In Search of the Liquidity Effect in a Modern Monetary Model*

Benjamin D. Keen†
University of Virginia
Washington and Lee University

First draft: October 2000
This version: April 2001

Abstract

This paper examines the impact of a monetary policy shock in a dynamic stochastic general equilibrium model with sticky prices and financial market frictions. First, we examine the shortcomings of monetary models emphasizing these frictions individually. The model then is specified to limit the response of prices and savings to a current period monetary disturbance. Our results show that this model can account for the following key responses to an expansionary monetary policy shock: a fall in the nominal interest rate; a rise in output, consumption, and investment; and a gradual increase in the price level. Finally, a detailed sensitivity analysis shows the model's results depend on the parameters assigned to critical structural features.

*I would like to thank Robert King, Jinill Kim, Christopher Otrok, and Robert Usarek for many helpful discussions and comments. This research also benefited from the comments of seminar participants at the Conference Board, Federal Reserve Banks of Atlanta, Richmond, and St. Louis, Saint Louis University, the University of Virginia, Washington and Lee University, and Washington State University.

†Please address correspondence to: Benjamin D. Keen, Department of Economics, Washington and Lee University, Lexington, VA 24450. Tel: (540) 463-8174. Fax: (540) 463-8639. E-mail: keenb@wlu.edu.

1 Introduction

Most macroeconomists believe that an increase in the quantity of money lowers the nominal interest rate on impact, produces a large effect on real variables within a few quarters, and affects prices gradually. Therefore, any plausible model of monetary policy should account for this behavior. Several competing monetary models currently exist with each emphasizing different structural features. However, most of these models are unable to generate all of the qualitative responses to a monetary policy shock. The purpose of this paper is to investigate the structural features sufficient to produce these responses within a dynamic stochastic general equilibrium (DSGE) model of monetary policy.

Two of the most popular structural features in monetary models are price stickiness and financial market frictions. In sticky price models, such as Kimball [1995], King and Watson [1996], Dotsey, King, and Wolman [1997], and Ireland [1997, 2001], monopolistically competitive producers are unable to fully adjust prices in response to a monetary disturbance. These models generate the appropriate responses of real variables and prices, but in most cases fail to produce a drop in the nominal interest rate following an expansionary monetary policy shock. In limited participation models, such as Christiano [1991], Christiano and Eichenbaum [1992a, 1995], and Dotsey and Ireland [1995], households are unable to completely adjust their savings to a monetary disturbance. These models, in contrast to sticky price models, capture the behavior of the nominal interest rate but in most circumstances are unable to produce responses on impact that fall primarily on output and not on the price level after a monetary disturbance.

Based on results from sticky price models and limited participation models, the natural research strategy is to combine both of these structural features in a model to generate the observed effects of a monetary policy shock. Previously, Dow [1995] and Christiano, Eichenbaum, and Evans (CEE) [1997] have examined combined models but neither was able to generate the appropriate responses to a monetary disturbance.[1] Furthermore, both models impose infinite transactions costs on the adjustment of prices and savings to a current period monetary policy shock.[2] Given the quarterly periodicity of these models, such an assumption is rather extreme. When the degree of those transactions costs are relaxed, Dotsey and Ireland [1995] show that the impulse response functions from a business cycle model can be qualitatively different.

This paper develops a DSGE model with sticky prices and financial market frictions that can generate the appropriate responses of output, consumption, investment, the price level, and the nominal interest rate to a monetary policy shock. To satisfy

[1]Dow [1995] is unable to produce a gradual adjustment for prices, while CEE [1997] is unable to generate the liquidity effect.

[2]In CEE [1997], 80% of the firms are unable to adjust their prices to a current period monetary disturbance while the remaining 20% have complete flexibility to adjust their prices.

the concerns of Dotsey and Ireland [1995], these responses are generated in a specification that enables prices and savings to partially adjust to a current monetary disturbance. Furthermore, a sensitivity analysis shows our results are robust to a broad range of parameter values. These findings suggest that sticky prices and financial market frictions should be routinely combined in future models of the monetary transmission mechanism.

The remainder of the paper proceeds as follows. Section 2 discusses the empirical effects of a monetary shock. Section 3 presents the implications of current monetary models on output, prices, interest rates, consumption, and investment. Section 4 introduces the model. Section 5 presents qualitative responses of the model to a monetary policy shock. Section 6 examines a variety of perturbations of key structural features of the model to determine the robustness of the results. Finally, Section 7 serves as a conclusion.

2 Empirical Effects of a Monetary Policy Shock

One tool used to analyze the monetary features of the data is to identify and estimate a vector autoregressive (VAR) model. This strategy is perceived, at least by some empirical macroeconomists, as a reasonable method by which to assess the effects of a monetary policy shock. A sample of the vast literature using VAR models includes Leeper and Gordon [1992], Strongin [1995], Leeper, Sims, and Zha [1996], CEE [1996, 1999], and Bernanke and Mihov [1998]. In these models, identifying assumptions are needed to isolate the monetary policy shock and to characterize its effects on economic variables. Different identifying assumptions can lead to disparate conclusions about those effects. Therefore, any characterization of the actual economy's response to a monetary policy shock should be robust over a broad range of identifying assumptions.

Instead of examining a large variety of models, each with its own identifying assumptions, we briefly analyze recent reviews of this literature by Leeper, Sims, and Zha [1996] and CEE [1999]. In their recent survey article, CEE [1999] examine the effects of a monetary policy shock under three of the more popular identification schemes used in the literature. Specifically, CEE [1999] consider each set of identifying assumptions in a seven-variable VAR model using quarterly data on output, Y_t, prices, P_t, commodity prices, $PCOM_t$, the federal funds rate, FF_t, total reserves, TR_t, nonborrowed reserves, NBR_t, and money, M_t.[3] The first identification scheme examined specifies FF_t as the policy instrument of the Federal Reserve. Sims [1986] and Bernanke and Blinder [1992] argue the merits of this specification on institutional grounds. The second identification scheme considered assumes that the policy instru-

[3] The specific definitions of Y_t, P_t, $PCOM_t$, FF_t, TR_t, NBR_t, and M_t used by CEE [1999] are the log of real GDP, the log of the implicit GDP price deflator, the smoothed change in the index of sensitive commodity prices, the federal funds rate, the log of total reserves, the log of nonborrowed reserves plus extended credit, and the log of either M1 or M2, respectively. Furthermore, they consider each identification scheme with both M1 and M2 as the measure of money.

ment is NBR_t. Christiano and Eichenbaum [1992c] claim that innovations to NBR_t are the best measure of exogenous monetary policy shocks. The third identification scheme examined sets the policy instrument as NBR_t/TR_t. Strongin [1995] argues that the short-run demand for total reserves is completely interest inelastic so, the effects of a monetary disturbance are internalized among the components of total reserves.[4] Conducting their analysis separately for each identification scheme, CEE [1999] show that their main inferences on the effects of a monetary policy shock are qualitatively robust. Specifically, all three policy measures find that an expansionary monetary policy shock causes the nominal interest rate to fall, output to rise, and the price level to increase slowly.[5]

In addition to the variables mentioned above, the literature also has undertaken a more detailed examination of how different aspects of the economy respond to a monetary disturbance. One such paper, Leeper, Sims, and Zha [1996], examines a 13-variable VAR model with both consumption and investment. They find that after an expansionary monetary policy shock both consumption and investment rise, but the increase in investment exceeds that of consumption.[6] As for the robustness of their results, CEE [1999] note that other authors have reached similar conclusions.[7] Furthermore, the qualitative responses of the nominal interest rate, output, and the price level to a monetary policy shock outlined above are robust to this model. As a result, any plausible model of the monetary transmission mechanism should generate responses from output, consumption, investment, the price level, and the nominal interest rate that are qualitatively consistent with the findings from empirical work by Leeper, Sims, and Zha [1996], CEE [1999], and others.

3 Implications of Current Models

Many current models of the monetary transmission process assume either price or financial market frictions, but most models do not combine both frictions. These sticky price models and limited participation models, however, in most cases fail to account for one or more characteristics of a monetary policy shock. This section begins by outlining the successes and failures of each friction when they are entered into a DSGE model separately. Based on these results, the natural reaction is to combine sticky prices and financial market frictions in a DSGE model of monetary policy. However, the two previous attempts to combine these frictions were unable to produce the appropriate responses to a monetary policy shock. In the last part of this section, important assumptions and key results from these combined DSGE mod-

[4] Total reserves are the sum of borrowed and nonborrowed reserves.

