CENTRAL BANK OF ICELAND

WORKING PAPERS No. 21

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by

Tor Einarsson and Milton H. Marquis

November 2003

CENTRAL BANK OF ICELAND

Economics Department

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ISSN: 1028-9445

Bank Intermediation and Persistent Liquidity Effects in the Presence of a Frictionless Bond Market*

Tor Einarsson
University of Iceland

and

Milton H. Marquis
Federal Reserve Bank of San Francisco
and
Florida State University

First Version: October, 2000
This Version: December, 2003

*We thank Jeffrey Wrase and participants at the Federal Reserve's Fall, 2000 Macro Conference in San Francisco, at the 2001 Society for Economics Dynamics Meeting in Stockholm, the Econometric Society European Meeting in Lausanne, the 18th Annual Congress of the European Economic Association in Stockholm, the Central Bank of Iceland, and Thorarinn G. Petursson for helpful comments. We also thank Flint Brayton for help with the durable goods stock and service flow series, Ruth Judson for her help with the deposit rate data, and Casey Cornwell, Tatiana Balehka, and Cameron Porsandeh for technical assistance. The opinions expressed in this paper are those of the authors and do not reflect the views of the Federal Reserve Bank of San Francisco or the Federal Reserve System.

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Abstract

An "expansionary" monetary policy that increases the growth rate of bank reserves is generally believed by policymakers to induce a "liquidity effect", or a persistent decline in short-term nominal interest rates, that stimulates real activity. Christiano, et al. (1991,1995,1997) have incorporated this feature of the economy into equilibrium business cycle models by introducing a commercial bank that acquires deposits from households and channels those funds to firms, which use them to fund their working capital expenses. Bank deposits are the only interest-bearing financial asset available to households, and bank loans are the only source of working capital finance available to firms. To obtain a liquidity effect in response to an unanticipated reserves injection, those models rely on an information friction whereby households precommit to a liquid asset position prior to the monetary shock. In practice, the capital markets are a major source of working capital finance, and U.S. data indicate that bank financing as a share of total short-term working capital finance is countercyclical. This paper extends this literature by introducing a bond market that allows for nonintermediated loans directly from households to firms, and examines the information friction that could induce liquidity effects and countercyclicality in the degree of bank intermediation of working capital finance. The results indicate that: (i) "sticky prices" are neither necessary nor sufficient to induce a liquidity effect; (ii) deposit precommitment by households along with a presetting of the deposit rate by banks does induce persistent liquidity effects, but results in excess volatility of consumption and investment; (iii) minimizing the deposit precommitment, while maintaining the preset deposit rate induces a weaker liquidity effect that is more in line with the data, without the excess volatility in consumption and investment; and (iv) the share of bank intermediation in working capital finance is countercyclical in all cases, including the absence of an information friction. [JEL Classifications: E4,E5. Keywords: financial intermediation, liquidity, monetary policy.]

I. Introduction

The principal economic functions performed by commercial banks are to: (i) act as a financial intermediary between lenders and borrowers, by originating loans and performing the necessary monitoring of borrowers; (ii) engage in valued asset transformation, i.e., from highly liquid deposit accounts to a portfolio of less liquid, generally larger denomination, riskier assets; and (iii) play a central role in the economy's payments system. [1] These economic functions are carried out through the traditional banking activities of providing highly-liquid demand accounts, and aggregating those funds into larger, less liquid, risky loans. The conduct of these activities is affected by a central bank policy that alters the total volume of reserves in the banking system, thus affecting the supply of funds available to banks in the provision of bank loans.

Christiano, et al. (1996) have well documented that an initial decline in short-term interest rates follows a "monetary shock" in the form of an unanticipated injection of (nonborrowed) reserves into the banking system, which is the so-called "liquidity effect." This decline is persistent, and is the mechanism by which an "expansionary" monetary policy is generally believed to stimulate economic activity. After this decline, Fisherian fundamentals associated with the higher long-run inflation premium drive interest rates up beyond their initial levels (where this shock is to the gross growth rate of reserves), and the stimulus to the economy reverses. In a series of papers, Christiano (1991), Christiano and Eichenbaum (1995), and Chari, et al. (1995) have examined conditions under which this liquidity effect will be operative and will exhibit a significant degree of persistence in the short run as is suggested by the data. They focus on the role of banks in converting their bank reserves and deposit funds from households into working capital loans to firms. They examine two market frictions that may induce a liquidity effect. The first that was originally suggested by Lucas (1990) and Fuerst (1992) involves a precommitment of households to a deposit position prior to a "monetary shock." The second, that has a long tradition in Keynesian models is a more or less *ad hoc* imposition of "sticky prices." [See Goodfriend and King (1997).]

However, in the Christiano, et al. models, bank loans are the only source of funds available to firms, and bank deposits are the only interest-bearing financial asset available to households. As a consequence of the former restriction, the "degree of bank intermediation" or the extent to which working capital loans are financed through bank lending cannot vary over the business cycle, since *all* working capital loans are financed by banks. The data indicate that this is not case. Commercial and industrial loans as a percentage of GDP is countercyclical. The second restriction permits an abstraction to be made away from the essential role that banks play in the economy's payment system by effecting final settlement in the purchase of goods and services. In one version of their

[1] This list should also include risk management which has become an increasingly important activity of banks, and financial intermediaries in general. However, most banking activities associated with risk management involve transactions between financial intermediaries, which is not the focus of this paper. See Allen and Santomero (1998) for perspective on this aspect of modern banking.

models, i.e., Chari, et al. (1995), a "shopping-time" technology is employed to capture the liquidity services of bank deposits. Otherwise, as a consequence of this second restriction, bank loans and bank deposits carry the same interest rate, with no difference in either their level or their volatility.

Einarsson and Marquis (2001) relax the first restriction under which the role that banks play as financial intermediaries can be treated in isolation from the alternative market mechanisms that bring together borrowers with lenders. In particular, a competitive bond (or commercial paper) market is introduced that represents a nonintermediated, direct lending channel from households to firms. This direct lending channel captures some of the lending to firms that would otherwise orginate with the banks. As the economy experiences shocks, the volume of lending to firms from banks versus the volume of funds raised through direct lending from households varies. Specifically, by relaxing the second restriction alluded to above, such that deposits carry a high liquidity value for households, who use them for transactions purposes, then deposits are tied to consumption. In this case, consumption-smoothing can limit the ability of banks, say, to raise adequate funds in response to a positive productivity shock in order to provide bank loans to the full extent of the (percentage) increase in demand that they are experiencing. Therefore, direct lending assumes a larger share of the funds made available for working capital finance, thus resulting in the countercyclical role of bank lending as a share of the total working capital financed by firms as is evidenced in the data.

This paper extends Einarsson and Marquis (2001) in a number of ways. First, it recognizes that not all firms have a quality rating that would permit them to issue bonds, but instead must resort to a financial intermediary to facilitate the loan between households and firms. To account for this factor in the aggregate firm context, bank loans and bonds are assumed to be imperfect substitutes, as in Marquis (2000). This assumption enables an examination to be made of the differences in interest rate behavior as well as in the volume of lending with respect to bank loans versus bonds. Second, restrictions that could lead to a liquidity effect are examined within the context of a model with a more complete financial sector. To facilitate this comparison, monopolistically-competitive intermediate goods producers are introduced that must finance their wage bill prior to production. Two potential restrictions are placed on the model that could induce liquidity effects. The first is that monopolistic producers set prices in advance of the shock. As in some of versions of Christiano, et al. (1996), this degree of price stickiness is insufficient to bring about a liquidity effect. Thus, their result is seen to generalize to a model that incorporates three additional features of the economy that significantly affect asset allocations: a bond market, a market for reproducible capital, and an explicit role for banks to play in the economy's payment system.

The second restriction is that the deposit market clears prior to the realization of the money shock. This involves both a precommitment of deposits by households and a determination of the deposit rate prior to the shock. These restrictions do induce a strong liquidity effect, as is true for the deposit precommitment case in Christiano et al. It is noteworthy that, in this model, it is not necessary for this result that gross investment

also be funded out of working capital finance and that the gross investment decision also represent a precommitment prior to the money shock, as is the case in Christiano (1991), for example. Moreover, the model produces persistence in the liquidity effect, without imposing additional frictions of an arbitrary transaction cost incurred by households for adjusting their financial asset portfolio that induces a sluggish, partial adjustment of deposits in periods subsequent to the shock as in Christiano et al. (1995). This persistence is shown to be due to the presence of the bond market. Absent the bond market, households are forced to absorb the monetary shock with liquid asset holdings, thus keeping the demand for real money balances relatively high and bringing about a slow price adjustment. The availability of the bond market provides households with a savings asset that helps to insulate their income somewhat from inflation. Thus, in response to a monetary shock, the demand for bonds increases, thereby mitigating the demand for real money balances, and inducing an overshooting of prices relative to their long-run equilibrium path. Consequently, the sharper initial price response results in lower expected inflation premia in nominal interest rates that dissipate slowly.

A final version of this model is estimated that minimizes the deposit precommitment, where only one percent of household deposits are precommited, but retains the presetting of the deposit rate by the bank. In this case, a persistent liquidity effect is still present and slightly weaker, which brings it more into line with the data, while removing the excess volatility in consumption. This suggests that deposit rate setting by the banks may be the more important friction that induces the liquidity effects that are observed in the data.

The model is developed in the section II. The calibration is described in Section III, and the simulation results are presented in Section IV. Section V concludes.

II. The Theoretical Model.

The model consists of five sectors: households, final goods producers, intermediate goods producers, commercial banks, and the monetary authority. Households provide labor services to intermediate goods producers and purchase final goods. They make labor/leisure, consumption/savings, and financial portfolio allocation decisions, where the last of these determines the stocks of money, bank deposits, and corporate bonds to carry forward into the next period. Its consumption goods purchases are constrained by a payments system technology in which the beginning-of-period stocks of real money and deposit balances limit the volume of real purchases. Firms in the final goods sector are competitive, and employ a Dixit-Stiglitz production technology that transforms intermediate goods into final goods, and yields a downward-sloping demand for intermediate goods. Intermediate goods producers are thus monopolistic competitors that buy capital goods from the final goods producers and rent labor services from households to produce intermediate goods for which they charge an equilibrium mean markup of price over marginal costs. The marginal costs are affected by a financing constraint that requires firms to pay for the labor services prior to production. These funds are acquired through a combination

of bank loans and bonds. To account for the lack of perfect substitutability between bank loans and bonds a financing portfolio adjustment cost function is introduced that ensures the existence of an optimal mix of funding sources. Banks take in deposit funds, set aside reserves to meet their reserve requirements, and loan out the remainder of the deposit funds to intermediate goods producers for their working capital expenses. The banks receive reserves injections from the government at a rate determined by a stochastic policy rule. Sticky price and limited participation versions of the model are examined in turn by having intermediate goods producers set prices in advance of the monetary shock, and by having households precommit to a deposit position with banks presetting interest rates prior to the money shock, respectively.

