$$

The equilibrium condition of the market for cash, equation (45), yields

$$\nu\left\{\hat{P}_t + \frac{\hat{C}_t}{\sigma} - (\frac{\beta}{1-\beta})\hat{i}_t^B\right\} + \frac{(1-\nu)}{\mu}\left\{\hat{P}_t + \frac{\hat{C}_t}{\sigma}\right. \quad \text{(C19)}$$

$$\left. + \left[\frac{1}{\beta} - (\frac{1}{\beta} - 1)\mu\right]\hat{i}_t^D - (\frac{1}{\beta} - 1)\hat{i}_t^B\right\} = 0.$$

Equation (C19) can be solved for $\hat{i}_t^B$.

Finally, the equilibrium condition of the goods market, equation (41), is

$$(1-\psi)(\frac{\tilde{Y}}{\tilde{C}})\hat{Y}_t = \hat{C}_t + \frac{\tilde{K}}{\tilde{C}}(E_t\hat{K}_{t+1} - \hat{K}_t) + \delta\frac{\tilde{K}}{\tilde{C}}\hat{K}_t. \quad \text{(C20)}$$

With nonseparable utility function as in (50), equations (C1), (C7), (C4), and (C5) are replaced by, using (A36) and (A37),

$$\hat{i}_t^B - E_t\pi_{t+1} = (1-\sigma^{-1})\Lambda\tilde{C}^{-\tau}(\hat{C}_t - E_t\hat{C}_{t+1}) \quad \text{(C21)}$$

$$+(1-\Lambda)\tilde{m}_H^{-\nu\tau}\tilde{d}^{\tau(\nu-1)}\nu\tau(E_t\hat{m}_{H,t+1}-\hat{m}_{H,t})+\tau(1-\nu)(E_t\hat{d}_{t+1}-\hat{d}_t),$$

$$\hat{N}_t=\frac{\tilde{N}-1}{\tilde{N}}\Big\{-\omega_t+(\tau+1-(1-1/\sigma+\tau)\,\Lambda\tilde{C}^{-\tau})\hat{C}_t \tag{C22}$$

$$+(1-\Lambda)\tilde{m}^{-\tau\nu}\tilde{d}^{\tau(\nu-1)}(-\tau\nu\hat{m}_t-\tau(1-\nu)\hat{d}_t)\Big\},$$

$$-(1+\tau\nu)\hat{m}_t^H-\tau(1-\nu)\hat{d}_t+(1+\tau)\hat{C}_t=\frac{\beta}{1-\beta}\hat{\imath}_t^B, \tag{C23}$$

$$-\tau\nu\hat{m}_t^H-[1+\tau(1-\nu)]\hat{d}_t+(1+\tau)\hat{C}_t=\frac{1-\mu+\beta\mu}{\mu-\mu\beta}\left[1+\hat{\imath}_t^B-\hat{\imath}_t^D\right]. \tag{C24}$$

References

Agénor, Pierre-Richard, "The Analytics of Segmented Labor Markets," in *Adjustment Policies, Poverty and Unemployment: The IMMPA Framework*, ed. by Pierre-Richard Agénor, Alejandro Izquierdo, and Henning Tarp Jensen, Blackwell Publishing (Oxford: 2006).

Agénor, Pierre-Richard, and Joshua Aizenman, "Contagion and Volatility with Imperfect Credit Markets," *IMF Staff Papers*, 45 (June 1998), 207-35.

Agénor, Pierre-Richard, George J. Bratsiotis, and Damjan Pfajfar, "Monetary Policy and Inflation Persistence with Imperfect Credit Markets," work in progress, University of Manchester and Tilburg University (December 2009).

Agénor, Pierre-Richard, and Nihal Bayraktar, "Contracting Models of the Phillips Curve," Working Paper No. 94, Centre for Growth and Business Cycle Research, University of Manchester (January 2008). Forthcoming, *Journal of Macroeconomics*.

Agénor, Pierre-Richard, and Peter J. Montiel, "Credit Market Imperfections and the Monetary Transmission Mechanism. Part I: Fixed Exchange Rates," Working Paper No. 76, Centre for Growth and Business Cycle Research, University of Manchester (October 2006).

——, "Credit Market Imperfections and the Monetary Transmission Mechanism. Part II: Flexible Exchange Rates," Working Paper No. 86, Centre for Growth and Business Cycle Research, University of Manchester (January 2007).

——, "Monetary Policy Analysis in a Small Open Credit-Based Economy," *Open Economies Review*, 19 (September 2008*a*), 423-55.