[5] Thornton [2001] argues that the finding of a liquidity effect in structural VAR models is the result of the Fed's endogenous response to bank borrowing rather than a response to an exogenous monetary policy shock.

[6] The measure of investment from Leeper, Sims, and Zha [1996] is non-residential investment.

[7] See Fisher [1997].

els are examined to help motivate the particular specification of price and financial market frictions in our model.

3.1 Sticky Price Models

The sticky price models such as Kimball [1995], King and Wolman [1996], Kiley [1997], and Ireland [1997, 2001] assume that firms are monopolistically competitive producers of differentiated goods. Each period, a fraction of the firms can adjust their price after observing the current period money growth rate. Remaining firms, however, must charge their previously set price.[8] After pricing decisions are made, all of the other endogenous variables are realized.

The impulse response functions from a temporary, 1% money growth shock in a basic sticky price model, similar to Kiley [1997] and Ireland [1997], are illustrated by the solid line in Figure 1.[9] The assumption of price stickiness forces the price level to adjust gradually after a monetary policy shock. This sluggish response enables output to rise temporarily. Since households prefer to spread out consumption over time, consumption responds very little to a monetary disturbance. Instead, most of this additional output is supplied to the investment sector, which puts downward pressure on the real interest rate. This action, however, does not necessarily push down the real interest rate because the rise in output also drives up the rental cost of capital. The higher rental cost increases the demand for investment, which puts upward pressure on the real interest rate. As a result, the size and direction of the real interest rate response depends on both the magnitude of investment demand and supply elasticities and the size of the increases in investment demand and supply. For the basic sticky price model in Figure 1, these factors combine to push the real interest rate somewhat higher. Together, the slight increase in the real interest rate and the positive inflation expectations present in the basic sticky price model raise the nominal interest rate. To account for the liquidity effect, a sticky price model must generate a large enough decline in the real interest rate to offset the positive inflation expectations. In the absence of other frictions, however, the basic sticky price model can not produce this result.

Some sticky price models, such as Kimball [1995], King and Watson [1996], and Ireland [2001], include adjustment costs of capital to assist in producing the liquidity effect. In a sticky price model, these costs reduce the elasticity of investment demand to the real interest rate and restrain the increase in investment demand caused by a monetary policy shock. Both of those effects put downward pressure on the real and nominal interest rates and curtail the volatility of investment. In addition, the lower

[8] Some models, such as Ireland [1997, 2001] and Kim [2000], introduce price rigidities via price adjustment costs. In these models, every firm can immediately respond to a monetary disturbance by adjusting their price, but each firm faces a quadratic cost in doing so.

[9] The basic sticky price model is a modification of the model presented in Section 4. Specifically, this model eliminates the financial market frictions and adjustment costs of capital from that model (i.e., $h' = 0$, $h'' = 0$, and $\chi = \infty$).

real interest rate decreases the opportunity cost of current consumption which causes consumption to rise on impact.

The impulse response functions from a temporary, 1% money growth shock in a sticky price model with adjustment costs of capital are shown as the dashed line in Figure 1.[10] A comparison of the two sets of impulse response functions shows the effects of adjustment costs of capital on the real and nominal interest rates, investment, and consumption in a sticky price model. For the model with adjustment costs of capital, the capital adjustment costs weakens the rise in the nominal interest rate to only 0.68 basis points. If this model is specified with larger capital adjustment costs, like Ireland [2001], it can push the real interest rate low enough to generate the liquidity effect.

Those models, however, sacrifice their ability to generate a response in investment that exceeds consumption. Consider the case of the sticky price model with adjustment costs of capital in Figure 1. That model produces nearly identical contemporaneous responses of consumption and investment, 0.71% and 0.82%, respectively, while still producing a small rise in the nominal interest rate. The larger capital adjustment costs needed to generate a liquidity effect in that model will further increase the response of consumption and diminish the response of investment. This will lead to a situation where the sticky price model with capital adjustment costs will be unable to generate a contemporaneous response of investment in excess of that of consumption. As a result, a model with sticky prices, whether or not it includes adjustment costs of capital, is unable to replicate all of the qualitative results described in Section 2.

3.2 Limited Participation Models

Limited participation models, such as Christiano and Eichenbaum [1992a, 1995], Dotsey and Ireland [1995], Dow [1995], and CEE [1997], assume that households begin with an initial level of money balances which they must allocate between consumption purchases and savings at the banks. In those models, financial market imperfections enable households to partially but not completely adjust their level of savings to a monetary policy shock.[11] In our model, the financial market frictions are specified in terms of a time cost that households must incur to adjust their portfolio. To achieve monetary effects in a limited participation model, firms must finance either their capital investment or labor costs with loans from the banks. Since labor is a flow variable, it seems more plausible that it can be financed internally. Therefore, our model assumes that firms must finance their capital investment with loans from the

[10] The sticky price model with capital adjustment costs is identical to the model presented in Section 4, except for the absence of the financial market frictions in this model (i.e., $h' = 0$, $h'' = 0$).

[11] Christiano and Eichenbaum [1992a, 1995], Dow [1995], and CEE [1997] assume that households make all savings decisions before the current period monetary policy shock is realized. Nonetheless, this difference does not affect the qualitative results of our model.

banks.[12] While this choice affects the impulse response functions of the model, it has little effect on the failure of most limited participation models to produce responses to a monetary policy shock on impact that fall primarily on output and not on prices.[13]

The impulse response functions from a temporary, 1% money growth disturbance in a basic limited participation model are reported in Figure 2 by the solid line.[14] Without any price stickiness and very little change in input factor costs, firms completely adjust their prices on impact.[15] As a result, almost all of the impact of a monetary policy shock falls on prices and not on output, which is the opposite of what one would expect. The financial market frictions prevent households from transferring assets from savings to cash balances as fast as the rate at which prices are rising. This in turn forces household consumption to fall, but, also, temporarily increases the funds available for investment. Additional resources supplied to the investment sector push down the real interest rate by 0.1 basis points. The nominal interest rate also declines slightly since there are not any inflation expectations in the model.[16] As a result, the basic limited participation model is able to generate a small liquidity effect, but it is unable to produce the appropriate effect on output and prices.

To generate a stronger liquidity effect, adjustment costs of capital can be included in a limited participation model. The dashed line in Figure 2 shows the impulse response functions from a temporary, 1% money growth shock in a limited participation model with adjustment costs of capital.[17] As in the case of the sticky price model, inclusion of adjustment costs of capital decreases the elasticity of the demand for investment. Therefore, the increase in supply of investment caused by the financial market frictions will result in a greater decline in the real and nominal interest rates

[12] Dow [1995] also assumes firms finance their capital investment purchases externally while Christiano and Eichenbaum [1992a, 1995], Dotsey and Ireland [1995], and CEE [1997] assume firms finance their labor costs externally.

[13] CEE [1997] show that a limited participation model with external financing of labor costs can generate the appropriate response for the price level when the average markup is 40% and savings are unable to adjust to a current period monetary policy shock. When the average markup is a more moderate 20%, CEE [1997] illustrate that their results for the price level do not hold. Dotsey and Ireland [1995] show that for specifications where savings can partially adjust to a current monetary policy shock, the positive responses of labor and output greatly diminish, which leads to a substantially faster adjustment of prices.

[14] This limited participation model is a modification of the model presented in Section 4. Specifically, the sticky prices and adjustment costs of capital are eliminated from that model by specifying the following parameter values: $\eta_1 = 1$ and $\chi = \infty$.

[15] The time costs households must incur to adjust their portfolio forces them to sacrifice leisure time. To compensate for less leisure, households initially demand a slightly higher wage. Those additional production costs encourage firms to set prices slightly above their new steady state value in order to push down output a little.

[16] Dow [1995] in his liquidity effects model finds similar results for the real and nominal interest rates.

[17] This limited participation model with adjustment costs of capital is identical to the model presented in Section 4, except for the absence of sticky prices in this model (i.e., $\eta_1 = 1$).

but a lesser increase in investment. The lower real interest rate also decreases the opportunity cost of current consumption, which dampens the decline in consumption present in the basic model. Inclusion of adjustment costs of capital in a limited participation model, however, has virtually no effect on the responses of output and prices. Thus, limited participation models are unable to generate a response on impact to a monetary policy shock that falls primarily on output and not on prices.