1. Household sector.

The representative household seeks to make its optimal set of decisions that maximize expected lifetime utility, or

$$\max_{\{X^d_{t+1}\}} E\Big[\max_{\{c_t,l_t,n_t(i),M^d_{t+1},B^d_{t+1}\}} E\Big(\sum_{t=0}^{\infty}\beta^t U(c_t,l_t)\Big|\Omega\Big)\Big|\Omega^H\Big], \quad \beta\in(0,1) \tag{1}$$

where period utility is derived from consumption, c_t, and leisure, l_t according to the utility function $U:\Re^2_+\rightarrow\Re$, which is continuous, continuously-differentiable, and strictly concave in each of its arguments, and the discount factor is given by β. In addition to consumption and leisure, the household chooses optimal sequences for the quantity of labor to supply to each of the intermediate goods firms, $\{n_t(i)\},\forall i$, where there is assumed to be a continuum of such firms arrayed on the unit interval. The sequence of portfolio allocation choices consists of the triple of financial assets stocks $\{M^d_{t+1},X^d_{t+1},B^d_{t+1}\}$. The conditioning information set for the choices of money, M^d_{t+1}, and bonds, B^d_{t+1}, is denoted Ω, and includes all contemporaneous information. The choice of deposits, X^d_{t+1}, may exclude the contemporaneous money shock, and thus has a conditioning information set $\Omega^H\subset\Omega$ in the case of precommitment. Otherwise, the deposit allocation is also selected on the basis full contemporaneous information and $\Omega^H=\Omega$. [2]

The household's budget constraint is given by:

$$P_tc_t+M^d_{t+1}+X^d_{t+1}+B^d_{t+1}$$

$$\leq\int_{i=0}^{1}W_tn_t(i)di+M^d_t+(1+r^d_t)X^d_t+(1+r^b_t)B^d_t+\Pi^F_t+\int_{i=0}^{1}\Pi^I_t(i)di+\Pi^{CB}_t \tag{2}$$

[2]Later in the paper we also examine the case of in which only a fraction of households precommit to their deposit position, while the remainder fully adjust their financial asset portfolios after observing the money shock.

where: P_t is the final goods price; labor income is given by $\int_{i=0}^{1} W_t n_t(i)di$, with W_t the money wage; r_t^d and r_t^b are the deposit and bond rates; and $\Pi_t^F, \Pi_t^I(i)$, and Π_t^{CB} are the *per capita* profits from the final goods firm, the *ith* intermediate goods firm, and the commercial bank, respectively.

The household's nominal consumption purchases are constrained by a payments system technology that is premised on the degree of liquidity in the household's financial asset portfolio, and the fact that money and bank deposits are imperfect substitutes in determining final settlement.

$$P_t c_t \leq \tilde{G}(M_t^d, X_t^d) \tag{3}$$

where $\tilde{G} : \Re_+^2 \rightarrow \Re_+$ is the payments technology that is continuous, continuously-differenti- able, concave in each argument, and homogeneous of degree one in M_t^d and X_t^d.

The household also faces a time resource constraint:

$$\int_{i=0}^{1} n_t(i)di + l_t \leq 1 \tag{4}$$

and non-negativity constraints $c_t, l_t, n_t(i), M_{t+1}^d, X_{t+1}^d, B_{t+1}^d \geq 0$.

2. A recursive formulation of the household's problem.

To set up this problem recursively, it is necessary to obtain a stationary version of the model. Looking ahead, this can be achieved by normalizing all nominal variables on the volume of bank reserves denoted Z_t, whose gross growth rate $\mu_t \equiv Z_{t+1}/Z_t$ is stochastic and determined by an exogenous policy rule. Dropping the time subscripts, define the following set of normalized variables: $p \equiv P/Z; m^d \equiv M^d/Z; x \equiv X^d/Z; b^d \equiv B^d/Z; w \equiv W/Z; \pi^F \equiv \Pi^F/Z; \pi^I(i) \equiv \Pi^I(i)/Z$; and $\pi^{CB} \equiv \Pi^{CB}/Z$. The household's value function is given by $v^H(s^H)$, where the household's state vector is defined as $s^H \equiv [m^d, x^d, b^d; S]$, with S representing the aggregate state vector defined below. The dynamic program can then be formulated as follows [where next period's values are denoted by primes ($'$) and the subscript on the expectations operators indicates the appropriate conditioning information set]:

$$v^H(s^H) = \max_{x^{d\prime}(s^H) \in \Gamma^h(s^H)} E_{\Omega^H} \Big\{ \max_{\gamma^h(s^H) \in \Gamma^h(s^H)} E_{\Omega}[U(c,l) + v^H(s^{H\prime})] \Big\} \tag{5}$$

where the household's optimal set of decision rules is given by $[x^{d\prime}(s^H), \gamma^h(s^H)]$, with the subset $\gamma^h(s^H) \equiv [c(s^H), l(s^H), n(i, s^H), m^{d\prime}(s^H), b^{d\prime}(s^H)]$. The feasible set of decision

rules is denoted $\Gamma^h(s^H)$, and is defined by the constraint set given by the normalized budget, normalized payment system, and time resource constraints displayed below, where the functional notation has been dropped for simplicity.

$$pc+(m^{d'}+x^{d'}+b^{d'})\mu \leq \int_{i=0}^{1} wn(i)di+m^d+(1+r^d)x^d+(1+r^b)b^d+\pi^F+\int_{i=0}^{1}\pi^I(i)di+\pi^{CB} \tag{6}$$

$$pc \leq G(m^d, x^d) \tag{7}$$

$$\int_{i=0}^{1} n_t(i)di + l_t \leq 1 \tag{8}$$

where $G = \tilde{G}/Z$.

The solution to the above dynamic programming problem yields the following set of Euler equations (where subcripts on U and G indicate partial derivatives).

$$\beta(1+r^{b'})E_\Omega[U_l'/w'] = U_l\mu/w \tag{9}$$

$$\beta E_\Omega[U_l'/w' + (U_c'/p' - U_l'/w')G_{m^{d'}}] = U_l\mu/w \tag{10}$$

$$E_{\Omega^H}[\beta U_l'(1+r^{d'})/w' + \beta(U_c'/p' - U_l'/w')G_{x^{d'}} - U_l\mu/w] = 0 \tag{11}$$

These three Euler equations have the interpretation of optimal marginal decisions, say, to reduce leisure by one unit today in order to increase labor supply, with the additional labor income carried forward in the form of bonds, equation (9), money, equation (10), and deposits, equation (11).

3. Final goods sector.

The final goods sector is assumed to be perfectly competitive and is modeled as a single aggregate price-taking, zero-profit firm. The sole factors of production are intermediate goods that enter into the following Dixit-Stiglitz production technology:

$$e_t = \Big[\int_{i=0}^{1} y_t^d(i)^{\frac{\gamma-1}{\gamma}}\Big]^{\frac{\gamma}{\gamma-1}}di, \quad \gamma > 1 \tag{12}$$

where e_t is the *per capita* output of final goods, and $y_t^d(i)$ is the *per capita* input of intermediate goods from the *ith* firm in the intermediate goods sector.

Define the unit price of the ith intermediate good to be $Q_t(i)$. Then, the period profit function for the final goods firm is given by:

$$\Pi_t^F = P_t e_t - \int_{i=0}^{1} Q_t(i) y_t^d(i) di \tag{13}$$

The firm has no dynamic choices and can therefore maximize profits period-by-period by choosing output, e_t, and its array of inputs $y_t^d(i),\ \forall i$, or

$$\max_{e_t, y_t^d(i)} \Pi_t^F \tag{14}$$

subject to (13). Defining the normalized intermediate goods price as $q_t(i) = Q_t(i)/Z_t$, the first-order condition becomes (after dropping the time subscripts):

$$q(i) = p\Big[e/y^d(i)\Big]^{\frac{1}{\gamma}}, \quad \forall i \tag{15}$$

Equation (15) represents the zero-profit conditions for the firm.

4. The intermediate goods sector.

There is a continuum of intermediate goods producers with identical technologies that transform capital and labor services into output. This technology is stochastic with each firm receiving the same productivity shock. Sales from the ith firm cannot exceed this production limit as given by:

$$y_t(i) \leq \theta F[k_t^d(i), n_t^d(i)] \tag{16}$$

where $y_t(i)$ is the firm's output, θ is the productivity shock that is assumed to follow a first-order Markov process, and $F : \Re_+^2 \rightarrow \Re_+$ is a constant returns to scale production technology that is continuous, continuously-differentiable, and concave in its arguments of capital, $k_t^d(i)$, and labor, $n_t^d(i)$.

As a monopoly producer, this firm faces a downward-sloping demand for its product, such that:

$$y_t(i) \geq D[Q_t(i), P_t, e_t] \tag{17}$$

where $D : \Re_+^3 \rightarrow \Re_+$ is the demand function that is homogeneous of degree one in e_t and homogenous of degree γ in P_t and $-\gamma$ in $Q_t(i)$.

While the firm is assumed to finance its gross investment out of current revenues, its wage bill is financed from the proceeds of bank loans and bond issuance. Assuming one-period bonds with a face value at date t of $B_{t+1}(i)$, and one-period bank loans with a face value at date t of $V^d_{t+1}(i)$, where both are retired at date $t+1$, the firm faces the following financing constraint:

$$W_t n^d_t(i) \leq B_{t+1}(i) + V^d_{t+1}(i) \tag{18}$$

To capture the lack of perfect substitutability between bonds and bank loans, the firm is assumed to pay a financing cost that varies with the composition of finance. This function is denoted $\tilde{T}[B_{t+1}(i), V^d_{t+1}(i), P]$, where $\tilde{T} : \Re^3_+ \rightarrow \Re$, and is continuous and continuously-differentiable in each argument, and convex in $B_{t+1}(i)$ and $V^d_{t+1}(i)$, and linearly, homogeneous of degree one in P_t.

Period profits for the firm are given by nominal sales revenues less gross investment expenditures less the cost of retiring its debt less its financing cost.

$$\Pi^I_t(i) = P_t y_t(i) - P_t[k_{t+1}(i)^d - (1-\delta)k^d_t(i)]$$

$$-(1+r^v_t)V^d_t - (1+r^b_t)B_t(i) - \tilde{T}[B_{t+1}(i), V^d_{t+1}(i), P], \quad \delta \in (0,1) \tag{19}$$

where δ is the rate of depreciation on capital, and r^v_t is the bank loan rate.

Assuming that there are no agency costs such that the firm acts in the interest of its shareholders, and that the firm's profits are paid out each period as dividends, it will choose its production point $[Q_t(i), y_t(i)]$, its factor inputs $[k^d_t(i), n^d_t(i)]$, and its working capital financing mix $[B_{t+1}(i), V^d_{t+1}(i)]$ in order to maximize the present discounted value of its future dividend stream, where the discount factor is determined by household preferences.

$$\max_{\{Q_t(i)\}} E_{\Omega^I}\Big\{ \max_{\{y_t(i), k^d_{t+1}(i), n^d_t(i), B_{t+1}(i), V^d_{t+1}(i)\}} E_\Omega\Big[\sum_{t=0}^{\infty} \beta^{t+1}\Big(\frac{U_{c_{t+1}}\tilde{G}_{M^d_{t+1}}}{P_{t+1}}\Big)\Pi^I_t(i)\Big]\Big\} \tag{20}$$

where $\tilde{G}_{M^d_{t+1}}$ denotes the partial derivative of $\tilde{G}$ with respect to M^d_{t+1}. Note that dividends are paid in monetary units (dollars), which must be held one period before using each dollar to purchase $\tilde{G}_{M^d_{t+1}}/P_{t+1}$ units of consumption goods, c_{t+1}. Each unit of consumption is valued next period at its marginal utility value, $U_{c_{t+1}}$, and must be discounted back one period as determined by the discount factor, β, to obtain its present value.

This optimization takes $[k^d_0(i), B_0(i), V^d_0(i)]$ as given, and is subject to the constraints imposed by the firm's technology, (16), its product demand schedule, (17), and its financing constraint, (18). In addition, "sticky prices" may be introduced by restricting

the conditioning information set, Ω^I, to exclude the current period monetary shock. Otherwise, prices are assumed to be set under full information, where $\Omega^I = \Omega$.