——, *Development Macroeconomics*, 3rd ed., Princeton University Press (Princeton, New Jersey: 2008*b*).

Atta-Mensah, Joseph , and Ali Dib, "Bank Lending, Credit Shocks, and the Transmission of Canadian Monetary Policy," *International Review of Economics and Finance*, 17 (March 2008), 159-76.

Beck, Thorsten, and Asli Demirguc-Kunt, "Small and Medium-Size Enterprises: Access to Finance as a Growth Constraint," *Journal of Banking and Finance*, 30 (November 2006), 2931-43.

Beck, Thorsten, Asli Demirguc-Kunt, and Vojislav Maksimovic, "Financing Patterns around the World: Are Small Firms Different?," *Journal of Financial Economics*, 89 (September 2008), 467-87.

Beck, Thorsten, and Heiko Hesse, "Why are Interest Spreads so High in Uganda?," *Journal of Development Economics*, 88 (March 2009), 192-204.

Bernanke, Ben S., and Mark Gertler, "Agency Costs, Net Worth and Business Fluctuations," *American Economic Review*, 79 (March 1989), 14-31.

Bernanke, Ben S., Mark Gertler, and Simon Gilchrist, "The Financial Accelerator in a Quantitative Business Cycle Framework," in *Handbook of Macroeconomics*, ed. by John B. Taylor and Michael Woodford, North Holland (Amsterdam: 2000).

Berstein, Solange, and Rodrigo Fuentes, "Concentration and Price Rigidity: Evidence for the Deposit Market in Chile," Working Paper No. 311, Central Bank of Chile (March 2005).

Bu, Yisheng, "Fixed Capital Stock Depreciation in Developing Countries: Some Evidence from Firm Level Data," *Journal of Development Studies*, 42 (juillet 2006), 881-901.

Canzoneri, Matthew, Robert Cumby, Behzad Diba, David López-Salido, "Monetary Aggregates and Liquidity in a Neo-Wicksellian Framework," *Journal of Money, Credit, and Banking*, 40 (December 2008) 1667-98.

Cole, Matthew A., and Eric Neumayer, "The Impact of Poor Health on Total Factor Productivity," *Journal of Development Studies*, 42 (August 2006), 918-38.

Chirwa, Ephraim W., and Montfort Mlachila, "Financial Reforms and Interest Rate Spreads in the Commercial Banking System in Malawi," *IMF Staff Papers* 51 (March 2004): 96-122.

Chowdhury, Ibrahim, Mathias Hoffmann, and Andreas Schabert, "Inflation Dynamics and the Cost Channel of Monetary Transmission," *European Economic Review*, 50 (May 2006), 995-1016.

Christensen, Ian, and Ali Dib, "The financial Accelerator in an Estimated New Keynesian Model," *Review of Economic Dynamics*, 11 (April 2008), 155-78.

Christiano, Lawrence J., Martin Eichenbaum, and Charles L. Evans, "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy," *Journal of Political Economy*, 113 (February 2005), 1-45.

Christiano, Lawrence, Roberto Motto, and Massimo Rostagno, "Two Reasons why Money and Credit may be Useful in Monetary Policy," Working Paper No. 13502, National Bureau of Economic Research (October 2007).

——, "Financial Factors in Business Cycles," unpublished, Northwestern University (May 2008).

Coenen, Gunter, and Roland Straub, "Does Government Spending Crowd in Private Consumption? Theory and Empirical Evidence for the Euro Area," *International Finance*, 8 (December 2005), 435-70.

Cúrdia, Vasco, and Michael Woodford, "Credit Frictions and Optimal Monetary

Policy," Working Paper No. 278, Bank for International Settlements (March 2009).

De Blas, Beatriz, "Performance of Interest Rate Rules under Credit Market Imperfections," *Economic Modelling*, 26 (May 2009), 586-96.

De Graeve, Ferre, "The External Finance Premium and the Macroeconomy: US Post-WWII Evidence," *Journal of Economic Dynamics and Control*, 32 (November 2008), 3415-40.

Faia, Ester, and Tommaso Monacelli, "Optimal Interest Rate Rules, Asset Prices, and Credit Frictions," *Journal of Economic Dynamics and Control*, 31 (October 2007), 3228-54.

Galí, Jordi, *Monetary Policy, Inflation, and the Business Cycle: An Introduction to the New Keynesian Framework*, Princeton University Press (Princeton, New Jersey: 2008).

Gerali, Andrea, Stefano Neri, Luca Sessa, and Federico M. Signoretti, "Credit and Banking in a DSGE Model of the Euro Area," unpublished, Banca d'Italia (May 2009).