3.3 Sticky Price and Limited Participation Models

Two previous studies, Dow [1995] and CEE [1997], have examined a combined model with both sticky prices and financial market frictions. Dow [1995] specifies the price and financial market frictions in terms of one period price and savings contracts. Specifically, price and savings decisions are made prior to observing the monetary policy shock. After the shock is observed, the remaining variables are determined. This model is able to generate the appropriate responses for output, consumption, investment, and the nominal interest rate. The one period price and savings contracts, however, prevent the model from producing a gradual increase in the price level after an expansionary monetary policy shock. Furthermore, Dotsey and Ireland [1995] explain that one period price and savings contracts set before observing the current period monetary disturbance place infinite transactions costs on these markets. They argue that this is an extreme assumption in models such as Dow [1995] and CEE [1997] that are trying to replicate quarterly business cycle behavior. When similar assumptions in other models are relaxed, Dotsey and Ireland [1995] show that the models' impulse responses can be qualitatively different which calls into question the results of those models.

CEE [1997] also specify financial market frictions in the form of one period savings contracts that are set before observing the monetary policy shock. The price frictions in CEE [1997], however, assume that 80% of firms set one period price contracts while the remaining firms have flexibility in setting their prices. Unlike Dow [1995] and our model, CEE [1997] assume firms finance labor costs externally and fix the capital stock with a depreciation rate of zero. Given this specification, the model is able to produce the output effect and a partial response in prices but is unable to generate the liquidity effect. Furthermore, the one period savings contracts in this model are also subject to the concerns outlined by Dotsey and Ireland [1995].

In summary, sticky price models have difficulty producing the liquidity effect while limited participation models in most cases are unable to generate a gradual adjustment in the price level. In light of these findings, it seems plausible to combine sticky prices and financial market frictions in a single model of monetary policy. Results from Dow [1995] and CEE [1997] demonstrate that simply combining these frictions does not guarantee success. The model developed in the next section extends Dow [1995] to allow for partial adjustment of prices and savings to a current period monetary policy shock. Our specification of the price and financial market frictions enables us to generate the appropriate responses from output, consumption, investment, the price level, and the nominal interest rate, while satisfying the concerns presented in Dotsey and Ireland [1995].

4 The Model

In this section, the distinct features of sticky price models and limited participation models are combined in a DSGE model to describe the transmission of monetary policy. Furthermore, this model allows some but not complete adjustment of price and savings to contemporaneous monetary policy shocks. The model is comprised of five sectors: firms, households, a capital supplier, banks, and the monetary authority. Firms are monopolistically competitive producers of output for consumption and investment. Each period, a fraction of all firms chosen from a known probability distribution, similar to Levin [1991], are allowed to adjust their price.[18] Those firms that cannot adjust their price must supply the level of output demanded at their previously set price. Households purchase consumption goods and deposit savings at banks, but these activities are constrained by the amount of cash households have on hand at the beginning of each period. Additionally, households incur a time cost whenever they adjust their portfolio. The capital supplier rents capital to firms and invests in new capital. To finance capital investment, the capital supplier borrows funds from the banking sector and pays them back with interest at the end of the period. The capital supplier also faces adjustment costs whenever they alter the size of the capital stock. Banks lend funds to the capital supplier and receive money from households and the monetary authority through deposits and lump-sum injections, respectively.

4.1 Households

Households are infinitely-lived agents with a preference for consumption and leisure. Restrictions on trade in the commodity and financial markets require households to use beginning of the period money balances, M_{t-1}, to fund consumption purchases, S_t, and savings, $M_{t-1} - S_t$. Such restrictions lead to the following cash constraint:

$$P_t c_t = S_t, \tag{1}$$

where P_t is the aggregate price index and c_t is consumption. This constraint is not a typical cash-in-advance constraint because households can adjust S_t.

A restriction that prevents any immediate adjustment of S_t to a monetary shock is a key factor in limited participation models such as Christiano [1991], Christiano and Eichenbaum [1992a, 1995], Dow [1995], and CEE [1997]. Implicitly, those models assume that the transactions costs to adjust S_t in response to an unexpected money

[18] Levin [1991] uses this structure for wage contracts.

shock in period t are infinite. While that assumption is reasonable in high frequency models, it seems impractical in a business cycle study designed to capture quarterly business cycle behavior. Like Dotsey and Ireland [1995], our model allows households to adjust S_t at finite but increasing time costs of the form $h_t = h(S_t/S_{t-1})$, where average and marginal costs are positive and an increasing function of the size of the adjustment ($h > 0$, $h' > 0$, $h'' > 0$).[19] Overall, the time spent adjusting ones portfolio cuts into leisure time according to the following time constraint:

$$n_t + l_t + h_t = 1, \tag{2}$$

where n_t is labor and l_t is leisure.

Households supply labor to the firms and hold a diversified portfolio of claims to the profits of the firms, capital supplier, and banks. At the end of each period, households receive their income for labor services and their share of the profits of the firms, D_t^f, capital supplier, D_t^c, and banks, $R_t X_t$. Since this household income and returns on savings are received after consumption purchases are fixed for the period, households store this wealth as money according to the following expression:

$$M_t = W_t n_t + D_t^f + D_t^c + R_t X_t + R_t(M_{t-1} - S_t), \tag{3}$$

where W_t is the nominal wage rate and R_t is the gross nominal interest rate. In the next period, households will spend this money on consumption purchases or save the money at banks.

Formally, the household's problem is to choose a plan for c_t, l_t, n_t, S_t, and M_t to maximize their expected utility:

$$E_0 \left[\sum_{t=0}^{\infty} \beta^t \left(\ln(c_t) + \theta \frac{l_t^{1-\zeta} - 1}{1-\zeta} \right) \right] \tag{4}$$

subject to (1), (2), and (3). In (4), $1 > \beta > 0$ and $\zeta > 0$. Following Blanchard and Kiyotaki [1987], the consumption good, c_t, in the utility function is a Dixit and Stiglitz [1977] aggregate of a continuum of many goods ($c_t(z)$, $z \in [0,1]$) where households prefer

$$c_t = \left[\int_0^1 c_t(z)^{(\varepsilon-1)/\varepsilon} dz \right]^{\varepsilon/(\varepsilon-1)}.$$

Cost minimization on the part of households implies that the demand for $c_t(z)$ is

$$c_t(z) = \left(\frac{P_t(z)}{P_t} \right)^{-\varepsilon} c_t,$$

[19] Christiano and Eichenbaum [1992a], King and Watson [1996], and Christiano and Gust [1999] impose similar time costs on household portfolio adjustment.

where P_t is a nonlinear price index:

$$P_t = \left[\int_0^1 P_t(z)^{1-\varepsilon} dz \right]^{1/(1-\varepsilon)}.$$

Utility maximization by households yields two efficiency conditions. The first efficiency condition sets the value of foregone marginal utility of leisure today equal to the interest rate times the discounted value of forgone marginal utility of leisure tomorrow:

$$u_l(c_t, l_t)/W_t = \beta E_t[R_{t+1} u_l(c_{t+1}, l_{t+1})/W_{t+1}]. \tag{5}$$

The second efficiency condition states that the value of an additional dollar of M_t spent on consumption must equal the value in forgone leisure to replenish the lost savings plus the value of the time costs households incurred adjusting their portfolio:

$$u_c(c_t, l_t)/P_t = R_t u_l(c_t, l_t)/W_t + h'_t u_l(c_t, l_t)/S_{t-1} - \beta E_t[h'_{t+1} u_l(c_{t+1}, l_{t+1}) S_{t+1}/S_t^2]. \tag{6}$$

In models without time adjustment costs, $h' = 0$, (6) is usually substituted into (5) so that (5) can directly relate the real value of consumption today to the discounted value of consumption tomorrow. In this model, however, the direct link between current and future consumption is broken because households can change their consumption purchases only by incurring a time cost to adjust their savings.

4.2 Firms

Firms are producers of differentiated products that seek to maximize the present value of current and future dividends for its owners, the households. Each period, firms consider two factors. First, they must decide the cost minimizing combination of factor inputs necessary to meet product demand. Second, firms must decide what new price to set if they are allowed to adjust their price in the current period.