5. A recursive representation of the ith intermediate goods firm's optimization.

Dropping time subscripts, define the normalized variables $b(i) \equiv B(i)/Z$, $v^d(i) \equiv V^d(i)/Z$, and $q(i) \equiv Q(i)/Z$, and let the firm's state vector be defined by $s^I(i) \equiv [k^d(i), b(i), v^d(i); S]$ and the firm's value function be given by $v^i[s^I(i)]$. The firm's dynamic program can be written in stationary form as:

$$v^i[s^I(i)] = \max_{q(i,s^I(i))\in\Gamma^i[s^I(i)]} E_{\Omega^I}\Big\{ \max_{\gamma^i[s^I(i)]\in\Gamma^i[s^I(i)]} E_{\Omega}\Big[\beta\Big(\frac{U_c' G_{m^d}'}{p'\mu}\Big)\times$$

$$\Big(q(i)y(i) - p[k^{d'}(i) - (1-\delta)k^d(i)] - (1+r^b)b(i) - (1+r^v)v^d(i) - T[b'(i), v^{d'}(i)]\Big)$$

$$+\beta v[s^{I'}(i)]\Big]\Big\} \tag{21}$$

where $T = \tilde{T}/Z$, and the firm's optimal decision rules are given by $(q[i, s^I(i)], \gamma^i[s^I(i)])$, with $\gamma^i[s^I(i)] \equiv (k^{d'}[i, s^I(i)], n^d[i, s^I(i)], y[i, s^I(i)], b'[i, s^I(i)], v^{d'}[i, s^I(i)])$. These decision rules are chosen from the feasible set, $\Gamma^i[s^I(i)]$, given by the firm's production technology, its product demand schedule, and its financing constraint, which can be rewritten after normalization as follows:

$$y(i) \leq \theta F[k^d(i), n^d(i)] \tag{22}$$

$$y(i) \geq D[q(i), p, e] \tag{23}$$

$$wn^d(i) \leq [b'(i) + v^{d'}(i)]\mu \tag{24}$$

The Euler equations for this optimization problem become:

$$E_\Omega\Big\{\frac{U_{c'}G_{m^{d'}}p}{\mu p'} - \beta\frac{U_{c''}G_{m^{d''}}}{\mu' p''}[p'(1-\delta) + \theta' F_{k^{d'}}q'] - \theta' F_{k^{d'}}\lambda'\Big\} = 0 \tag{25}$$

$$E_\Omega\Big\{\frac{U_{c'}G_{m^{d'}}}{\mu p'}\Big[\frac{\mu\theta F_{n^d}q}{w} - T'_{b^d}\Big] - \beta\frac{U_{c''}G_{m^{d''}}(1+r^{b'})}{\mu' p''} + \frac{\theta F_{n^d}\mu}{w}\lambda\Big\} = 0 \tag{26}$$

$$E_\Omega\Big\{\frac{U_{c'}G_{m^{d'}}}{\mu p'}\Big[\frac{\mu\theta F_{n^d}q}{w} - T'_{v^d}\Big] - \beta\frac{U_{c''}G_{m^{d''}}(1+r^{v'})}{\mu' p''} + \frac{\theta F_{n^d}\mu}{w}\lambda\Big\} = 0 \tag{27}$$

$$E_{\Omega^I}\Big\{\beta\frac{U_{c'}G_{m^{d'}}y}{\mu p'}-\lambda D_q\Big\}=0 \tag{28}$$

where λ is the Lagrange multiplier on (23).

Equation (25) represents the optimal marginal decision, say, to reduce investment and use the proceeds to increase the dividend payout. Note that the second term in (25) is the discounted value of the usual penalty for a marginal reduction in next period's capital stock, while the last term, involving λ, reflects the loss from tightening the product demand schedule constraint that is faced by the monopolist next period.

Equations (26) and (27) represent optimal marginal decision, say, to increase employment in the current period in order to raise production and increase the dividend payout, with the greater cost reflected in higher bond financing in (26) and higher bank loan financing in (27). Note here that there is an additional current period cost to the firm of adjusting its financing mix, which is captured by the terms involving the partial derivatives, $T_{b^{d'}}$ and $T_{v^{d'}}$, and there is an additional benefit of the higher production from a relaxation of the product demand schedule constraint faced by the monopolist, as reflected in the last term of both equations.

Equation (28) is the optimal intratemporal marginal decision on price setting, where a higher product price raises revenues but tightens the product demand schedule constraint.

6. The banking sector.

The commercial banking sector is competitive and is represented by a single aggregate profit-maximizing firm. However, under deposit precommitment by households, the deposit market clears prior to the monetary shock. This implies that the equilibrium level of bank deposits and the equilibrium bank deposit rate are predetermined with respect to the current realization of the monetary policy actions. Monetary shocks are therefore absorbed by the bank loan market.

Using the prime notation, the bank begins the period by receiving *per capita* deposits, X', from households, against which it must set aside reserves. The bank retains required reserves, Z^r, in the amount:

$$Z^{r\prime}=\zeta X', \quad \zeta\in(0,1) \tag{29}$$

where ζ is the reserve requirement ratio. In the case of deposit precommitment by households, $Z^{r\prime}=E_{\Omega^H}[Z']$. For the case of no precommitment, $Z^{r\prime}=Z'$. The remainder of the bank's deposit funds along with any unanticipated injection of reserves by the central bank are loaned out to firms in the amount:

$$V'=(1-\zeta)X'+R^u \tag{30}$$

where $R^u \equiv Z' - E_{\Omega^H}[Z']$ denotes the unanticipated reserve injection. Normalizing on Z, the value of normalized bank loans, defined as $v = V/Z$, is then given by:

$$v' = \begin{cases} (1-\zeta)x' + 1 - E_{\Omega^H}[\mu]/\mu, & \text{with deposit precommitment} \\ [(1-\zeta)/\zeta], & \text{without deposit precommitment} \end{cases} \tag{31}$$

Each period the bank pays dividends to households equal to its (*per capita*) net cash flows, Π^{CB}, where:

$$\Pi^{CB\prime} = Z^{r\prime} + (1 + r^{v\prime})V' - (1 + r^{d'} + \xi)X', \quad \xi > 0 \tag{32}$$

where ξ is the marginal cost of servicing deposit accounts. Equilibrium deposit and bank loan rates are found as the first-order condition to the period profit-(net cash flow-) maximization, consistent with the bank choosing its balance sheet for the upcoming period, or

$$\max_{Z^{r\prime}, X'} E_{\Omega^H}\Big[\max_{V'} \Pi^{CB\prime}\Big] \tag{33}$$

subject to its reserves requirements, equation (29), and its balance sheet constraint, equation (30).

After normalization, the first-order condition becomes:

$$1 + r^{d'} + \xi - \zeta = (1-\zeta)E_{\Omega^H}(1 + r^{v\prime}) \tag{34}$$

Looking ahead, we note that from equation (31), a positive monetary shock can cause the supply of bank loans to rise relative to deposits, and from equation (34), the bank loan rate to fall. This is the source of the liquidity effect in models of Christiano, et al. (previously cited). However, in those models no distinction is made between the bank loan rate and the deposit rate. In this model, under deposit precommitment, the deposit rate is unaffected by the monetary shock in the current period since the deposit market has already cleared.

7. The monetary authority.

The only role of government in the model is to provide reserves to the banking system. It does so in accordance with a reserves growth rule,

$$Z' = \mu Z, \quad E[\mu] > \beta, \tag{35}$$

where μ is stochastic and follows a first-order Markov process.

8. Equilibrium.

Let the aggregate state vector be defined as $S = [m, x, b, v, k; \theta, \mu]$ and the aggregate laws of motion as $\Lambda_1(S) = [m' = m(S), x' = x(S), v' = v(S), k' = k(S)]$. The vector of aggregate *per capita* decision rules is given by: $\Lambda_2(S) = [C(S), N(i,S), L(S), \tilde{m}^d(S), \tilde{x}^d(S), \tilde{b}^d(S)]$.

A *recursive competitive equilibrium* for this economy can be defined as: (i) the set of household decision rules: $[x^{d'}(s^H), \gamma^h(s^H)]$; (ii) the set of decision rules for each of the intermediate goods firms: $(q[i, s^I(i)], \gamma^i[s^I(i)])$, $\forall i$; (iii) the aggregate laws of motion, $\Lambda_1(S)$, and the vector of aggregate decision rules: $\Lambda_2(S)$; (iv) the vector of pricing functions: $[p(S), q(i,S), r^d(S), r^v(S), r^b(S), \lambda(S)]$; (v) the aggregate laws of motion governing the exogenous state variables, $\theta(S)$ and $\mu(S)$; and (vi) the value functions: $v^H(s^H)$ and $v^i(s^I)$, $\forall i$, that satisfy:

(1) (*household optimization*): Equations (9)-(11), given the payment system and time resource constraints, equations (7) and (8);

(2) (*profit-maximization by the final goods firm*): Equation (15), given its production technology, equation (12);

(3) (*optimization by the intermediate goods firms*): Equations (25)-(28), given their technology, product demand, and financing constraints, equations (22)-(24), $\forall i$ firms;

(4) (*profit-maximization by the bank*): Equation (34), given the reserve requirement and technology constraints, that are combined in equation (31);

(5) (*aggregate consistency conditions*): $c(s^H) = C(S), n(i, s^H) = N(i,S), l(s^H) = L(S)$, $m^d(s^H) = \tilde{m}^d(S), x^d(s^H) = \tilde{x}^d(S); b^d(s^H) = \tilde{b}^d(S)$;

and

(6) (*equilibrium conditions*): in the final goods market: $e(S) = C(S) + k'(S) - (1-\delta)k$; labor market: $n^d(i, s^I) = N(i,S), \forall i$; capital market: $\int_{i=0}^{1} k^d(i)di = k$; money market: $\tilde{m}^d = m$; deposit market: $\tilde{x}^d = x$; bank loan market: $\int_{i=0}^{1} v^d(i)di = v$; and the bond market: $\tilde{b}^d = b$.

III. Calibration.

To perform the simulation exercises with the model, it is necessary to specify functional forms for the utility function, U, the payments system technology, G, the production technology in the intermediate goods sector, F, the demand schedule for intermediate goods, D, and the portfolio cost function, T. The steady-state version of the model can then be calibrated to U.S. data, and a numerical solution to the stochastic version of the model can be found.