Goodfriend, Marvin, and Bennett T. McCallum, "Banking and Interest Rates in Monetary Policy Analysis: A Quantitative Exploration," *Journal of Monetary Economics*, 54 (July 2007), 1480-507.

Goodhart, Charles, and Boris Hofmann, "House Prices, Money, Credit and the Macroeconomy," Working Paper No. 888, European Central Bank (April 2008).

Hulsewig, Oliver, Eric Mayer, and Timo Wollmershauser, "Bank behavior, Incomplete Interest Rate Pass-through, and the Cost Channel of Monetary Policy Transmission," *Economic Modelling*, 26 (November 2009), 1310-27.

Ireland, Peter N., "Sticky-Price Models of the Business Cycle: Specification and Stability," *Journal of Monetary Economics*, 47 (February 2001), 3-18.

——, "Money's Role in the Monetary Business Cycle," *Journal of Money, Credit, and Banking*, 36 (December 2004), 969-83.

Jones, Barry E., and Livio Stracca, "Are Money and Consumption Additively Separable in the Euro Area? A Non-Parametric Approach," Working Paper No. 704, European Central Bank (December 2006).

——, "Does Money Matter in the IS Curve? The Case of the UK," Working Paper No. 904, European Central Bank (June 2008).

Kaufmann, Sylvia, and Johann Scharler,"Financial Systems and the Cost Channel Transmission of Monetary Policy Shocks," *Economic Modelling*, 26 (January 2009), 40-46.

Keen, Benjamin D., and Yongsheng Wang, "What is a Realistic Value for Price Adjustment Costs in New Keynesian Models?," *Applied Economics Letters*, 14 (September 2007), 789-93.

Liu, Philip, "A Small New Keynesian Model of the New Zealand Economy," Discussion Paper No. 2006/03, Reserve Bank of New Zealand (May 2006).

McCallum, Bennett T., "Monetary Policy Analysis in Models without Money," *Federal Reserve Bank of Saint Louis Review*, 83 (August 2001), 145-60.

Moura, Marcelo L., and Alexandre de Carvalho, "What can Taylor Rules Say about Monetary Policy in Latin America?," forthcoming, *Journal of Macroeconomics* (December 2009).

Nolan, Charles, and Christoph Thoenissen, "Financial Shocks and the US Business Cycle." *Journal of Monetary Economics*, 56 (May 2009), 596-604.

Ogaki, Masao, Jonathan Ostry, and Carmen M. Reinhart, "Saving Behavior in Low- and Middle-Income Developing Countries: A Comparison," *IMF Staff Papers*, 43 (March 1996), 38-71.

Ozdemir, Bilge K., "Retail Bank Interest Rate Pass-through: The Turkish Experience," *International Research Journal of Finance and Economics*, No. 28 (June 2009), 7-15.

Rabanal, Pau, "Does Inflation Increase after a Monetary Policy Tightening? Answers Based on an Estimated DSGE Model," *Journal of Economic Dynamics and Control*, 31 (March 2007), 906-37.

Ravenna, Federico and Carl E. Walsh, "Optimal Monetary Policy with the Cost Channel," *Journal of Monetary Economics*, 53 (March 2006), 199-216.

Rotemberg, Julio J., "Monopolistic Price Adjustment and Aggregate Output," *Review of Economic Studies*, 49 (October 1982), 517-31.

Rudebusch, Glen, "Monetary Policy Inertia: Fact or Fiction," *International Journal of Central Banking*, 2 (December 2006), 85-135.

Scharler, Johann, "Do Bank-based Financial Systems Reduce Macroeconomic Volatility by Smoothing Interest Rates?," *Journal of Macroeconomics*, 30 (September 2008), 1207-21.

Sorensen, C. K., and T. Werner, "Bank Interest Rate Pass-Through in the Euro Area: A Cross-Country Comparison," Working Paper No. 580, European Central Bank (January 2006).

Surico, Paolo, "The Monetary Policy of the European Central Bank," *Scandinavian Journal of Economics*, 109 (March 2007), 115-35.

Tillmann, Peter, "Do Interest Rates Drive Inflation Dynamics? An analysis of the Cost Channel of Monetary Transmission," *Journal of Economic Dynamics and Control*, 32 (September 2008), 2723-44.

Tovar, Camilo E, "DSGE Models and Central Banks," Working Paper No. 258, Bank for International Settlements (September 2008).