4.2.1 Input Demand

Taking the price of firm z as given, that firm seeks a composition of inputs that satisfies its demand and minimizes its costs. Each firm demands labor, $n_t(z)$, and capital services, $k_t(z)$, to produce output, $y_t(z)$, according to a Cobb-Douglas production function:

$$y_t(z) = (k_t(z))^\alpha (n_t(z))^{1-\alpha}.$$

Firms hire labor and rent capital from perfectly competitive labor and capital markets, respectively. The capital stock is predetermined in the aggregate but profit maximization implies efficient allocation of capital across firms. Thus, the real production costs incurred by the zth firm are

$$q_t k_t(z) + n_t(z)(W_t/P_t),$$

where q_t is the user cost of capital. Cost minimization on the part of the zth firm yields the following factor demands:

$$\psi_t \alpha [n_t(z)/k_t(z)]^{1-\alpha} = q_t,$$

$$\psi_t (1-\alpha)[k_t(z)/n_t(z)]^{\alpha} = W_t/P_t,$$

where ψ_t is the Lagrange multiplier on the constraint and is interpreted as the real marginal cost. Since the user cost of capital and the real wage are identical for each firm, the capital-labor ratio and the real marginal cost are not firm specific. Nonetheless, higher levels of aggregate output drive up input factor prices which causes an increase in the real marginal cost. If prices are completely flexible, the real marginal cost is $(\varepsilon - 1)/\varepsilon$ which implies that the average mark-up of the price over marginal cost is $\varepsilon/(\varepsilon - 1)$.

4.2.2 Price Setting Behavior

The price setting behavior employed is based on the wage contract rules in Levin [1991]. This rule allows each firm to have its own specific opportunities to adjust its price. If a firm does not have a price adjustment opportunity in a particular period, it must satisfy all demand at the price charged in the previous period. The advantage of this pricing rule is that it replicates economic conditions by allowing the timing and magnitude of price changes to vary across firms.

Formally, a random draw determines whether a firm can adjust its price in a particular period. The fraction of firms that last adjusted their price j periods ago is ω_j, such that

$$\sum_{j=1}^{J} \omega_j = 1.$$

Let η_j be the fixed conditional probability that a firm can adjust its price given that it has not had the opportunity to do so in the last $j-1$ periods. At the maximum, a firm can go J straight periods without a price adjustment opportunity so that $\eta_J = 1$. Therefore, ω_j evolves such that

$$\begin{aligned} \omega_1 &= \sum_{j=1}^{J} \eta_j \omega_j, \\ \omega_{j+1} &= (1-\eta_j)\omega_j \text{ for } j = 1, ..., J-1. \end{aligned}$$

Other time-dependent pricing rules such as Taylor [1980] and Calvo [1983] are special cases of the Levin [1991] style pricing rule.

The random nature of this pricing rule has important consequences for optimal price setting. Let $v_{j,t}$ be the real value of a firm in period t that last adjusted its price $t-j$ periods ago. When a firm is given the opportunity to adjust its price, it will seek to maximize the present value of expected future profits to households such that

$$v_{0,t} = \max_{P_t^*}\{D_{0,t}^f \lambda_t + \beta E_t[\eta_1 v_{0,t+1} + (1-\eta_1)v_{1,t+1}]\}, \tag{7}$$

where

$$\lambda_t = u_l(c_t, l_t)/W_t,$$

and

$$D_t^f(z) = P_t(z)y_t(z) - W_t n_t(z) - P_t q_t k_t(z). \tag{8}$$

The value of those firms that last adjusted $t-j$ periods ago is

$$v_{j,t} = D_{j,t}^f \lambda_t + \beta E_t[\eta_{j+1} v_{0,t+1} + (1-\eta_{j+1})v_{j+1,t+1}], \tag{9}$$

for $j = 1, 2, ..., J-1$.[20] In (7) and (9), λ_t is the Lagrange multiplier from (3) in the household's problem where it measures the marginal utility value of an additional dollar of profits to the household.[21]

Determining the optimal price involves maximizing current and expected future profits. To make the value function of the adjusting firm a function of current and future dividends, we substitute (9) into (7) for $j = 1, 2, ..., J-1$. By integrating the demand schedule and cost minimizing quantities of inputs into (7) before maximization, the optimal price for an adjusting firm, P_t^*, can be written as

$$P_t^* = \frac{\varepsilon}{\varepsilon - 1} \frac{\sum_{j=0}^{J-1} \beta^j E_t[(\omega_{j+1}/\omega_1)\lambda_{t+j}\psi_{t+j}P_{t+j}^{1+\varepsilon}y_{t+j}]}{\sum_{j=0}^{J-1} \beta^j E_t[(\omega_{j+1}/\omega_1)\lambda_{t+j}P_{t+j}^{\varepsilon}y_{t+j}]}, \tag{10}$$

where $\omega_{j+1}/\omega_1 = (1-\eta_{j+1})(1-\eta_j)...(1-\eta_1)$.[22] Since none of the factors influencing pricing decisions in (10) are firm specific, all adjusting firms in period t set the same profit maximizing price, P_t^*.

4.3 Capital Supplier

The capital supplier owns all of the capital in the economy. At the beginning of a period, the capital supplier rents capital to firms but must wait until the end of that same period to receive its rental income. This forces the capital supplier to

[20] The max operator is excluded from (9) because these firms are not changing their prices.

[21] If the value of dividends to the representative household is expressed in terms of the marginal utility of consumption, λ_t is affected by the lost interest and time costs associated with the decline in savings needed to fund the additional consumption. In this case, λ_t is expressed as

$$\lambda_t = [u_c(c_t, l_t)/P_t - h_t'(1/S_{t-1})u_l(c_t, l_t) + \beta E_t[h_{t+1}'(S_{t+1}/S_t^2)u_l(c_{t+1}, l_{t+1})]]/R_t.$$

[22] Cost minimization on the part of the households and capital supplier yields the demand schedule for the zth firm: $y_t(z) = [P_t(z)/P_t]^{-\varepsilon} y_t$.

borrow funds from the banking sector to finance its current capital accumulation. At the end of the period, the loans are paid in full with interest. Consequently, the real cost of capital investment is $R_t i_t$. This restriction is not unique in limited participation models. In Christiano and Eichenbaum [1992a, 1995], and CEE [1997], for example, money is borrowed for labor costs but not for capital investment. While this assumption assists in replicating business cycle behavior, it implies that interest rate fluctuations have an immediate impact on labor demand and output. Such an effect is not present in this model since all borrowing takes place only to finance capital investment.

In our model, the capital supplier faces costs of adjusting the capital stock. Dow [1995], Kimball [1995], King and Watson [1996], Kim [2000], and Ireland [2001] find that those adjustment costs help explain interest rate behavior by restricting the ability of investment to respond to changes in monetary policy. These adjustment costs, $i_t - \varphi(i_t/k_t)k_t$, are resources lost in the conversion of investment to capital. We assume that incorporating new capital at slower rates rather than higher rates is less costly, so that $\varphi' > 0$ and $\varphi'' < 0$. The adjustment costs are modeled as described in Hayashi [1982], which means that the capital accumulation equation is

$$k_{t+1} - k_t = \varphi(i_t/k_t)k_t - \delta k_t. \tag{11}$$

The capital supplier seeks to maximize the value of the discounted stream of dividend payments to households. The value of dividends to households is the households' purchasing power in the next period multiplied by the additional utility gained from consumption and the discounted value of future consumption. Therefore, the capital supplier solves

$$\max_{i_t, k_{t+1}} \; E_0 \left[\sum_{t=0}^{\infty} \beta^t \lambda_t D_t^c \right],$$

where

$$D_t^c = P_t q_t k_t - P_t R_t i_t$$

subject to (11). Optimal capital accumulation yields the following two efficiency equations:

$$\varphi'(i_t/k_t)\tau_t = \lambda_t P_t R_t,$$

$$\tau_t = \beta E_t[\tau_{t+1}\{(1-\delta) - (i_{t+1}/k_{t+1})\varphi'(i_{t+1}/k_{t+1}) + \varphi(i_{t+1}/k_{t+1})\} + \lambda_{t+1}P_{t+1}q_{t+1}],$$

where τ_t is the Lagrange multiplier that indicates the present value of an additional unit of capital. The first efficiency equation states that the marginal value of an additional unit of capital equals the marginal cost of investment. The second efficiency equation equates the shadow price of a unit of capital with the discount value of its expected future benefits.