1. Functional forms.

In the household sector, preferences are characterized as logarithmic, with the period utility function given by (dropping the time subscripts):

$$U(c,l) = \ln c + \eta \ln l, \quad \eta > 0 \tag{36}$$

The payment system technology is Cobb-Douglas, and can be expressed in terms of normalized variables as:

$$G(m^d, x^d) = g_0 m^{d g_1} x^{d(1-g_1)}, \quad g_0 > 0, g_1 \in (0,1) \tag{37}$$

In the intermediate goods sector, the production technology is Cobb-Douglas, or

$$\theta F[k^d(i), n^d(i)] = \theta A k^d(i)^{\alpha} n^d(i)^{(1-\alpha)}, \quad \alpha \in (0,1), \quad \forall i \tag{38}$$

The demand schedule for intermediate goods can be expressed in terms of normalized variables by solving the first-order condition for the final goods sector, equation (15), for $y(i)$:

$$D[e, p, q(i)] = e[p/q(i)]^{\gamma}, \ \gamma > 1, \quad \forall i \tag{39}$$

The portfolio adjustment cost function is quadratic in real bonds and real bank loans and satisfies the homogeneity properties for prices:

$$\tilde{T}(P, B'(i), V^{d'}(i)) = P\tau_0\Big[\tau_1\Big(\frac{B'(i)}{P}\Big)^2 + (1-\tau_1)\Big(\frac{V^{d'}(i)}{P}\Big)^2\Big], \quad \tau_0 > 0, \tau_1 \in (0,1), \quad \forall i \tag{40}$$

Normalizing equation (40) on Z yields:

$$T(p, b'(i), v^{d'}(i)) = p\tau_0\mu^2\Big[\tau_1\Big(\frac{b'(i)}{p}\Big)^2 + (1-\tau_1)\Big(\frac{v^{d'}(i)}{p}\Big)^2\Big], \quad \tau_0 > 0, \tau_1 \in (0,1), \quad \forall i \tag{41}$$

The aggregate laws of motion for the exogenous variables are: (i) for total factor productivity:

$$\ln \theta' = \rho^p \ln \theta + \epsilon^{p\prime}, \quad \rho^p \in (0,1), \quad \epsilon^p \sim iidN(0, \sigma^{p2}) \tag{42}$$

and (ii) for the gross growth rate of bank reserves:

$$\ln \mu' = \bar{\mu} + \rho^m \ln \mu + \epsilon^{m\prime}, \quad \bar{\mu} > (1-\rho^m)e^{\beta}, \quad \rho^m \in (0,1), \quad \epsilon^m \sim iidN(0, \sigma^{m2}) \tag{43}$$

2. Calibration. In equilibrium, all intermediate goods producers have the same technology and cost structure, and face identical product demand schedules. Consequently, as monopolists, they will choose the same production point implying $y(i) = y$ and $q(i) = q, \quad \forall i$ producers. Therefore, from equation (12),

$$e = y, \tag{44}$$

and then from equation (15),

$$q = p. \tag{45}$$

With these relationships, the model consists of nineteen equations: (7) -(11),(22)-(28),(31), (34), and (42)-(45), and equilibrium in the final goods market, seventeen endogenous variables: $C, k, N, L, m, x, b, v, p, q, w, r^d, r^b, r^v, \lambda$, two exogenous variables: θ, μ, and seventeen parameters: $g_0, g_1, \beta, \eta, A, \alpha, \gamma, \delta, \tau_0, \tau_1, \zeta, \xi, \bar{\mu}, \rho^m, \rho^p, \sigma^m$, and σ^p, where the last four parameters are required to characterize the stochastic processes for μ and θ. To perform the steady-state calibration, thirteen restrictions are needed. Parameters and steady-state values in the real sector of the economy are obtained from the calibration procedure outlined in Cooley and Prescott (1989), with two exceptions. Government capital was excluded from the capital stock, and the stock and service flows from consumer durables were obtained from the estimates derived by the Federal Reserve Board. Using annual data from 1960 to 1998, this procedure yielded a quarterly capital/output ratio of $k/y = 10.516$, a quarterly depreciation rate of $\delta = 0.0182$, and a value for $\alpha = 0.314$. From the monetary data, the sample average currency-deposit ratio (with deposits defined as the sum of OCDs and DDAs) is $m/x = 0.365$. The prime rate and 90-day commercial paper rate were used as proxies for the bank lending rate, r^v, and the bond rate, r^b, respectively. Over the sample period 1973-1998, these rates averaged $r^v = 9.403$ percent and $r^b = 7.451$ percent on an annualized basis. The deposit rate was proxied by the Federal Reserve Board's estimate of a weighted-average rate of return on bank transaction accounts (OMS rate), which for 1973-1999 averaged $r^d = 4.721$ percent on an annualized basis. In the model, the monetary rule governs the mean growth rate of bank reserves which determines the steady-state inflation rate. Over the period 1960 to 1998, the CPI inflation rate averaged 3.98 percent per year. [3] The reserve requirement ratio was set equal to the current value for transaction deposits of $\zeta = 0.1$. For

[3] As a note, the inflation rate is close to the 3.61 percent average annual growth rate of total bank reserves over this period.

the average price mark-up in the intermediate goods sector, we used the value of ten percent suggested by Goodfriend and King (1997), implying that $\gamma = 11$. Data from the *Quarterly Financial Reports for Manufacturing Companies, 1980* was used to fix the ratio of bonds to bank loans, which was set equal to the ratio of commercial paper plus "other short-term debt" to short-term bank debt, or $b/v = 0.824$. Leisure time was set at $L = 0.68$, which is the fraction of time households devote to leisure on average based on survey data discussed in Juster and Stafford (1991). The scale parameter in the production technology for intermediate goods was arbitrarily set to $A = 1$. Finally, the parameter τ_1 was set to 0.7, which is approximately in the middle of the feasible range of $\tau_1 \in (0.5, 1)$. These restrictions are consistent with the following parameter values: $g_0 = 3.5787, g_1 = 0.4995, \eta = 1.6185, \beta = 0.9914, \tau_0 = 0.0270$, and $\xi = 0.0094$. Following Kydland and Prescott (1982), and others in the RBC literature, the productivity shocks were assumed to have a high degree of persistence, and ρ^p was set to 0.95. Using quarterly data from 1973:1 to 2000:1, the standard deviation of output was 1.668 percent, implying $\sigma^p = 0.0092$. Following the procedure of Cooley and Hansen (1989), the money rule was estimated by regressing the gross growth rate of total bank reserves on a constant and its lagged value. This regression yielded the estimate $\rho^m = 0.73$. Given that the "nominal distortion" in the model with respect to resource allocations comes from the inflation rate, we used the mean and the standard deviation of the CPI quarterly inflation rate of 1.0 and 0.68 percent, respectively, to obtain implied parameters for the reserves growth rule, which yielded values for $\mu = (1 + 0.01)/(1 - 0.73) = 3.74$, and $\sigma^m = 0.0046$.

IV. Simulation Results.

We report simulation results for four versions of the model. [4] The first is referred to as the "baseline model" in which $\Omega^H = \Omega^I = \Omega$, such that there are no information frictions involved in either intermediate goods price setting or in the deposit market. A "sticky price" version of the model is examined by setting $\Omega^H = \Omega$, but where $\Omega^I \neq \Omega$, that is, intermediate goods producers set the product price after the productivity shock, but prior to the monetary shock. A third version of the model involving "full precommitment" of deposits sets $\Omega^I = \Omega$, but $\Omega^H \neq \Omega$, that is, the deposit market clears after the productivity shock and prior to the monetary shock. A final version of the model involves "partial precommitment" of deposits by households. Here, again after the productivity shock and prior to the monetary shock, only a small fraction (one percent) of households precommit to a deposit position, while the commercial bank continues to preset the deposit rate.

[4] The models were solved using the parameterized expectations algorithm (PEA) developed by Marcet (1988) and DenHaan and Marcet (1990).

1. Second moments.

Referring to Table 1, all four models predict that the degree of bank intermediation, measured as the ratio of bank loans to output, is countercyclical, with the correlation between this measure and output lying in the range of -0.3 to -0.4. These figures match the correlation in the data of -0.372 quite well, where bank loans are measured as the volume of (per capita) commercial and industrial loans of domestically chartered U.S. banks plus those offered by foreign bank affiliates. [5] This result is consistent with the previous findings of Einarsson and Marquis (2001) and is attributed to the fact that the volume of deposits, and hence the volume of bank loans, is linked closely to consumption due to the liquidity services that bank deposits offer households. As with other equilibrium monetary business cycle models [such as Cooley and Hansen (1989)], the cyclical properties of real variables in these models are dominated by productivity shocks versus monetary shocks. Here, a positive productivity shock increases the intermediate goods firms' demand for working capital loans. Banks respond, as is evident by the positive correlation of real bank loans with output. However, consumption smoothing limits the ability of banks to respond fully to this increase in loan demand, and as a consequence, firms rely more heavily on funds raised in the bond market to meet their working capital expenses. This induces the countercyclical behavior of the degree of bank intermediation in lending to firms.

[Insert Table 1.]

From the data, nominal interest rates tend to be relatively smooth, with the percent standard deviation of the deposit rate, $\sigma^d = 0.105$, less than one-third that of the bond rate, $\sigma^b = 0.383$, and of the bank lending rate, $\sigma^v = 0.387$. Moreover, the correlations of the deposit rate with output, $\rho_{r^d,y} = 0.168$, and of the bank lending rate with output, $\rho_{r^v,y} = 0.174$, tend be about one-half that of the correlation between the bond rate and output, $\rho_{r^b,y} = 0.331$. However, all of these correlations are much below the nearly perfect positive correlation between nominal interest rates and output that has been a troublesome prediction of the "limited participation" models examined by Christiano, et al. (previously cited). The exception is Chari, Christiano, and Eichenbaum (1995), where a combination of restrictions that include a costly financial asset portfolio adjustment of households and a partially endogenous monetary policy is required to get this correlation down. Einarsson and Marquis (2001) show that simply adding a direct lending channel via a bond market that allows households to adjust their financial asset portfolio to shocks, is sufficient to match the data on this score, even when there are no information frictions in the model. These results recur in the "baseline model" of this paper, where

[5] Beginning in the 1980s, branches and agencies of foreign banks operating in the United States have significantly increased their market share of C&I loans. This share is currently around 20%. See McCauley and Seth (1992) and Carey, Post, and Sharpe (1998) for discussions.

interest rates tend to be smooth, with percent standard deviations near 0.4 (albeit deposit rates are not distinctly less volatile than the other rates), and more significantly where all of the contemporaneous correlations between interest rates and output are below 0.2. Imposing "sticky prices" does not substantially alter these predictions. However, introducing deposit precommitment and presetting of the deposit rate by the banks does affect these predictions by smoothing interest rates, with percent standard deviations cut nearly in half to a range between 0.16 to 0.29, and by increasing the correlations of interest rates with output, where the latter are in the range of 0.3 to 0.6 and thus remain far below unity.

The bottom three rows of Table 1 provide the contemporaneous correlations between the gross growth rate of bank reserves and interest rates. As detailed by Christiano, et al. (previously cited), nominal interest rates tend to fall contemporaneously with an increase in the growth rate of nonborrowed reserves. In the first column of Table 1, this "liquidity effect" is suggested by the negative contemporaneous correlations between the gross growth rate of nonborrowed reserves and the deposit rate, $\rho_{\mu,r^d} = -0.185$, the bond rate, $\rho_{\mu,r^b} = -0.252$, and the bank loan rate, $\rho_{\mu,r^v} = -0.145$. Without any information friction, these correlations from the "baseline model" are 0.87 to 0.88, suggesting the inflation premium that is attached to nominal interest rates increases with this acceleration in the supply of bank reserves, referred to by Christiano (1991) as the long-run Fisherian fundamentals of nominal interest rates. Imposing sticky prices markedly reduces this contemporaneous correlation to 0.54, but does not reverse the sign and as will be discussed below, results in even higher positive cross-correlations in periods following the monetary shocks. Therefore, the *ad hoc* imposition of sticky prices is not sufficient to bring about a decline in interest rates in response to a surprise acceleration in the supply of bank reserves. These results are consistent with Christiano, et al. (1997) for the parameterization of their model with log-linear utility. [6]

Imposing the alternative information friction whereby households precommit to a deposit position and banks preset the deposit rate prior to the monetary shock is sufficient to generate a liquidity effect. In the "full precommitment" model, nominal interest rates all decline with the monetary shock. The deposit and bank lending rates have correlations with the gross growth rate of bank reserves that are negative and similar in value to the data, with $\rho_{\mu,r^d} = -0.16$ and $\rho_{\mu,r^v} = -0.23$. The bond rate appears to be more systematically responsive to the shock, with a stronger negative correlation with output at $\rho_{\mu,r^b} = -0.41$ than appears in the data. With "partial precommitment," when only one percent of the households precommit to their deposit position, but banks still preset the deposit rate, the liquidity effect is seen to be weaker. In particular, the bond rate correlation with the gross growth rate of bank reserves falls to $\rho_{\mu,r^b} = -0.26$, which is very close to the data, while the correlations of reserves growth with the deposit rate

[6]By reducing the intertemporal elasticity of substitution in consumption, Christiano et al. (1997) were able to obtain a liquidity effect. However, as they emphasize, this feature came at the expense of a significant deterioration in the predictions of the "sticky price" version of their model along other dimensions.

and the bank lending remain low at $\rho_{\mu,r^d} = \rho_{\mu,r^v} = -0.13$, as in the data.