Wang, Pengfei, and Yi Wen, "Another Look at Sticky Prices and Output Persistence," *Journal of Economic Dynamics and Control*, 30 (December 2006), 2533-52.

Woodford, Michael, "How Important Is Money in the Conduct of Monetary Policy?," *Journal of Money, Credit, and Banking*, 40 (December 2008), 1561-98.

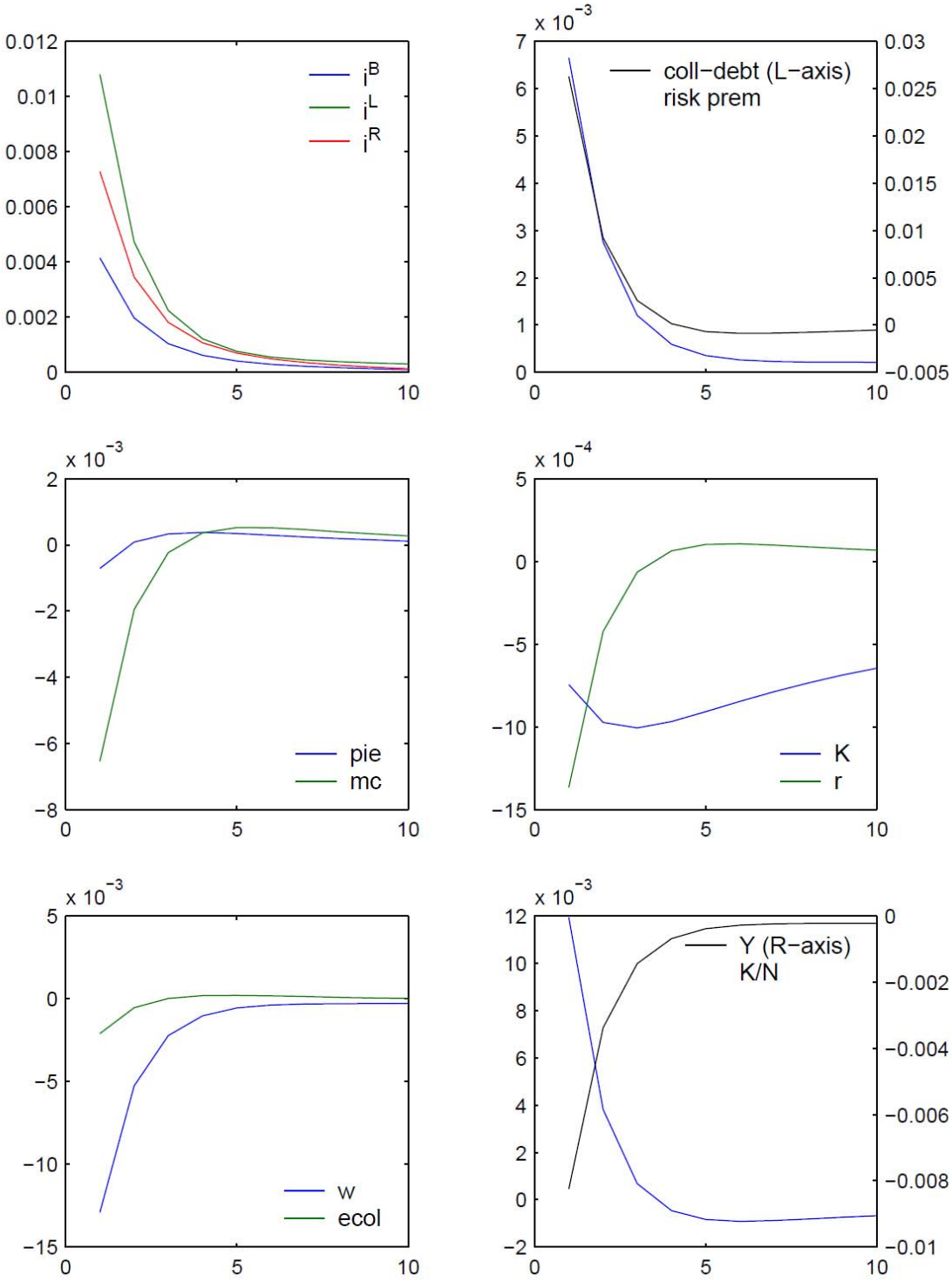
Wong, Sen Min, "Monetary Policy Analysis in a Fixed Exchange Rate Economy With Credit Market Imperfections—A Theoretical and Empirical Exploration for Malaysia," unpublished PhD Thesis, University of Manchester (April 2008).

World Bank, *Dominican Republic: The Foundations of Growth and Competitiveness*, Report No. 35731-DO (Washington DC: 2006).