4.4 Banks

The banks, which are owned by the households, coordinate lending from households to the capital supplier. Each period, banks receive household deposits, S_t, and lump-sum injections from the monetary authority, $X_t = M_t - M_{t-1}$. Banks lend those funds to the capital supplier to finance its capital purchases. A gross interest rate, R_t, is paid to households and charged to the capital supplier to equate loan supply and demand:

$$P_t i_t = M_{t-1} - S_t + X_t.$$

At the end of the period, loans are paid back with interest, $R_t P_t i_t$, savings deposits are returned with interest, $R_t(M_t - S_t)$, and dividends are paid to households, $R_t X_t$.

4.5 Monetary Authority

The monetary authority conducts monetary policy by transferring money to the banking sector according to the following money growth rule:

$$\triangle \ln(M_t) = \rho_M \triangle \ln(M_{t-1}) + (1 - \rho_M) \ln(\mu) + \varepsilon_{Mt},$$

where μ is the steady state gross money growth rate, $1 > \rho_M > 0$, and $\varepsilon_{Mt} \sim N(0, \sigma_M^2)$.

5 Qualitative Responses to a Monetary Shock

The first-order conditions and identity equations from the households, firms, capital supplier, banks, and monetary authority form a nonlinear system describing the model's equilibrium. This system of equations is solved to determine the model's steady state equilibrium. The system is then linearized around its nonstochastic steady state, and its linear rational expectations equilibrium is computed using the solution methodology of King and Watson [1995, 1998]. The technical appendix details the system of nonlinear equations, the model's steady state, and the linearized behavioral equations used to calculate the rational expectations equilibrium.[23]

The parameter values specified in the model are fairly standard in the literature. We assume that the discount factor, β, is 0.99, and θ is selected so that the nonstochastic steady state value of labor, $\overline{n}$, is 0.2. In this model, the elasticity of labor supply is approximately equal to $4/\zeta$.[24] Parameter estimates in Christiano and Eichenbaum [1992b] suggest the labor supply elasticity is at least 5.0. Thus, ζ is set to 0.8.

[23] The technical appendix is available on my web page at www.people.virginia.edu/~bdk3c/.

[24] The elasticity of labor supply to the real wage equals $\left(\frac{(1-\overline{n}-\overline{h})}{\overline{n}}\right)\left(\frac{1}{\zeta}\right) \approx \frac{4}{\zeta}$ in the nonstochastic steady state.

Christiano and Eichenbaum [1992a] note that the average and marginal time adjustment costs, h and h', are small near the steady state. Since the model will be linearized around the nonstochastic steady state, we need only to specify h, h', and h''. Following King and Watson [1996], households spend an equivalent of 1% of their average working time, $\overline{n}$, adjusting their portfolio when the steady state annual inflation rate is 4%, so $\overline{h} = 0.01\overline{n} = 0.002$. In practical terms, this assumption implies that if people work 40 hours a week, they spend only 24 minutes of that week adjusting their portfolio. To keep the marginal time costs small, we employ King and Watson's [1996] assumption that the time adjustment costs rise to $1.06\overline{h}$ when the inflation rate is 8%, and they fall to $0.95\overline{h}$ when the inflation rate is 0%. Based on these assumptions, the first and second derivatives for the time adjustment costs are $h' = 5.5\overline{h}$ and $h'' = 100\overline{h}$, respectively.

On the production side, capital's share of output, α, is set to 0.33 and the depreciation rate is 0.025 quarterly or 10% on an annual basis. The elasticity of demand, ϵ, is set equal to 11, which implies that the average mark-up in the economy is a modest 10%. The conditional probability of price adjustment, η_j, will be constant for all j as in Calvo [1983].[25] Specifically, we set $\eta_j = 0.25$ so that a firm has a 25% chance of adjusting its price each period. This conditional probability of price adjustment implies that each firm holds its price constant for an average of four periods (quarters), which is consistent with survey evidence.[26]

We assume that the investment adjustment cost function, $\varphi(i_t/k_t)$, does not have any average and marginal adjustment costs around the steady state (i.e., $\varphi = i/k$ and $\varphi' = 1$). Prior research yields little information about the elasticity of the investment-capital ratio to Tobin's q, $\chi = [-(i/k)\varphi''/\varphi']^{-1}$. In the benchmark model, the adjustment cost parameter, χ, is set to 1, which is consistent with Chirinko's [1993] empirical examination of investment functions. The fact that Baxter and Crucini [1993] find that the value of χ significantly affects the behavior of their model leads us to conduct a sensitivity analysis of our model to different values of χ in Section 6.

The appropriate estimate for the money persistence parameter, ρ_M, depends on the definition of money used and the sample period estimated.[27] Initially, the benchmark model is analyzed assuming $\rho_M = 0$ in order to isolate the effects of an unexpected monetary shock from the expected inflation effects associated with an autocorrelated money growth shock. Note that the influence of positive values of ρ_M is examined in Section 6. The average annual inflation rate in the economy is 4%, so the steady state gross growth rate of money, μ, is set to 1.01.

Figure 3 displays the impact of a temporary, 1% monetary policy shock in a

[25] Levin [1991] and Calvo [1983] pricing rules are effectively equivalent when the conditional probailities, α_j, in Levin are constant and J is sufficiently large. In this paper, $J = 12$ when the Calvo approximation is employed.

[26] See Rotemberg and Woodford [1997] for a discussion of this survey evidence.

[27] CEE [1998] discuss the influence of the definition of money on the structure of the driving process.

sticky price and limited participation model with adjustment costs of capital. A quick glance at Figure 3 shows that this combined model can account for the qualitative effects of a monetary policy shock as outlined in Section 2. To fully understand the implications of combining price and financial market frictions, the contribution of each friction is examined separately. Table 1 documents the contemporaneous impact of this monetary policy shock on the nominal interest rate, R, the real interest rate, r, output, y, consumption, c, investment, i, and the price level, P, in the following benchmark models: the sticky price model with adjustment costs of capital, the limited participation model with adjustment costs of capital, and the sticky price and limited participation model with adjustment costs of capital. Note that the presence of price stickiness in the combined model causes its impulse response function for the price level to be practically identical to its response in the sticky price model. Thus, the response of output in the combined model mirrors its response in the sticky price model.

Table 1: The Impact of a Monetary Policy Shock on Three Models
with Adjustment Costs of Capital

	Basis points		Percent			
Model	R	r	y	c	i	P
Sticky Price	0.68	-19.68	0.73	0.71	0.82	0.27
Limited Participation	-42.94	-39.06	-0.04	-0.17	0.44	1.04
Sticky Price and Limited Particiaption	-40.94	-61.13	0.73	0.58	1.29	0.27

The increase in production caused by the price stickiness lifts up the capital rental rate. A higher rental rate then pushes up demand for investment. Furthermore, the sluggish price adjustment raises the real wealth of households. Since households prefer to spread out consumption over time, this additional real wealth is supplied to the investment sector. The financial market frictions further increase the supply of investment by forcing households to expend time to shift money balances from savings to consumption purchases. Indeed, Table 1 reveals that the contemporaneous response of investment in the combined model, 1.29%, is nearly the same as the sum of its responses in the sticky price model, 0.82%, and in the limited participation model, 0.44%.

The increase in investment demand and supply caused by the price stickiness and the increase in investment supply triggered by the financial market frictions come together to drive down the real interest rate in the combined model. Again, the contemporaneous 61.13 basis points decline of the real interest rate in the combined model is almost equal to the sum of its 19.68 basis points fall in the sticky price model and its 39.06 basis points drop in the limited participation model. This strong negative response in the real interest rate dominates the positive inflation expectations caused by the price stickiness to bring down the nominal interest rate. Finally, the lower real interest rate, which drives up consumption 0.71% in the sticky price model, and the financial market frictions, which forces down consumption 0.17% in the limited participation model, unite to raise consumption a more moderate 0.58% in the combined model.

This sticky price and limited participation model with adjustment costs of capital can account for the effects of a positive monetary disturbance: the rise in output, the larger relative increase in investment than consumption, the gradual increase in the price level, and the decline in the nominal interest rate. The combined model generates those responses without imposing implausible assumptions that are often necessary in models which examine these frictions separately. For example, this model does not need to impose high capital adjustment costs which are usually necessary to account for the liquidity effect in sticky price models. For our purposes, capital adjustment costs are considered implausibly high if they dampen investment to the point where the increase in consumption exceeds the increase in investment. Furthermore, our model does not need to assume that households face infinite transactions costs to adjust their savings to a current monetary disturbance and that the markup is at least 40%, as some limited participation models must assume, to generate a gradual increase in prices.[28] Not only is this combined model free of such assumptions, but its results are robust to a broad range of parameter values as will be shown next.