To examine the liquidity effect in more detail, Table 2 displays the cross-correlations of the bond rate with output for each of the four models and compares that with the data. The data indicate that a significant lead-lag relationship between nonborrowed reserves and the 90-day commercial paper rate exists with negative leads and small, positive lags of non-borrowed reserves over the bond rate, and where the strongest liquidity effect is not contemporaneous, but occurs with a lag of one quarter, i.e., $\rho_{r_t^b,\mu_{t-1}} = -0.27$. This pattern is not matched by either the "baseline" model or the "sticky price" model, where the inflation tax effect is very strong. Contrary to these predictions, both of the "precommitment models" yield a similar pattern of cross-correlations to those observed in the data, with the strongest effect occurring with a one-quarter lag. While the correlations appear stronger in both models than is observed in the data, and the "partial precommitment" model has slightly lower values, there is not much to choose between the two models on this score.

[Insert Table 2.]

To differentiate between these two "precommitment" models, refer to the statistics in Table 1 concerning investment and consumption. For the "full precommitment" model, both consumption and investment are significantly more volatility and much less correlated with output than is found in the data. Most striking is the counterfactual prediction that consumption is more volatile than output, with the model predicting $\sigma_c = 2.07$ versus $\sigma_c = 0.921$ in the data. Investment is approximately fifty perent more volatile than in the data with $\sigma_i = 9.43$ in the model versus $\sigma_i = 6.277$ in the data. These statistics also imply that the model predicts a negative correlation between consumption and investment. Finally, the correlation between consumption and output is $\rho_{c,y} = 0.43$ versus $\rho_{c,y} = 0.849$ in the data, and the correlation between investment and output is $\rho_{i,y} = 0.51$ versus $\rho_{i,y} = 0.943$ in the data. For most researchers these counterfactual predictions would be sufficient grounds to reject the model as is.

However, when the fraction of households precommiting to their deposit position prior to the money shock is reduced to one percent, effectively limiting the information friction to the bank's presetting of deposit rates, the resulting "partial precommitment" model yields predictions for the second moments of consumption and investment that are much more in line with the data. Consumption volatility, with a percent standard deviation of $\sigma_c = 1.51$, is still too high, but is significantly less than output, while investment actually becomes slightly smoother than is observed in the data, with $\sigma_i = 5.52$. In addition, the correlations between consumption and output and between investment and output are high at $\rho_{c,y} = 0.80$ and $\rho_{i,y} = 0.74$, which are much more in accord with the data.

2. Impulse response functions.

To examine in greater detail the dynamic properties of the models that produced the business cycle statistics described above, the impulse response functions of key variables related to productivity and monetary shocks are computed and displayed in Figures 1-6. The response of the "baseline" model to a productivity shock is similar to that for the "sticky price" model, thus only the results of the former are shown in Figure 1. A positive productivity shock is seen to increase employment (Figure 1a) and output (Figure 1b), with an attendant rise in the need for working capital finance by firms. This greater funding need is financed in part by an increase in real bonds (Figure 1c) and to a lesser extent by an increase in real bank loans (Figure 1d). Consumption-smoothing causes a lesser percentage increase in consumption (Figure 1e) than in investment (Figure 1f), and as a consequence households allocate a greater share of the increase in financial wealth to bonds than to liquid assets (money and bank deposits). Bank loans, therefore, cannot respond to the same extent as the supply of bonds, with the tighter loan market inducing a sharper increase in the bank lending rate (Figure 1g) than in the bond rate (Figure 1h). Note that this lesser degree of responsiveness in the supply of bank loans relative to bonds causes the degree of bank intermediation to decline. This mechanism is the dominant factor that induces the countercyclicality in the degree of bank intermediation over the business cycle.

[Insert Figure 1.]

The impulse response functions of the two "precommitment" models to a positive productivity shock are also similar to each other. In Figure 2, the impulse response functions associated with a productivity shock in the "partial precommitment" model are displayed. Qualitatively, the responses look much like those of the "baseline" model. However, quantitatively, the increases in employment, output, consumption, and investment (Figures 2a,2b,2e,2f) are all greater in the "partial precommitment" model. This is due to the fact that interest rates do not respond as strongly as before, with a greater effect on the bank loan rate (Figure 2g) than on the bond rate (Figure 2h). This lesser rise in both rates mitigates the impact of the shock on the financing costs of intermediate goods firms, which therefore expand employment and output to an even greater extent. In addition, while both the bond and bank loan markets expand, there is an even greater percentage increase in real bonds (Figure 2c) than in real bank loans (Figure 2d) relative to what was evidenced in the "baseline" model. In isolation, this factor tends to cause the degree of bank intermediation to become even more strongly countercyclical.

[Insert Figure 2.]

Figures 3 and 4 display the impulse response functions for the "baseline" and "sticky price" models to a positive shock to the growth rate of bank reserves. The reserves injection raises the quantity of nominal bank lending in the initial quarter by an identical amount in the two models. However, because prices are fixed in the "sticky price" model in the initial period, the increase in real bank lending is greater in that model. Unlike the limited participation models of Christiano et al. (previously cited), bank lending only represents a portion of the funds available to firms to fund their working capital expenses. It is necessary to examine the equilibrium response of the bond market to determine how this reserves injection affects the total allocation of short-term credit to firms. As discussed above, the absence of a liquidity effect causes nominal rates in both models to rise. However, compared with the "sticky price" model, the "baseline" model causes an even greater percentage increase in anticipated inflation, such that the initial increases in real interest rates [Figures 3(i,j) and 4(i,j)] are higher in the "sticky price" model. As a consequence, the intermediate goods firms experience a greater increase in their borrowing cost in the "sticky price" model and reduce their demand for labor to an even greater extent. Therefore, the increase in real bank loans (Figures 3d and 4d) brought about by the reserves injection is more than offset by the decrease in real bonds (Figures 3c and 4c) in both models, with this response more pronounced in the "sticky price" model.

[Insert Figures 3 and 4.]

In addition, with higher real interest rates, employment (Figures 3a and 4a) and output (Figures 3b and 4b) both decline more sharply when prices are sticky. Also, with prices fixed in the initial period of the shock, and with the liquid asset allocation having already been predetermined, consumption (Figure 4e) does not respond (from the payment system constraint). However, with prices rising in the "baseline" model, consumption (Figure 3e) will initially decline. Therefore, in the "sticky price" model, investment (Figure 3f) must absorb not only the greater decline in output, but a lesser allocation of output, than in the baseline model (Figure 3e), given that the propensity to consume is higher. This tends to add persistence to the response of the real economy to monetary shocks. Finally, in both models a reserves injection increases the degree of bank intermediation while output falls, thus compounding the countercyclical response of bank intermediation over the business cycle induced by productivity shocks. This effect shows up in Table 1 with the relatively high correlation figures for $\rho_{(V'/py),y}$ for these models.

Figures 5 and 6 display the impulse response functions for the two "precommitment" models to a positive shock to the growth rate of bank reserves. With prices flexible, the price level rises immediately while inflation expectations decrease, either already on impact (the "full precommitment" model), or from quarter three onwards (the "partial precommitment" model.) In both models, the information friction is sufficient to induce a "liquidity effect," with declines occurring in both the nominal bank loan rate (Figures

5g and 6g) and the nominal bond rate (Figures 5h and 6h). The decline in nominal rates is strong enough to bring about a fall in the real interest rates [Figures (5i,j) and 6(i,j)]. Declining real interest rates reduce the borrowing costs for intermediate goods producers, who increase their hiring, and employment (Figures 5a and 6a) and output (Figures 5b and 6b) rise. Greater household income increases the financial wealth of households, but with a disproportionate share being allocated to bonds due to consumption smoothing, and deposit precommitment. Therefore, in nominal terms, firms meet their increased borrowing needs more with bonds than with bank loans, and to such an extent that with the higher price level, the volume of real bank loans (Figures 5d and 6d) declines, while the volume of real bonds (Figures 5c and 6c) rises.

[Insert Figures 5 and 6.]

There are two effects of the higher degree of deposit precommitment that are evidenced by these simulations. First, a greater precommitment of deposits further curtails the ability of banks to raise deposit funds to meet the higher loan demand. As a consequence, the degree of bank intermediation in the initial periods is more sharply reduced in the "full precommitment" model than in the "partial precommitment" model.

Second, the higher degree of deposit precommitment reduces consumption (Figures 5e and 6e) through the payments system constraint. As a consequence, the propensity to consume in the initial periods declines, and a greater share of the higher output is allocated to investment (Figures 5f and 6f). This adds persistence to the real effects of the monetary shocks. In the limit of the "full precommitment" case, this characteristic of the dynamics of the model results in the excess volatility of both consumption and investment as described above, and as reported in Table 1.

3. Persistence in the liquidity effect.

An issue that has been of some concern to the literature on "limited participation" models is the inherent lack of persistence in the liquidity effect of a reserves injection into the banking system. [See Christiano (1991, 1992) for discussions.] The data suggest that the short-run decline in nominal interest rates could be present for up to six quarters after the shock [Christiano, Eichenbaum, and Evans (1997)]. By contrast, deposit precommitment in models without a bond market typically yield only a one-period liquidity effect. To overcome this shortcoming of the models, Christiano and Eichenbaum (1992) have proposed the introduction of small adjustment costs in the process by which households modify their deposit position in response to a monetary (reserves) shock.

In the "precommitment" versions of the model proposed in this paper, the presence of the bond market allows flexibility in the household's financial asset portfolio selection that enhances the persistence of the liquidity effect. To illustrate this feature of the model, a version with "full precommitment," but without the bond market is calibrated,

estimated, and simulated. [7] The simulation results are then compared with the "full precommitment" version above, which was selected due to the fact it had the strongest liquidity effect.

In Figure 7, impulse response functions to a one standard deviation reserves shock are presented for the two "full precommitment" models, one including the bond market (the model described in the text), and the other without a bond market. Note in panels 7a and 7b that the response of the nominal price level differs qualitatively between the two models. With the bond market present, Figure 7a, there is an immediate increase and overshooting of the nominal price level. It then declines slowly and monotonically to its new steady-state value.

By contrast, when the bond market is absent, Figure 7b, the price level monotonically approaches the new steady state from below. This difference owes to the role played by the bond market in the household's absorption of the additional nominal income that results from the reserves injection. In both models, the reserves injection increases the funds available for banks to lend and there is a rise in the firm's total nominal borrowings. These additional funds increase the household's nominal income from wages and profits.

In the absence of a bond market, with deposits precommited and nominal consumption predetermined, the only choice in the allocation of these additional funds that is available to the household is to increase its nominal money holdings, which mitigates the price adjustment that would otherwise take place in order to match the household's expected real money demand for the upcoming period. This implies that inflation is expected to rise in the future, which attaches a higher inflation premium to nominal interest rates. In Figure 7f, the bank loan rate is seen to respond with an immediate overshooting of nominal rate above its long-run trend, hence precluding any persistent liquidity effect from materializing. Alternatively, when a bond market is available to the household to help absorb this shock, the household is free to choose to carry less of its additional financial wealth forward in the form of nominal money holdings, and the resulting price level must rise more abruptly to accommodate the future expected real money demand. As a consequence, the inflation premia in nominal rates remain low, and the liquidity effect persists as shown in Figure 7e. This portfolio response is illustrated in Figure 7g by the plot of the ratio of money to the sum of money plus bonds. It is seen that the demand for money relative to bonds is initially below its long-run equilibrium and that the adjustment path is relatively long-lived.