Table 1
Parameter Values: Benchmark Case

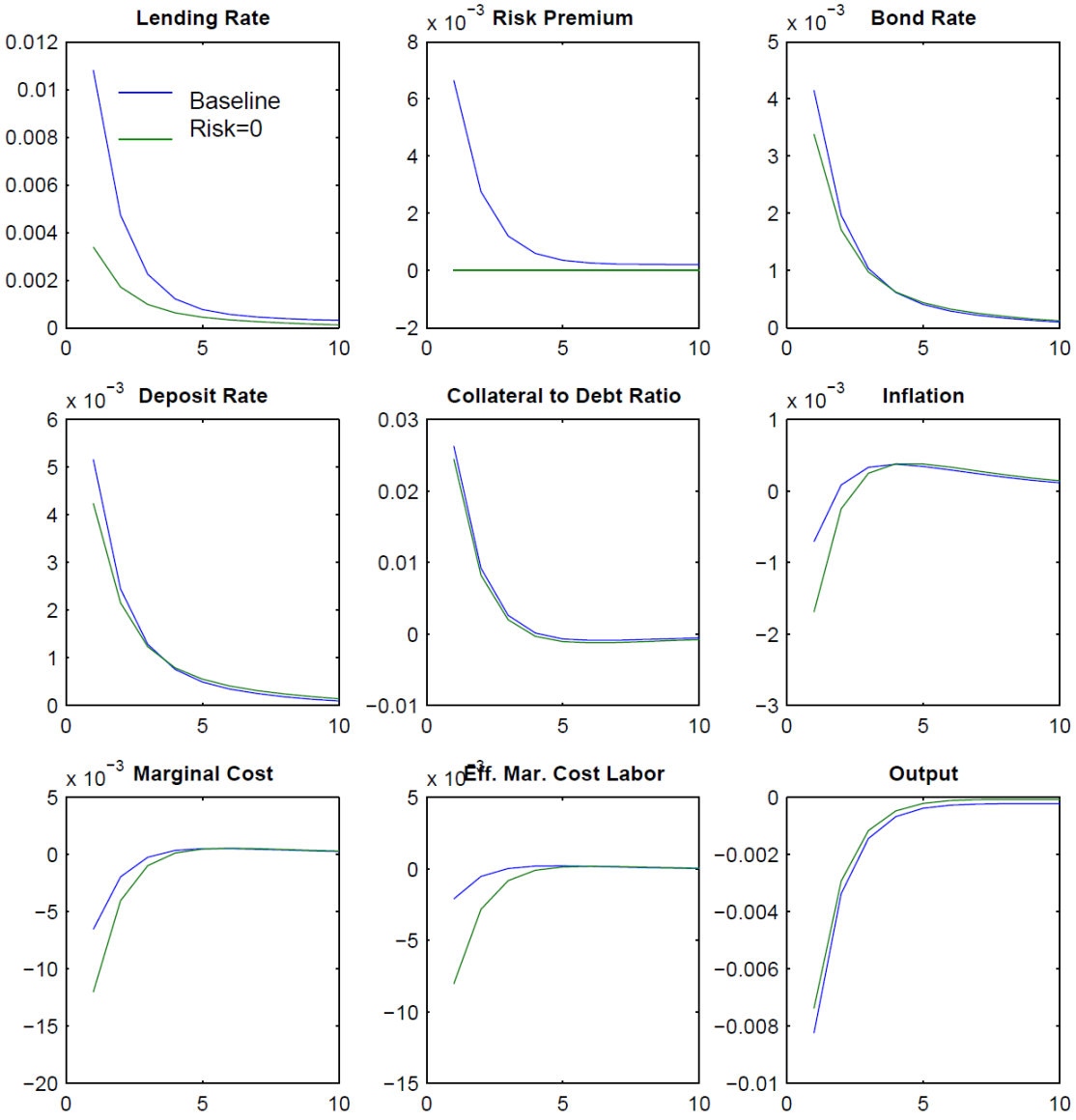
Parameter	**Value**	**Description**
Households		
β	0.95	Discount factor
σ	0.6	Elasticity of intertemporal substitution
η_N	1.5	Relative preference for leisure
η_x	1.5	Relative preference for money holdings
ν	0.2	Share parameter in index of money holdings
Θ	8.6	Adjustment cost parameter, investment
Production		
θ	10.0	Elasticity of demand, intermediate goods
α	0.65	Share of labor in output, intermediate good
ϕ_F	74.5	Adjustment cost parameter, prices
δ	0.06	Depreciation rate of capital
Government		
ψ	0.2	Share of government spending in output
Bank		
κ	0.5	Effective collateral-loan ratio
ϕ_1	0.05	Elasticity of risk premium wrt collateral
ϕ_2	0.9	Elasticity of risk premium wrt cyclical output
ζ_D	1.0	Speed of adjustment of deposit rate
ζ_L	1.0	Speed of adjustment of loan rate
Central bank		
μ	0.1	Reserve requirement rate
χ	0.0	Degree of persistence in interest rate rule
ε_1	1.5	Response of refinance rate to inflation deviations
ε_2	0.2	Response of refinance rate to output growth
Policy shock		
ρ_ϵ	0.4	Degree of persistence, monetary policy shock
σ_ϵ	0.01	Standard deviation, monetary policy shock