6 Sensitivity Analysis

The impact of a monetary disturbance on the benchmark sticky price and limited participation model depends in part on the parameter values assigned to critical structural features. In particular, different parameter values for the price setting rule, time adjustment costs, capital adjustment costs, and money growth persistence influence the ability of this model to account for the observed behavior of key variables to a monetary policy shock. Table 2 reports the contemporaneous response of the nominal interest rate, the real interest rate, output, consumption, investment, and the price level, to a 1% money growth shock for various parameterizations of the model. To begin, Panel A of Table 2 reports the results for the benchmark parameter values specified in Section 5. As shown in Figure 3, a monetary disturbance on the benchmark parameter values of the model generates the observed responses for key economic variables. An important result produced by this parameterization of the combined model is that the nominal interest rate falls after an expansionary monetary shock. This result, however, is sensitive to parameter values assigned to

[28] For example, see CEE [1997] and Christiano and Gust [1999].

certain structural features of the model.

Table 2: The Impact of a Monetary Policy Shock in the Combined Model

	Basis points		Percent			
Parameter	R	r	y	c	i	P
Panel A: Benchmark parameter values						
	-40.94	-61.13	0.73	0.58	1.29	0.27
Panel B: Price setting rules						
$\eta_1 = \eta_2 = \eta_3 = 0,\ \eta_4 = 1$	-41.87	-68.32	0.73	0.59	1.22	0.27
$\eta_1 = 1$	-42.94	-39.06	-0.04	-0.17	0.44	1.04
Panel C: Time adjustment costs values						
$h' = 7.0\overline{h},\ h'' = 200\overline{h}$	-60.75	-80.88	0.73	0.50	1.57	0.27
$h' = 5.5\overline{h},\ h'' = 100\overline{h}$	-40.94	-61.13	0.73	0.58	1.29	0.27
$h' = 4.75\overline{h},\ h'' = 50\overline{h}$	-25.09	-45.32	0.73	0.64	1.10	0.27
$h' = 0,\ h'' = 0$	0.68	-19.68	0.73	0.71	0.82	0.27
Panel D: Capital adjustment costs values						
$\chi = 1$	-40.94	-61.13	0.73	0.58	1.29	0.27
$\chi = 2$	-18.24	-38.04	0.74	0.43	1.89	0.26
$\chi = 5$	3.58	-15.65	0.75	0.25	2.66	0.25
$\chi = 10$	12.81	-6.04	0.76	0.14	3.09	0.24
$\chi = 100,000$	22.33	4.12	0.77	-0.01	3.73	0.23
Panel E: Money growth persistence values						
$\rho_M = .8$	83.15	11.62	0.21	0.12	0.52	0.79
$\rho_M = .4$	28.63	-4.84	0.58	0.47	1.01	0.42
$\rho_M = .2$	-4.47	-29.85	0.67	0.54	1.16	0.33
$\rho_M = .1$	-22.30	-44.81	0.70	0.56	1.23	0.30

6.1 Price Setting Rules

First, we examine the effects of adjusting the price setting rule. Specifically, Panel B considers setting prices according to Taylor [1980] style four-period contracts ($\eta_1 = \eta_2 = \eta_3 = 0$ and $\eta_4 = 1$) or by allowing complete price flexibility ($\eta_1 = 1$). In the case of Taylor [1980] price contracts, the qualitative responses of key economic variables to a monetary disturbance are nearly identical to that generated by the benchmark pricing rule. This finding suggests that our model's results are robust across different time dependent pricing rules. An assumption of complete price flexibility, however, overturns the model's ability to capture the appropriate responses of output, consumption, and the price level to a monetary policy shock. Thus, a specification of completely flexible prices essentially converts this model into a limited participation model with adjustment costs of capital.

6.2 Time Adjustment Costs

Next, we examine the effects of changing the size of the time adjustment costs. Recall, the benchmark parameter values for the time adjustment costs are $h' = 5.5\overline{h}$ and $h'' = 100\overline{h}$. As the size of h' and h'' increases, households must spend more time adjusting their savings after a monetary shock. This in turn leads to a greater decline in consumption and makes available even more resources for investment. Thus, the rise in investment and the fall in real and nominal interest rates is enhanced. Panel C demonstrates that higher time adjustment costs produce precisely these results. Moreover, Panel C reveals that when financial market frictions are eliminated, $h' = 0$ and $h'' = 0$, the model is unable to produce a decline in the nominal interest rate following an expansionary monetary policy shock. Without these time costs, the model is essentially a sticky price model with adjustment costs of capital.

6.3 Adjustment Costs of Capital

Another perturbation we explore is the effects of changes in the adjustment costs of capital. Specifically, in this model capital adjustment costs get smaller as the elasticity of the investment-to-capital ratio, χ, becomes larger. As these adjustment costs get smaller, the demand for investment becomes more elastic to changes in the real interest rate and more responsive to changes in output. The result is a larger increase in investment and a smaller decrease in the real interest rate. For large values of χ, the real interest rate will not fall enough to compensate for the positive expected inflation effect, so that the nominal interest rate will rise after an expansionary monetary disturbance. An examination of Panel D in Table 2 reveals that when $\chi = 1$ and $\chi = 2$ the capital adjustment costs are large enough to push down the nominal interest rate. In contrast, when capital adjustment costs are smaller ($\chi = 5$ and $\chi = 10$), the real interest rate does not decline enough to compensate for the positive inflation expectations in the model. As a result, the nominal interest rate rises after an expansionary monetary policy shock. In the extreme case where capital adjustment costs are effectively nonexistent ($\chi = 100,000$), the nominal interest rate rises by more than 22 basis points after a 1% money growth shock. Those findings suggest that modest capital adjustment costs are necessary to generate the liquidity effect in a sticky price and limited participation model.[29]

6.4 Money Growth Persistence

Finally, we investigate the effects of changes in the money growth persistence parameter, ρ_M. Specifically, the higher expected inflation rates due to increased money growth persistence affects the model on two key dimensions. First, the higher expected inflation rates restrain or even prevent the nominal interest rate from falling

[29] Kimball [1995], King and Watson [1996], and Kim [2000] also argue that adjustment costs of capital are helpful in explaining the behavior of the nominal interest rate.

after an expansionary monetary policy shock. Second, firms raise their prices higher in the face of greater expected inflation. Higher prices translate into smaller increases in output, consumption, and investment. In Table 2, Panel E shows that the nominal interest rate falls after an expansionary monetary disturbance at modest levels of money growth persistence ($\rho_M = 0.1$ and $\rho_M = 0.2$). At greater levels of persistence ($\rho_M = 0.4$ and $\rho_M = 0.8$), however, the higher expected inflation effect pushes up the nominal interest rate. Further, Panel E confirms that prices rise faster and output, consumption, and investment increase less as ρ_M rises.

This sensitivity analysis shows that our sticky price and limited participation model can generate the appropriate responses to a monetary policy shock for a broad range of parameterizations. The ability of the combined model to produce the liquidity effect is the one result that is especially sensitive to the parameterization of the model. In particular, low capital and time adjustment costs and high money growth autocorrelation hamper the ability of this model to generate the liquidity effect. Note that this inability to capture the liquidity effect at some plausible parameter values does not necessarily constitute a failure of the model. The model can be modified with additional features to slow the rise in prices and contribute to a persistent increase in output.[30] The slower rise in prices depresses the nominal interest rate by decreasing the expected inflation effect.

7 Conclusion

Recent macroeconomic research has focused on developing a DSGE model that can replicate important features of the monetary transmission mechanism. Any plausible model of monetary policy needs to generate a fall in the nominal interest rate, a gradual increase in the price level, and a rise in output, consumption, and investment after a expansionary monetary policy shock. However, most current monetary models emphasizing sticky prices or financial market frictions are unable to replicate this behavior. This paper specifies a DSGE model with both sticky prices and financial market frictions that can generate the appropriate responses to a monetary disturbance. Our model generates these results without having to impose implausibly high transactions costs on the adjustment of prices and savings to a current period monetary policy shock.