[Insert Figure 7.]

[7] This required the obvious modifications to the household's budget constraint, and to the firm's profit function and financing constraint. The calibration was altered by setting $\tau_1 = 0$ in the firm's "portfolio adjustment cost function," equation (40), and having the banks finance all of the intermediate goods firms' wage bill. The implication of this calibration is to impose a convex cost structure on bank loans, with the marginal cost of the loan rising with the size of the loan. To maintain equal marginal costs of total borrowing across the two model versions (evaluated in the steady state), τ_0 was lowered to 0.0065. This is the minimal change that we could make to the model while dropping out the bond market, and it is still seen to be sufficient to eliminate the persistence in the liquidity effect.

Because these bonds are used to finance working capital, the siphoning off of nominal income into the bond market allows firms meet their financing needs without relying entirely on the bank's ability to raise additional deposit funds. As a consequence, the supply of funds available to firms (bank loans plus bonds), Figure 7c, exceeds the supply that is available in the absence of a bond market, Figure 7d, with the former exhibiting a high degree of persistence.

Therefore, viewed from this perspective, in the presence of a bond market, this additional supply effect drives down the nominal interest rate to a greater extent, thus resulting in a persistent liquidity effect; whereas, in the absence of the bond market, the liquidity effect is very weak and lasts only for one period. Table 3 reports the cross-correlations between reserves growth and the bank loan rate in the two models. With the bond market present, the lead-lag relationship generated by the model accord well with the U.S. data (where the bank loan rate is taken to be the prime lending rate). However, in the model without a bond market, the weak contemporaneous liquidity effect is seen to be dominated by the "inflation tax" effect at all relevant correlations.

[Insert Table 3.]

While the "full precommitment" model is used in this section to illustrate the mechanism that induces persistence in the liquidity effect, the "partial precommitment" model with a bond market present exhibits similar qualitative features. The principal difference is that the price level overshooting portrayed in Figure 7a is much more muted, and the peak response does not occur until three periods (quarters) after the monetary shock.

V. Conclusions.

It is commonly believed by policy makers that open market operations that ease the supply of bank reserves will induce a temporary, but persistent decline in short-term nominal interest rates. Falling rates will then stimulate real activity until inflation expectations associated with the more rapid rate of growth of the money supply that ensues drives borrowing costs higher and subsequently retards the economy's expansion. Attempting to capture this intuition in a theoretical model has proven challenging, given that rational expectatations, general equilibrium models are unable to deliver this dynamic response to an increase in the growth rate of bank reserves without a significant market friction. Chari, et al. (1995) and Christiano et al. (1991,1995,1997) have examined one such friction in the form of a precommitment of households to a liquid asset position that was first suggested by Lucas (1990) and Fuerst (1992). These models are capable of delivering this dynamic response, where banks acquire deposit funds from households to lend to firms, which in turn use the proceeds to fund their working capital expenses. However, in practice, a large share of working capital is financed by direct lending, and

U.S. data suggest that the role that banks play in this process has cyclical properties, with a larger role being played during recessions and a lesser role during expansions.

This paper extends this literature on "liquidity effects" by developing a model in which firms can choose to raise funds either by borrowing from banks or by issuing bonds. The simulation exercises reported in this paper indicate that "sticky prices" are neither necessary nor sufficient to generate a liquidity effect (for logarithmic utility); however, information frictions in the deposit market may produce a "liquidity effect" and at the same time match the countercyclical role played by banks in funding working capital expenses of firms. These information frictions manifest themselves in two ways. One is the precommitment by households to a deposit position prior to the monetary (reserves) shock. The second is that the deposit rate is preset prior to the monetary shock. When both of these frictions are operative, the model yields excess volatility in consumption and investment that calls into question the validity of the theory. However, when the deposit precommitment is minimal, such that the principal restriction is a preset deposit rate, the liquidity effect is still present, bank intermediation remains countercyclical, and the behavior of consumption and investment is much more in line with the data.

These results suggest that research in this area may benefit by shifting the focus toward the interest rate policies of banks. Three features of these policies could profitably be explored. First, deposit rates on transaction accounts move quite sluggishly, given that they represent average rather than marginal rates. Second, interest rates paid on managed liablities are more responsive to market rates; however, managed liabilities represent only a small fraction of deposit funds. Third, interest rates on bank loans to firms are normally tied to lines of credit. These agreements typically have loan conditions attached that reflect the firms qualification for drawing down their lines of credit, and these conditions are subject to change. All of these issues may significantly affect the cyclical properties of bank lending, and hence its role in transmitting monetary policy decisions to the real economy.

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Table 1: Summary of Second Moments

	U.S. Data 1973:1−2000:1		Baseline Model		"Sticky" Price Model		Full Precommitment		Partial Precommitment	
variable, x	σ_x	ρ_{xy}	σ_x	ρ_{xy}	σ_x	ρ_{xy}	σ_x	ρ_{xy}	σ_x	ρ_{xy}
output, y	1.668	1.000	1.64	1.00	1.63	1.00	1.62	1.00	1.77	1.00
consumption, c	0.921	0.849	1.12	0.97	1.13	0.91	2.07	0.43	1.51	0.80
investment, i	6.277	0.943	5.66	0.71	4.62	0.90	9.43	0.51	5.52	0.74
employment, n	1.563	0.899	0.61	0.78	0.77	0.70	1.11	0.66	1.14	0.84
deposit rate, r^d	0.105	0.168	0.38	0.18	0.43	0.19	0.18	0.51	0.16	0.61
bond rate, r^b	0.383	0.331	0.44	0.13	0.49	0.14	0.21	0.33	0.18	0.43
bank lending rate, r^v	0.387	0.174	0.42	0.18	0.47	0.19	0.29	0.50	0.17	0.61
real bonds, B'/P			2.86	0.78	3.52	0.72	4.41	0.66	4.03	0.85
real loans, V'/P	3.591	0.115	1.58	0.71	1.72	0.54	2.44	0.38	1.84	0.77
degree of bank intermediation, V'/Py	3.777	−0.321	1.22	−0.42	1.60	−0.42	2.36	−0.29	1.23	−0.30
ρ_{μ, r^d}	−0.185		0.88		0.54		−0.16		−0.13	
ρ_{μ, r^b}	−0.252		0.87		0.57		−0.41		−0.26	
ρ_{μ, r^v}	−0.145		0.88		0.54		−0.23		−0.13	

Notes: Data on the deposit rate and stock and flows of consumer durables were provided by the Federal Reserve Board.
All remaining data were extracted from the FAME database. All series were HP−filtered.

Table 2: Cross−correlations of the Bond Rate with the Gross Growth Rate of Nonborrowed Reserves

$\mathbf{Corr(r^b_t, \mu_{t-s})}$

lag, s	4	3	2	1	0	−1	−2	−3	−4
U.S. Data (1973:1−2000:1) 90−day Commercial Paper Rate	−0.11	−0.08	−0.15	−0.27	−0.25	0.03	0.12	0.05	0.06
Baseline Model	0.16	0.32	0.52	0.71	0.88	0.45	0.17	−0.02	−0.14
"Sticky" Price Model	0.29	0.48	0.60	0.74	0.55	0.22	0.03	−0.11	−0.17
Full Precommitment Model	−0.22	−0.32	−0.43	−0.57	−0.42	−0.13	0.07	0.18	0.24
Partial Precommitment Model	−0.19	−0.27	−0.39	−0.56	−0.27	−0.04	0.11	0.19	0.23

Notes: s = number of periods that μ_t leads r^b_t.
All data are HP−filtered.

Table 3: Cross−correlations of the Bank Loan Rate with the Gross Growth Rate of Nonborrowed Reserves

$\mathbf{Corr(r^{v}_{t}, \mu_{t-s})}$

lag, s	4	3	2	1	0	−1	−2	−3	−4
U.S. Data (1973:1−2000:1) Prime Lending Rate	−0.10	−0.10	−0.16	−0.23	−0.15	0.08	0.12	0.08	0.09
Full Precommitment With a Bond Market	−0.24	−0.30	−0.37	−0.43	−0.21	0.01	0.14	0.22	0.24
Full Precommitment Without a Bond Market	0.04	0.09	0.14	0.22	0.11	0.06	0.02	0.02	0.04

Notes: s = number of periods that μ_t leads r^{v}_{t}.
All data are HP−filtered.

Figure 1: Response to a one−standard deviation productivity shock in the "baseline" model

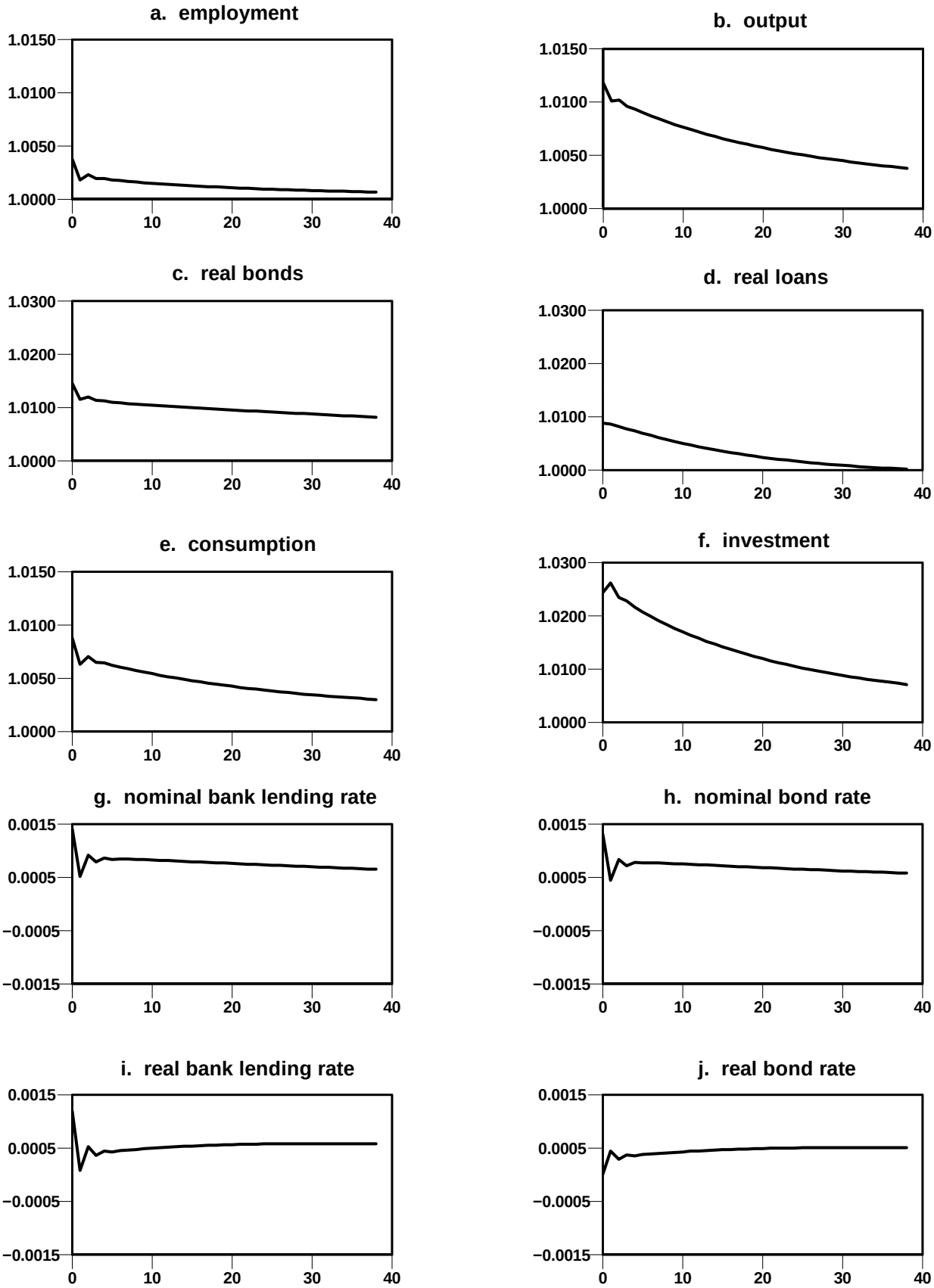


Figure 2: Response to a one−standard deviation productivity shock in the "partial precommitment" model