Figure 1
Baseline Experiment: Increase in Refinance Rate
(Deviations from Steady State)



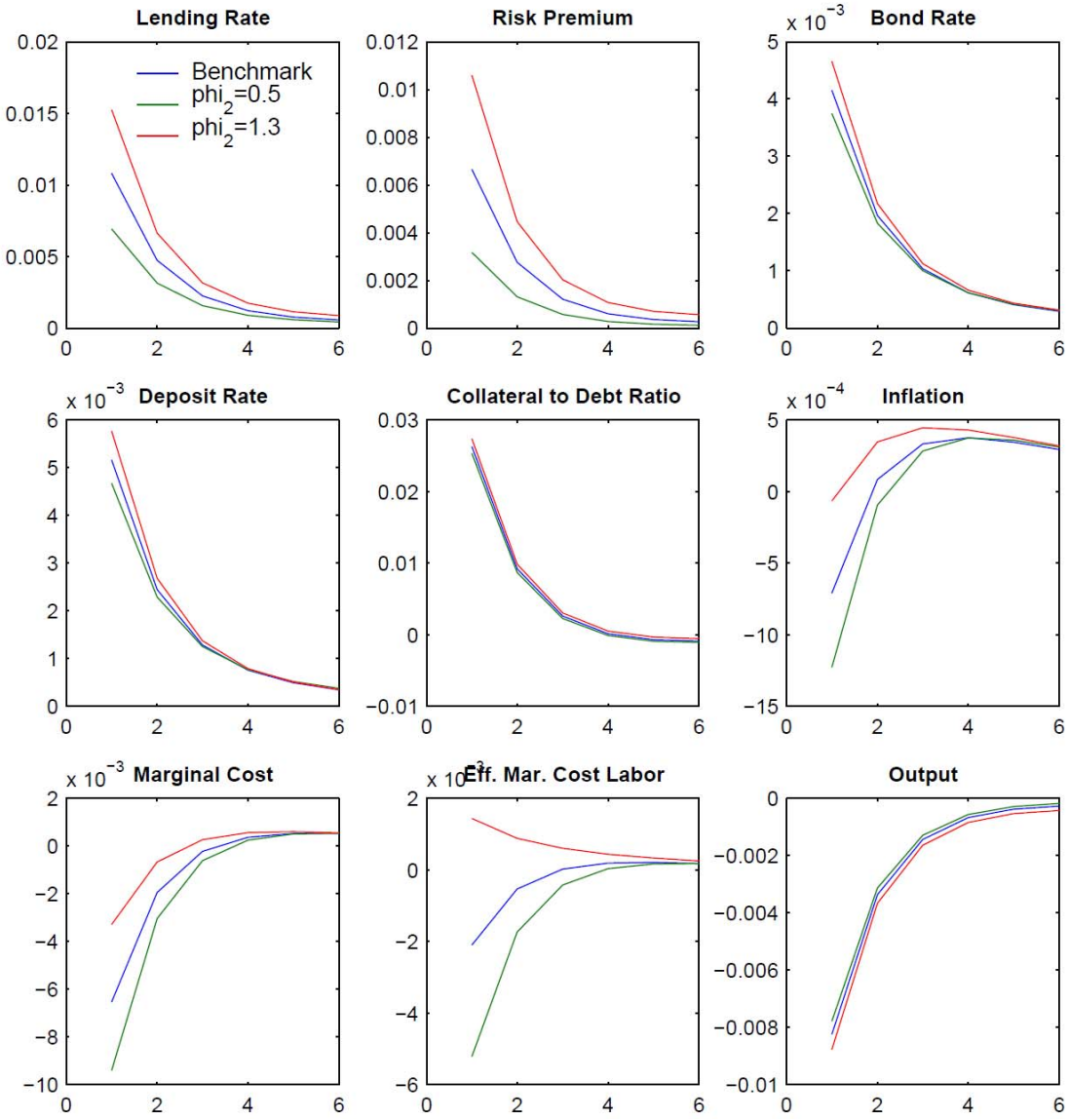
Note: Interest rates, inflation rate and the repayment probability are measured in absolute deviations, that is, in the relevant graphs, a value of 0.05 for these variables corresponds to a 5 percentage point deviation in absolute terms.