Sensitivity analysis reveals that the ability of this model to produce the appropriate responses to a monetary policy shock is robust to a broad range of parameter values. Nevertheless, these results, particularly the liquidity effect, depend on the parameter identification of key structural features. At first glance, the sensitivity of our results to parameter identification might seem like a shortcoming of the model. Empirical studies, however, find that the qualitative effects of a monetary policy shock

[30] For example, see Dotsey, King, and Wolman [1997] and Kiley [1997].

are sensitive to identifying assumptions.[31] As opposed to being problematic, the sensitivity of our results appears to provide a theoretical justification for the seemingly inconsistent behavior of empirical models.

A broader goal in monetary economics is to develop a usable model for policy analysis. The more a theoretical model imitates the actual behavior of the economy, the closer we come to achieving that goal. This paper contributes to that objective by explaining in a structural model the effects of a monetary policy shock on key economic variables. Our findings suggest that future macroeconomic research should routinely combine price and financial market frictions rather than examining them separately.

[31] See Pagan and Robertson [1995] for a detailed examination of this issue.

References

[1] Baxter, Marianne, and Mario J. Crucini, 1993, 'Explaining Savings-Investment Correlations,' *American Economic Review*, 83, 416-435.

[2] Blanchard, Olivier J., and Nobuhiro Kiyotaki, 1987, 'Monopolistic Competition and the Effects of Aggregate Demand,' *American Economic Review*, 77, 647-666.

[3] Bernanke, Ben S. and Alan S. Blinder, 1992, 'The Federal Funds Rate and the Channels of Monetary Transmission,' *American Economic Review*, 82, 901-921.

[4] Bernanke, Ben S. and Ilian Mihov, 1998, 'Measuring Monetary Policy,' *Quarterly Journal of Economics*, 113, 869-902.

[5] Calvo, Guillermo A., 1983, 'Staggered Prices in a Utility Maximizing Framework,' *Journal of Monetary Economics*, 12, 383-398.

[6] Chirinko, Robert S., 1993, 'Business Fixed Investment Spending: A Critical Survey of Modeling Strategies, Empirical Results and Policy Implications,' *Journal of Economic Literature*, 31, 1875-1911.

[7] Christiano, Lawrence J., 1991, 'Modeling the Liquidity Effect of a Money Shock,' Federal Reserve Bank of Minneapolis *Quarterly Review*, 15, 3-34.

[8] Christiano, Lawrence J., and Martin Eichenbaum, 1992a, 'Liquidity Effects and the Monetary Transmission Mechanism,' *American Economic Review*, 82, 346-353.

[9] Christiano, Lawrence J., and Martin Eichenbaum, 1992b, 'Current Real-Business Cycle Theories and Aggregate Labor-Market Fluctuations,' *American Economic Review*, 82, 430-450.

[10] Christiano, Lawrence J., and Martin Eichenbaum, 1992c, 'Identification and the Liquidity Effect of a Monetary Policy Shock,' in *Political Economy, Growth and Business Cycles*, edited by Alex Cukierman, Zvi Hercowitz, and Leonardo Leiderman, Cambridge and London: MIT Press, 335-370.

[11] Christiano, Lawrence J., and Martin Eichenbaum, 1995, 'Liquidity Effects, Monetary Policy and the Business Cycle,' *Journal of Money, Credit and Banking*, 27, 1113-1136.

[12] Christiano, Lawrence J., Martin Eichenbaum, and Charles L. Evans, 1996, 'The Effects of Monetary Policy Shocks: Evidence from the Flow of Funds,' *Review of Economics and Statistics*, 78, 16-34.

[13] Christiano, Lawrence J., Martin Eichenbaum, and Charles L. Evans, 1997, 'Sticky Prices and Limited Participation Models: A Comparison,' *European Economic Review*, 41, 1201-1249.

[14] Christiano, Lawrence J., Martin Eichenbaum, and Charles L. Evans, 1998, 'Modeling Money,' Working Paper No. 6371. Cambridge: National Bureau of Economic Research.

[15] Christiano, Lawrence J., Martin Eichenbaum and Charles L. Evans, 1999, 'Monetary Policy Shocks: What Have We Learned and to What End?' Chapter 2, in John Taylor and Michael Woodford (eds.), *Handbook of Macroeconomics,* Amsterdam: Elsevier Science Publication.

[16] Christiano, Lawrence J. and Christopher J. Gust, 1999, 'Discussion of Andrew Levin, Volker Wieland, and John C. Williams, 'Are Simple Monetary Policy Rules Robust to Model Uncertainty?" in John Taylor (ed.), *Monetary Policy Rules,* Chicago: The University of Chicago Press.

[17] Dixit, Avinash, and Joseph Stiglitz, 1977, 'Monopolistic Competition and Optimum Product Diversity,' *American Economic Review*, 67, 297-308.

[18] Dotsey, Michael, Robert G. King, and Alexander L. Wolman, 1997, 'Menu Costs, Staggered Price-Setting and Elastic Factor Supply,' manuscript, University of Virginia and Federal Reserve Bank of Richmond.

[19] Dotsey, Michael, and Peter Ireland, 1995, 'Liquidity Effects and Transaction Technologies,' *Journal of Money, Credit, and Banking*, 27, 1441-1471.

[20] Dow, James P. Jr., 1995, 'The Demand and Liquidity Effects of Monetary Shocks,' *Journal of Monetary Economics*, 36, 91-115.

[21] Fisher, Jonas, 1997, 'Monetary Policy and Investment,' manuscript, Federal Reserve Bank of Chicago.

[22] Hayashi, Fumio, 1982, 'Tobin's Marginal and Average q: A Neoclassical Interpretation,' *Econometrica*, 50, 213-224.

[23] Ireland, Peter, 1997, 'A Small, Structural, Quarterly Model for Monetary Policy Evaluation,' *Carnegie-Rochester Conference Series on Public Policy*, 47, 83-108.

[24] Ireland, Peter, 2001, 'Sticky-Price Models of the Business Cycle: Specification and Stability,' *Journal of Monetary Economics*, 47, 3-18.

[25] Kiley, Michael T., 1997, 'Staggered Price Setting and Real Rigidities,' Finance and Economics Discussion Series No. 97-46, Board of Governors of the Federal Reserve System.

[26] Kim, Jinill, 2000, 'Constructing and Estimating a Realistic Optimizing Model of Monetary Policy,' *Journal of Monetary Economics*, 45, 329-359.

[27] Kimball, Miles, 1995, 'The Quantitative Analytics of the Basic Neomonetarist Model,' *Journal of Money, Credit, and Banking*, 27, 1241-1277.

[28] King, Robert G., and Mark Watson, 1995, 'System Reduction and Solution Algorithms for Singular Linear Difference Systems Under Rational Expectations,' manuscript, University of Virginia, forthcoming *Computational Economics.*

[29] King, Robert G., and Mark Watson, 1996, 'Money, Prices, Interest Rates, and the Business Cycle,' *Review of Economics and Statistics*, 78, 35-53.

[30] King, Robert G. and Mark Watson, 1998, 'The Solution of Singular Linear Difference Systems Under Rational Expectations,' *International Economic Review*, 39, 1015-1026.

[31] King, Robert G., and Alexander L. Wolman, 1996, 'Inflation Targeting in a St. Louis Model of the 21st Century,' Federal Reserve Bank of St. Louis *Review*, 78, 83-107.

[32] Leeper, Eric M. and David B. Gordon, 1992, 'In Search of the Liquidity Effect,' *Journal of Monetary Economics*, 29, 341-369.

[33] Leeper, Eric M., Christopher A. Sims, and Tao Zha, 1996, 'What Does Monetary Policy Do?' *Brookings Papers on Economic Activity*, 2, 1-78.

[34] Levin, Andrew, 1991, 'The Macroeconomic Significance of Nominal Wage Contract Duration,' University of California at San Diego Working Paper No. 91-08.

[35] Pagan, Adrian R. and John C. Robertson, 1995, 'Resolving the Liquidity Effect,' Federal Reserve Bank of St. Louis *Review*, 77, 33-54.

[36] Rotemberg, Julio and Michael Woodford, 1997, 'An Optimization-Based Econometric Framework for the Evaluation of Monetary Policy,' *NBER Macroeconomics Annual*, 297-345.