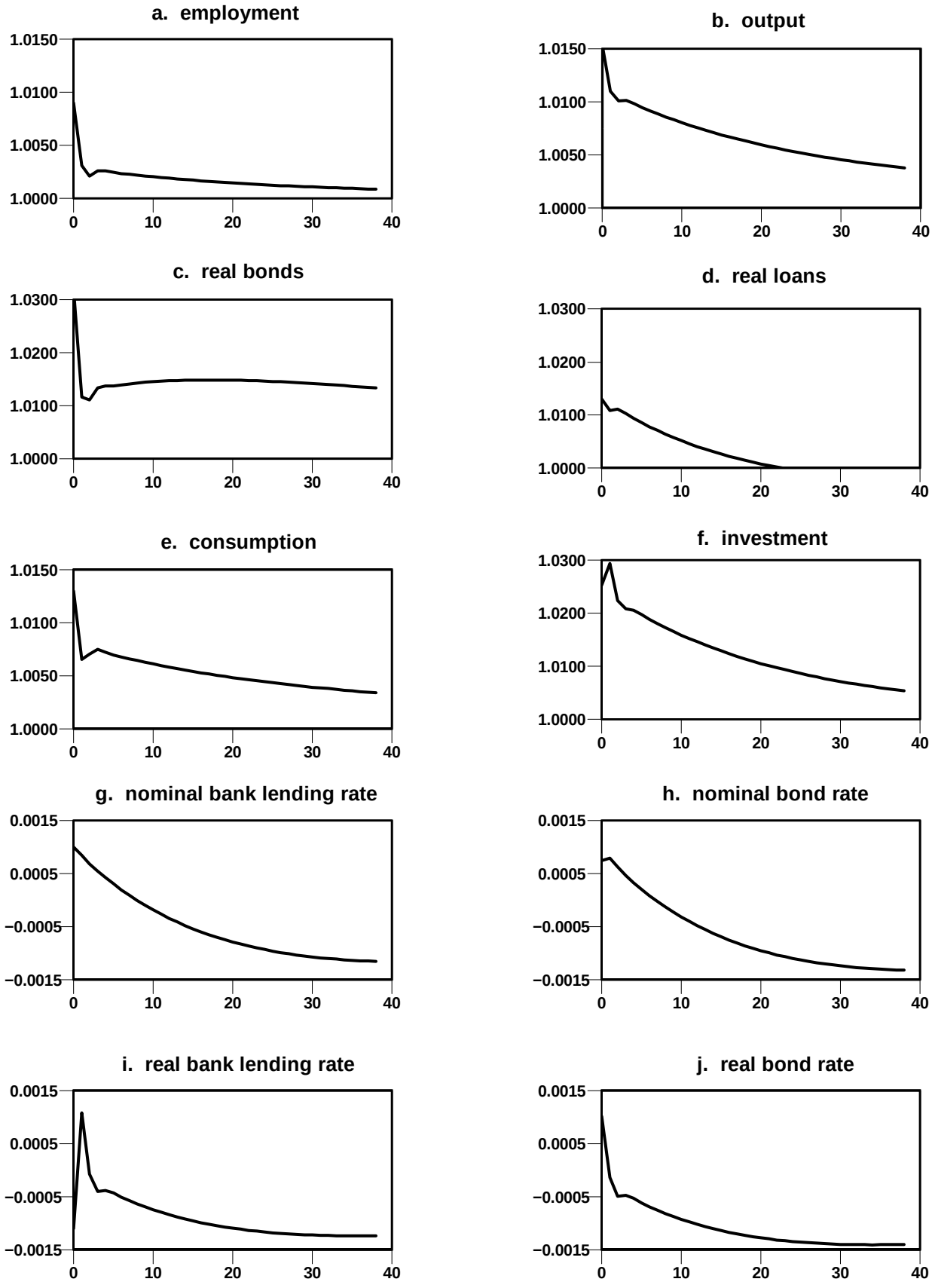


Figure 3: Response to a one−standard deviation monetary (reserves) shock in the "baseline" model

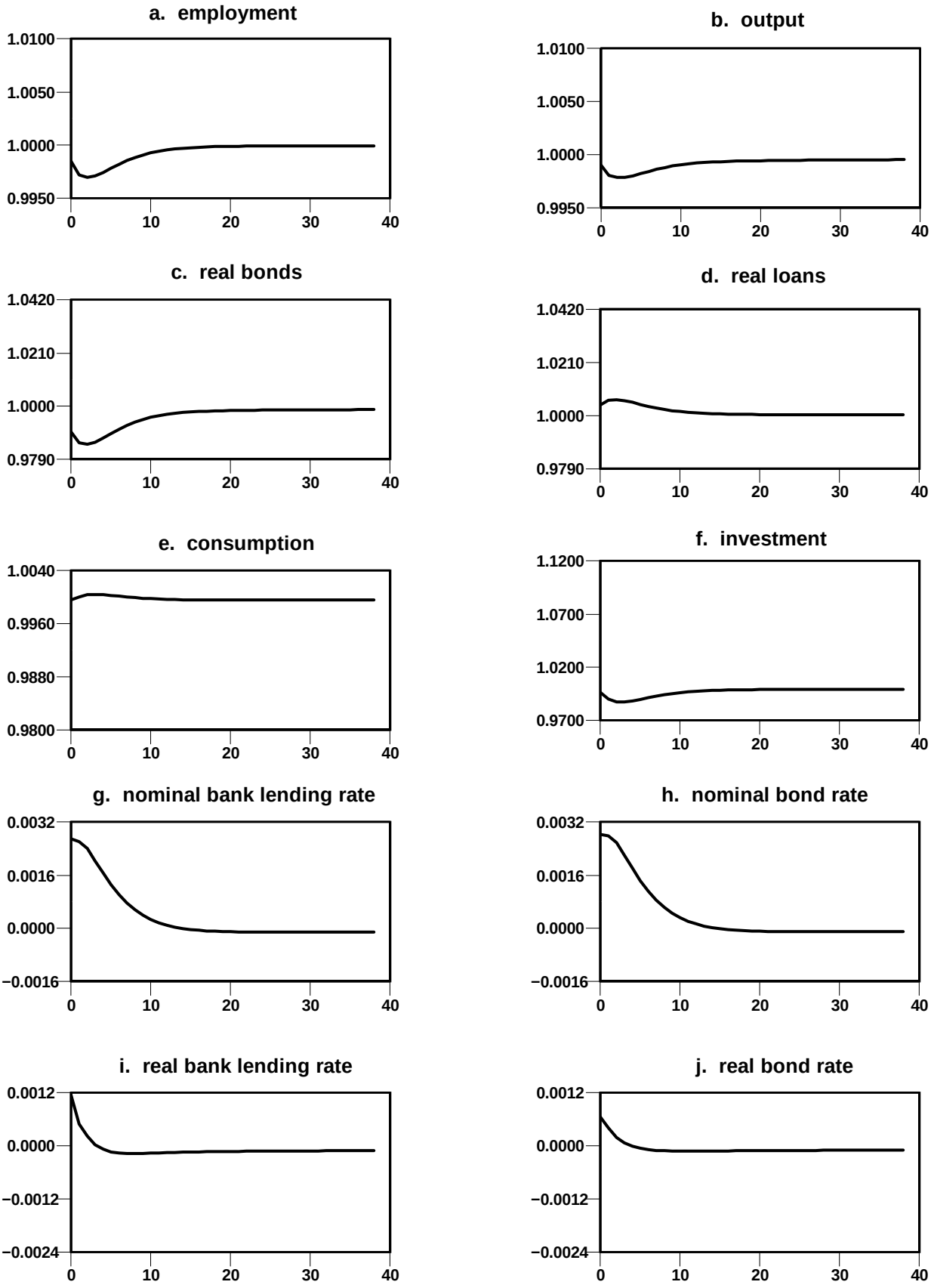


Figure 4: Response to a one−standard deviation monetary (reserves) shock in the "sticky price" model

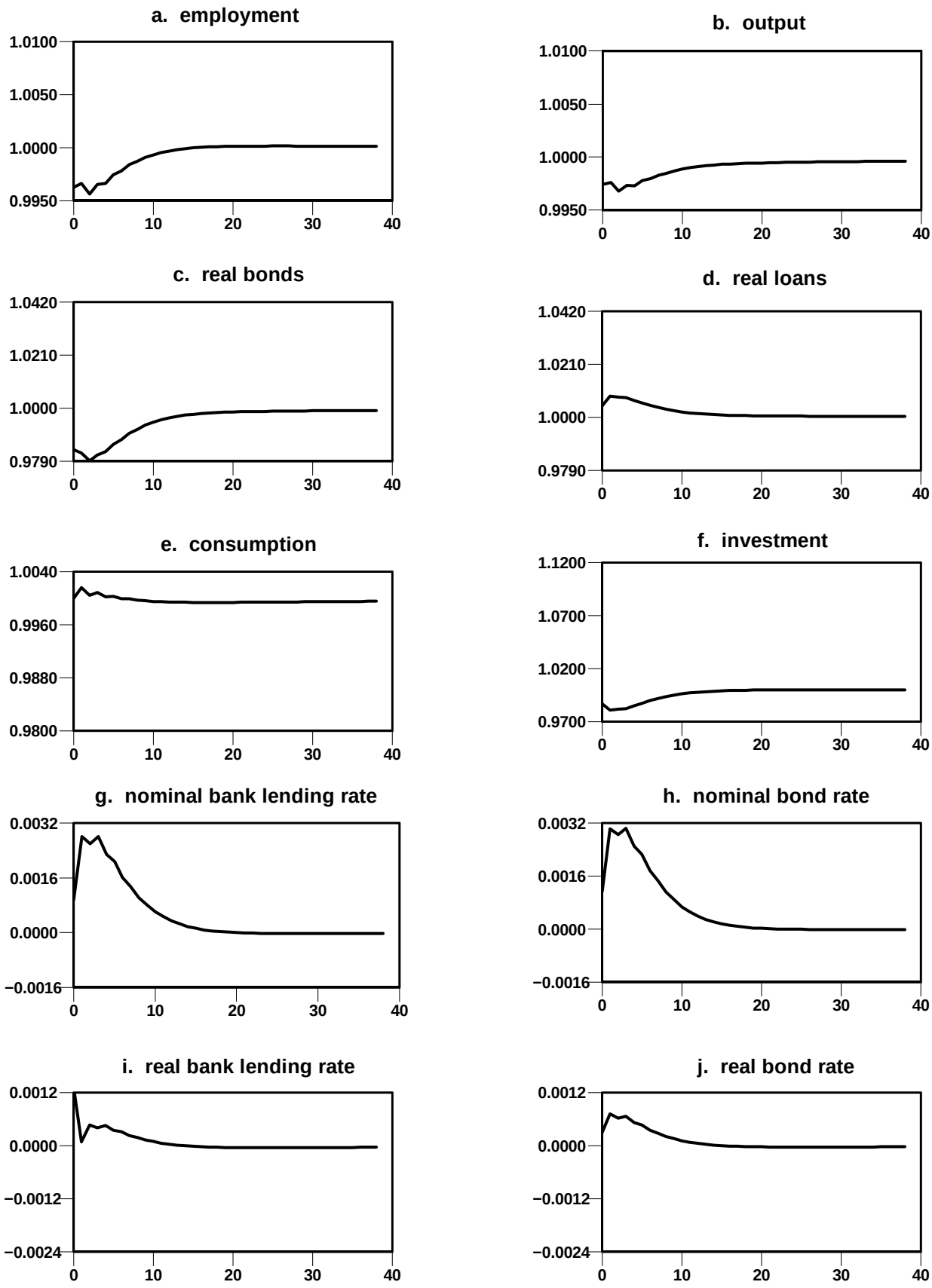


Figure 5: Response to a one−standard deviation monetary (reserves) shock in the "full precommitment" model