Figure 2
Increase in Refinance Rate: with and without Credit Market Frictions
(Deviations from Steady State)



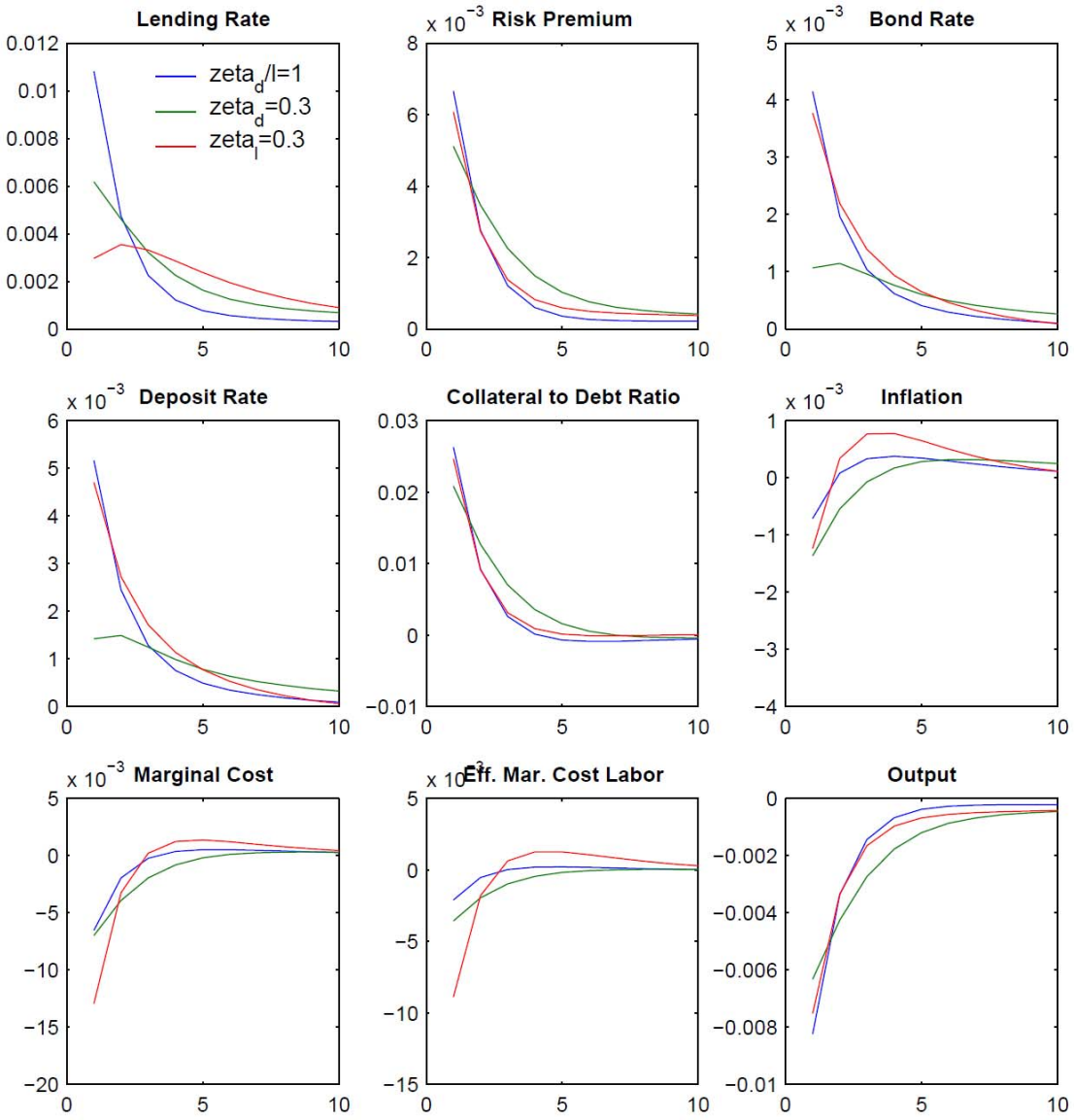
Note: See note to Figure 1.