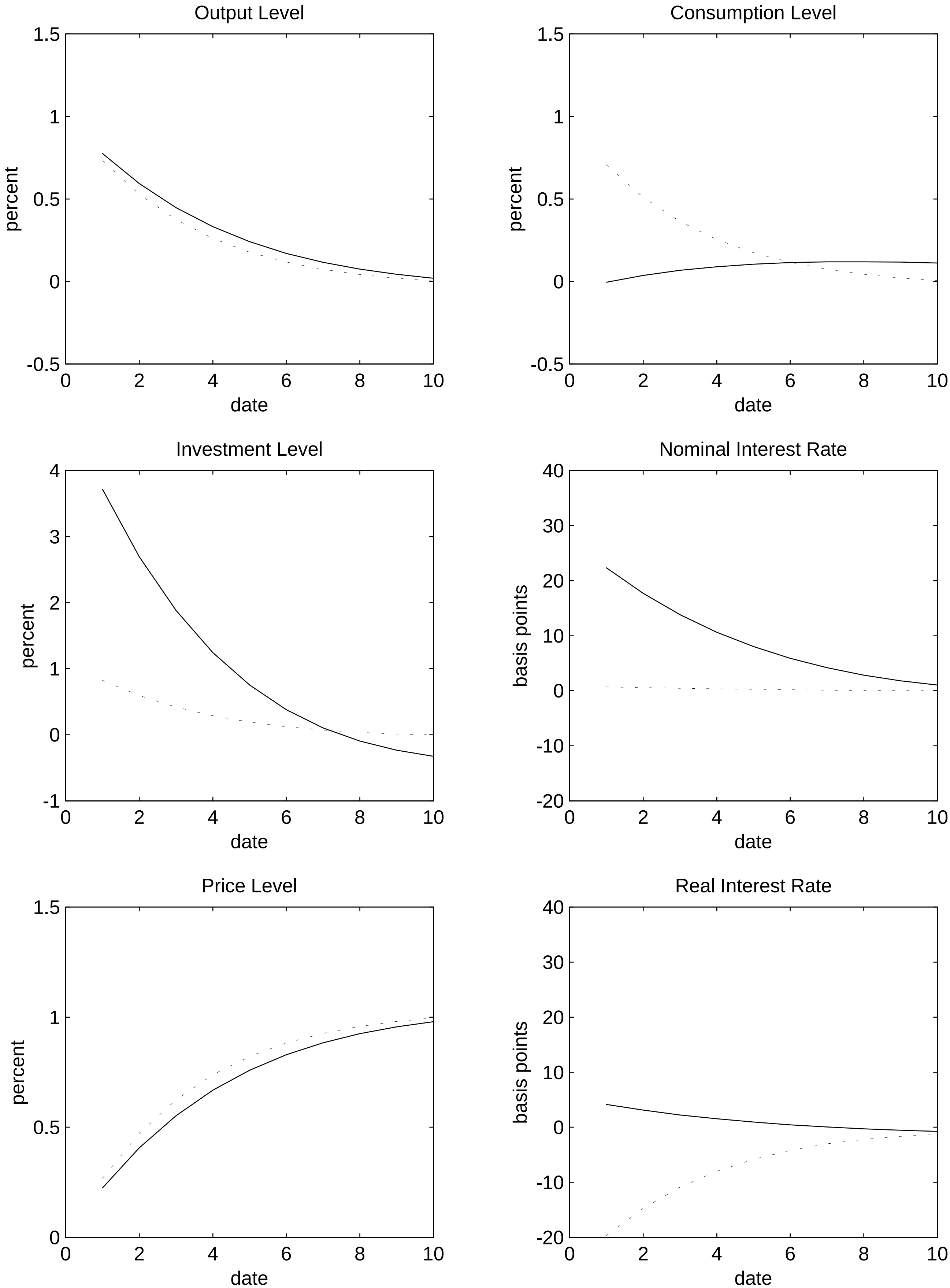
[37] Sims, Christopher A., 1986, 'Are Forecasting Models Usable for Policy Analysis?' Federal Reserve Bank of Minneapolis *Quarterly Review*, 10, 2-16.

[38] Strongin, Steven, 1995, 'The Identification of Monetary Policy Disturbances: Explaining the Liquidity Puzzle,' *Journal of Monetary Economics*, 35, 463-497.

[39] Taylor, John B., 1980, 'Aggregate Dynamics and Staggered Contracts,' *Journal of Political Economy*, 88, 1-23.

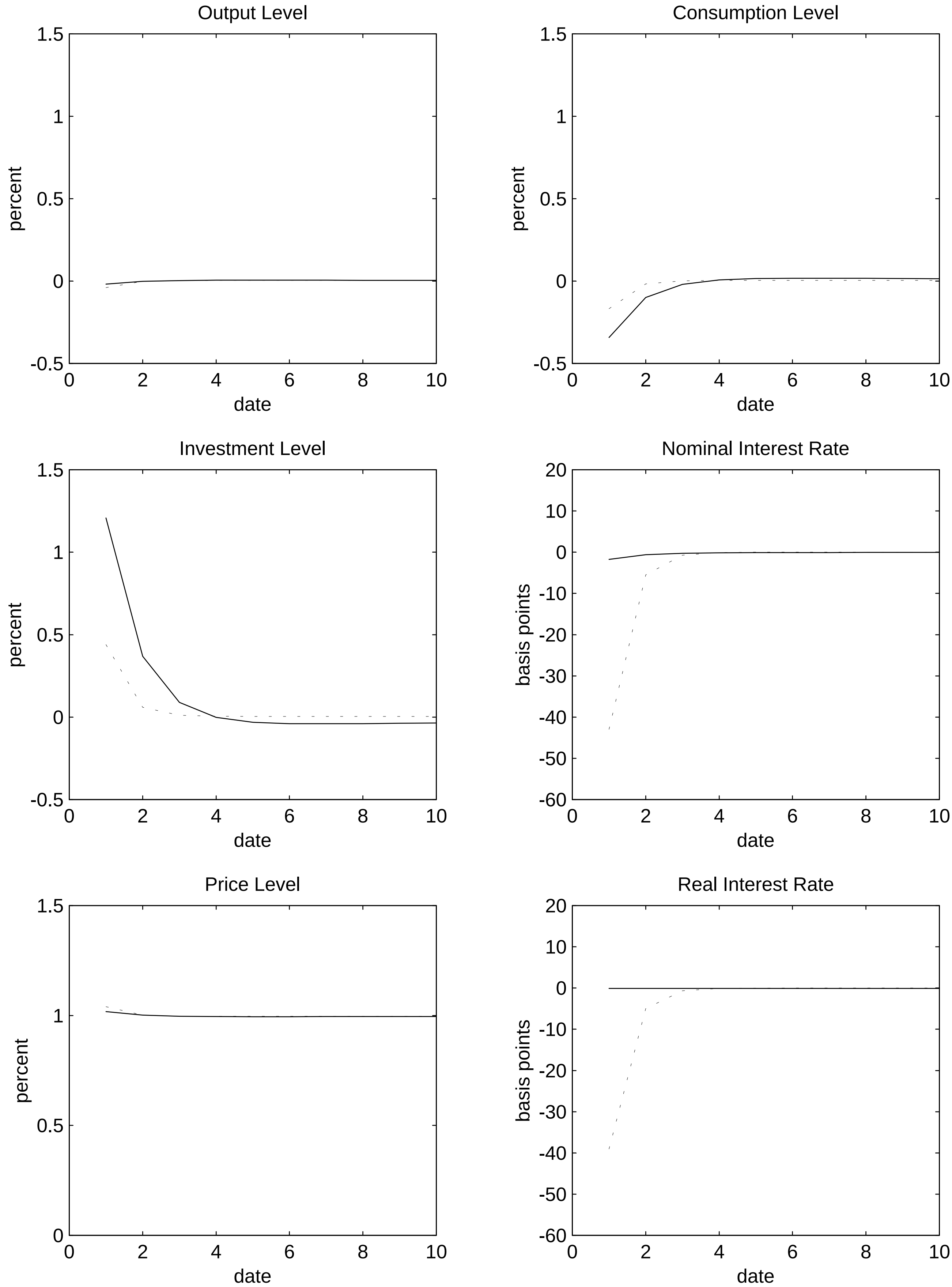
[40] Thornton, Daniel L., 2001, 'The Federal Reserve's Operating Procedure, Nonborrowed Reserves, Borrowed Reserves and the Liquidity Effect,' *Journal of Banking and Finance*, 32, 155-167.

Figure 1: Sticky Price Model



(___) Basic model (---) Model with capital adjustment costs

Figure 2: Limited Participation Model



(___) Basic model (---) Model with capital adjustment costs

Figure 3: Sticky Price and Limited Participation Model
with Capital Adjustment Costs