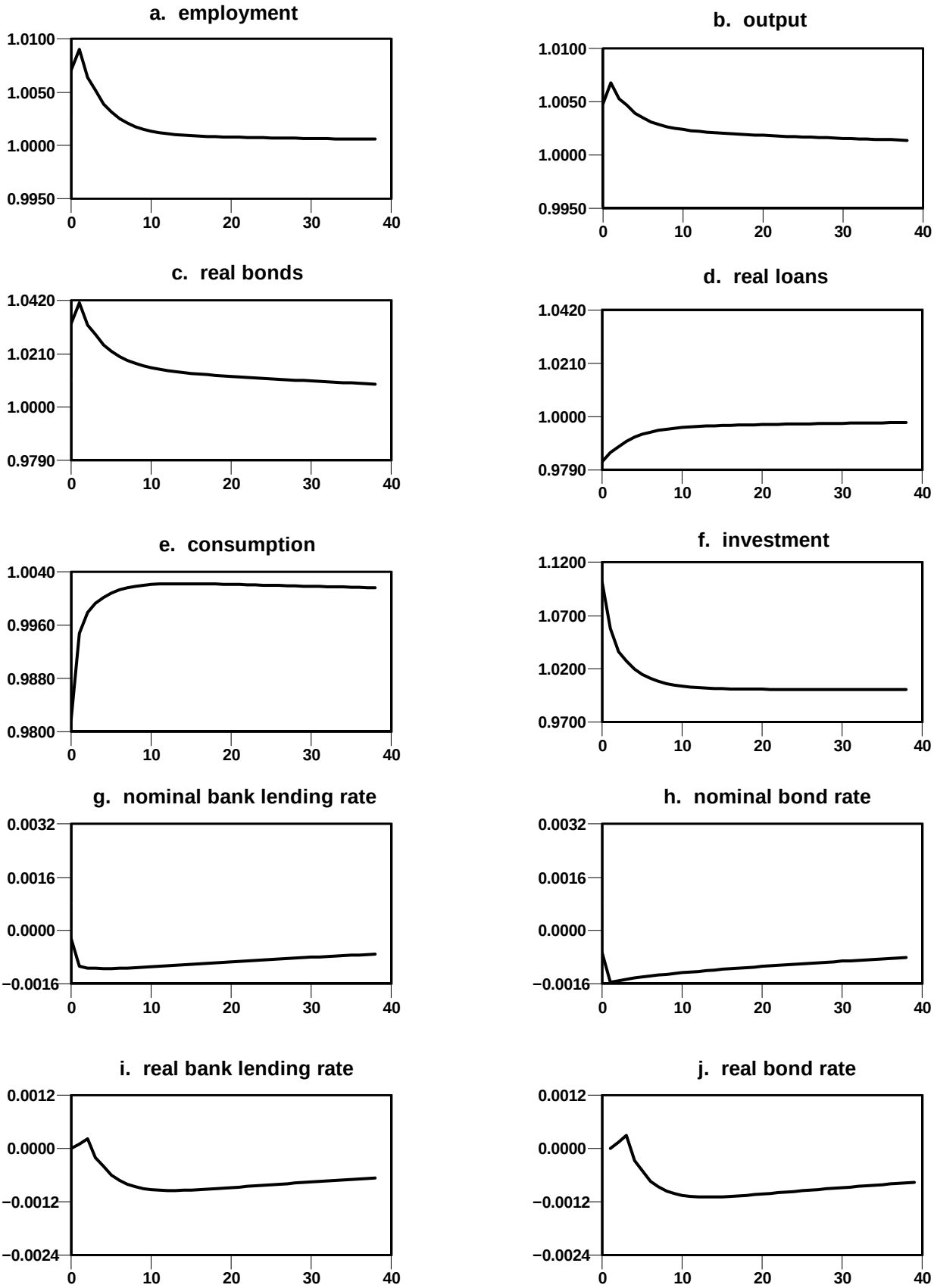


Figure 6: Response to a one−standard deviation monetary (reserves) shock in the "partial precommitment" model

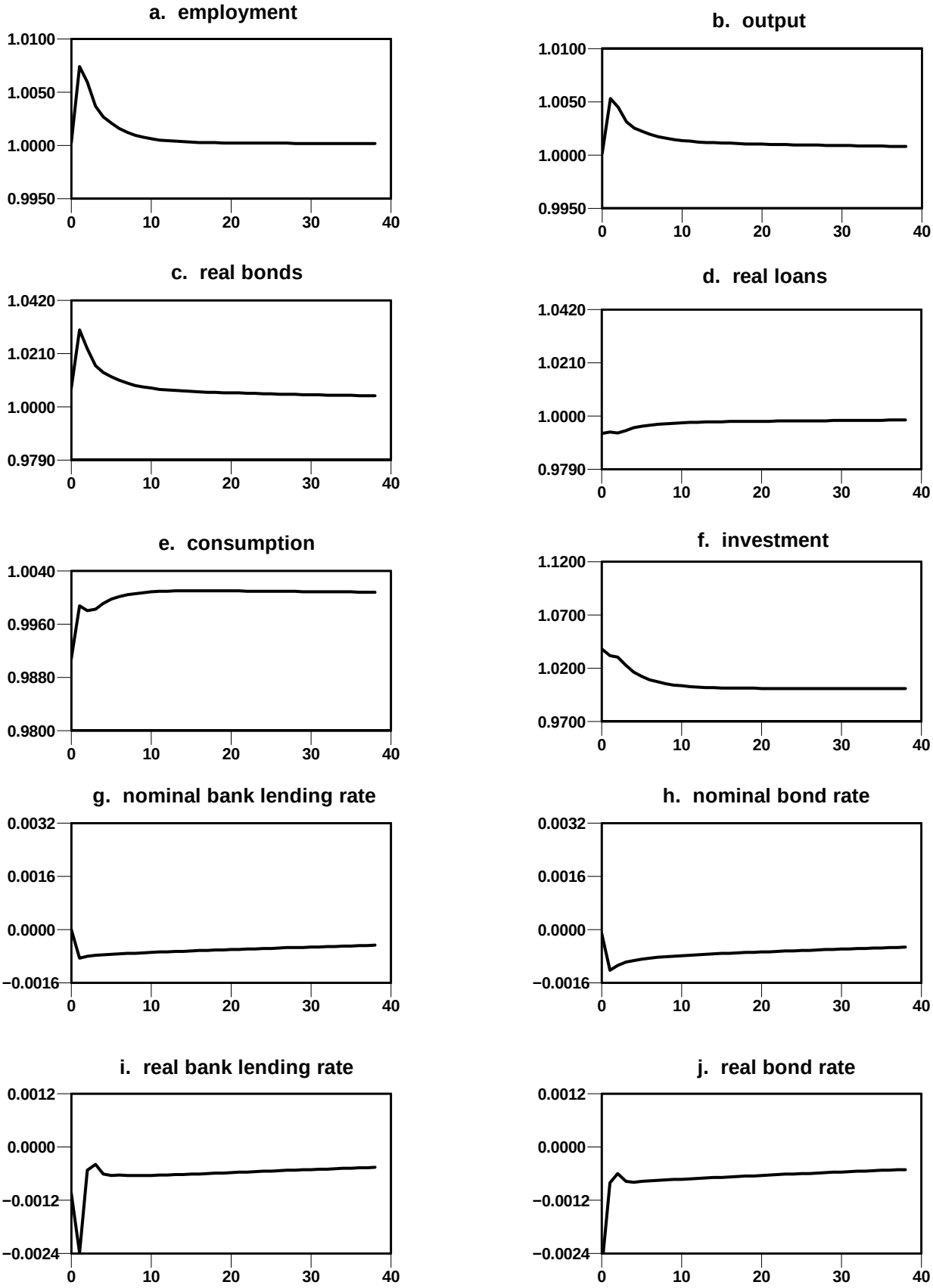
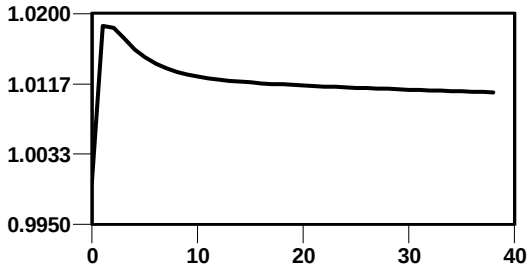


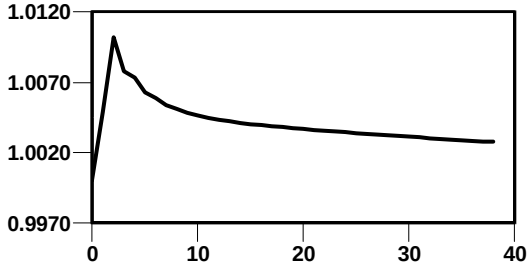
Figure 7: Response to a one−standard deviation monetary (reserves) shock in "full precommitment" models with and without a bond market

Model with a Bond Market

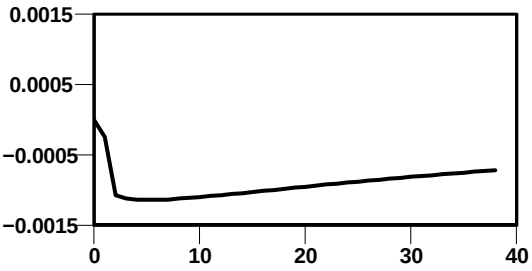
a. nominal price level



c. real bonds plus bank loans

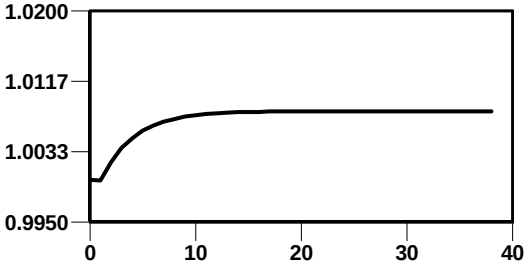


e. nominal bank lending rate

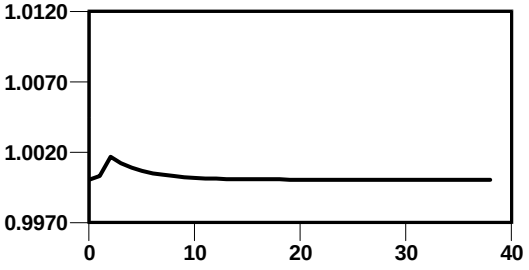
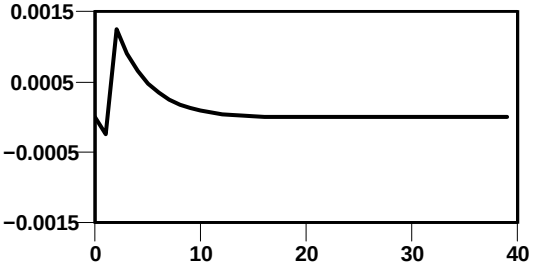


Model without a Bond Market

b. nominal price level



d. real bank loans



f. nominal bank lending rate