Figure 3
Increase in Refinance Rate: Alternative Elasticities of the Risk Premium
(Deviations from Steady State)



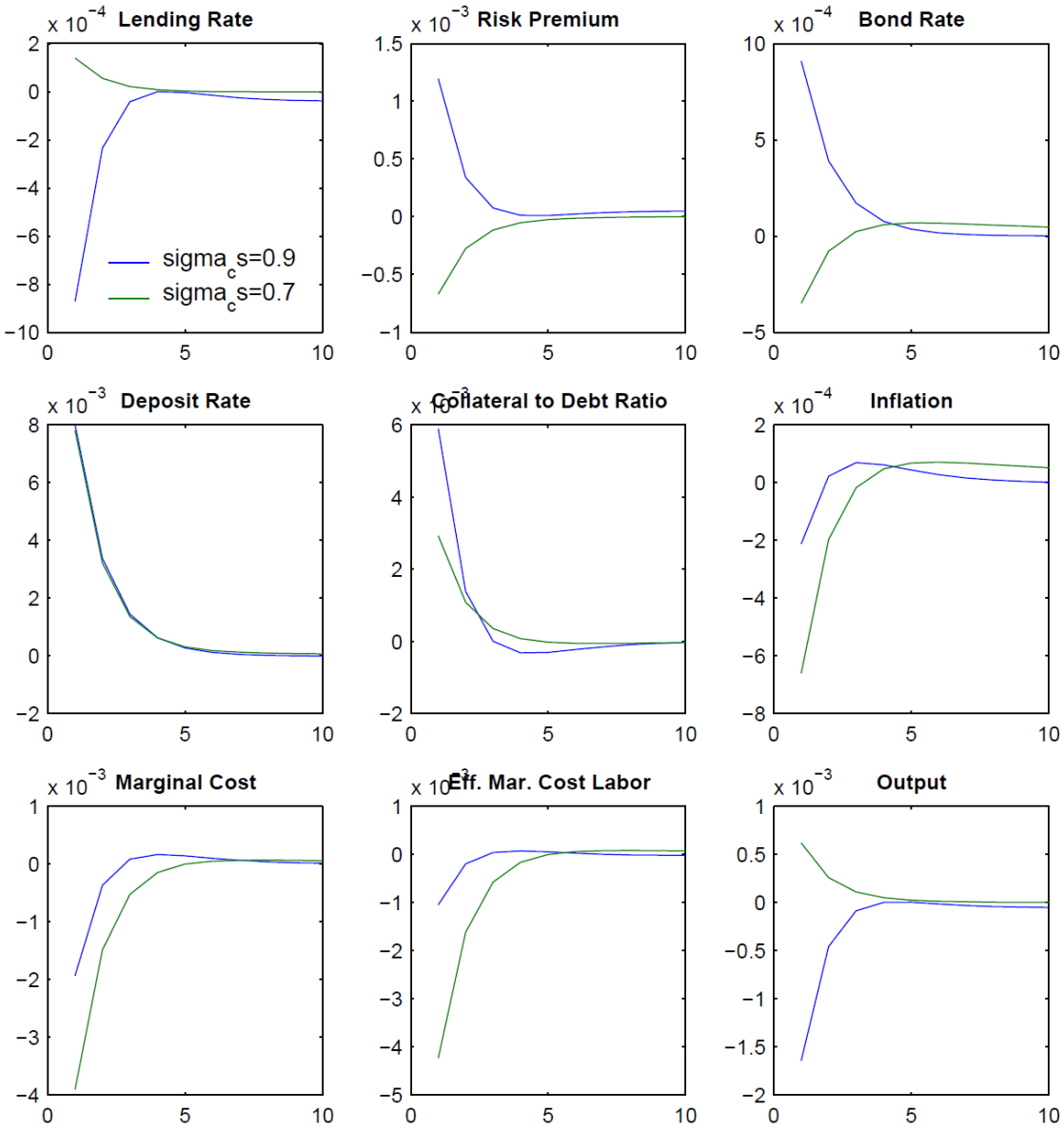
Note: See note to Figure 1.

Figure 4
Increase in Refinance Rate: Gradual Adjustment in Bank Rates
(Deviations from Steady State)



Note: See note to Figure 1.

Figure 5
Increase in Refinance Rate: Nonseparable Utility Function
(Deviations from Steady State)



Note: See note to Figure 1.

Figure 5 (continued)
Increase in Refinance Rate: Nonseparable Utility Function
(Deviations from Steady State)