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ABSTRACT

The purpose of this paper is to construct a quantitative equilibrium model with price setting and use it to ask whether staggered price setting can generate persistent output fluctuations following monetary shocks. We construct a business cycle version of a standard sticky price model in which imperfectly competitive firms set nominal prices in a staggered fashion. We assume that prices are exogenously sticky for a short period of time. Persistent output fluctuations require endogenous price stickiness in the sense that firms choose not to change prices very much when they can do so. We find the amount of endogenous stickiness to be small. As a result, we find that such a model cannot generate persistent movements in output following monetary shocks.

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A long-standing question in macroeconomics is, What fraction of output variability can be attributed to monetary instability? Answering this question requires constructing models in which monetary disturbances play a role in business cycle fluctuations. Ever since the early 1970s, macroeconomists have known that it is possible to construct general equilibrium models in which monetary disturbances generate contemporaneous output fluctuations. Examples of such endeavors include Lucas (1972, 1990), Fischer (1977), Phelps and Taylor (1977), and Lucas and Woodford (1993). Macroeconomists have also known that it is very difficult to construct models in which monetary disturbances generate persistent movements in output. If monetary instability is to account for a significant fraction of business cycle fluctuations, monetary shocks must generate persistent movements in output. The literature on staggered price setting provides the most promising avenue for generating persistence. In a classic paper, Taylor (1980) showed that staggered wage contracts as short as one year are capable of generating persistence in aggregate variables similar to those observed in postwar business cycles. Blanchard (1983) showed that such results also hold when firms set prices in a staggered fashion. In both of these papers, the rules for setting wages or prices are exogenously specified.

Taylor (1980) argued that economies with staggered wage contracts display persistent movements in output even when the contracts last for as short a time as one year. In particular, Taylor (p. 2) points out that

> Because of the staggering, some firms will have established their wage rates prior to the current negotiations, but others will establish their wage rates in future periods. Hence, when considering relative wages, firms and unions must look both forward and backward in time to see what other workers will be paid during their own contract period. In effect, each contract is written relative to other contracts, and this causes shocks to be passed on from one contract to another—a sort of "contract multiplier."

The purpose of this paper is to construct a quantitative equilibrium model with staggered price setting and use it to ask whether the analog of the contract multiplier generated by price setting can generate persistent output fluctuations. In the literature on sticky prices the standard model is a static one in which imperfectly competitive firms set nominal prices and real money balances enter the consumer's utility function. (See, for example, Blanchard and Kiyotaki 1987, Ball and Romer 1989, 1990.) Our model basically takes this setup and turns it into a business cycle model by adding time and uncertainty as well as staggered price setting. (For some recent work embedding sticky prices in business cycle models, see Ohanian and Stockman 1994, Cho and Cooley 1995, King and

Watson 1995, Rotemberg 1995, Woodford 1996, and Yun 1996.) We find that a quantitative version of such a model cannot generate persistent movements in output following monetary shocks.

In our model there is a continuum of monopolistically competitive firms that produce differentiated products using capital and labor. These firms set nominal prices for a fixed number of periods and do so in a staggered fashion. In particular, in each period t, a fraction $1/N$ of these firms choose new prices which are then fixed for a year. The consumer side of the model is standard. Consumers are infinitely lived and have preferences over consumption, leisure, and real money balances. The nominal money supply follows an exogenous stochastic process.

We solve a version of our model with plausible parameter values and use it to investigate the impact of monetary shocks. In our baseline model, we mimic Taylor's (1980) preferred setting of parameters by letting prices be sticky for a year and setting $N = 4$, so that one-fourth of the firms set prices in the first quarter, one-fourth set them in the second quarter, and so on. We find that shocks to the money supply can have substantial effects on output. In particular, in our baseline model, an innovation to the growth rate of the money supply that causes it to grow by an extra 1% in a year leads to an increase in output of 3.3%. In sharp contrast to Taylor, we find that there is no persistence; after a year output has essentially returned to its original steady state.

We go on to investigate the conjecture of Taylor (1980) and Blanchard (1983) that even if the period over which prices are sticky is relatively short—say, one year—increasing the amount of staggering by increasing N increases the amount of price inertia and leads to persistent movements in output following a monetary shock. We considered versions of our model with $N = 4$, 12, and 52, corresponding to quarterly, monthly, and weekly staggering. We find that there is no persistence of output in any of the three versions. Thus the Taylor-Blanchard conjecture fails to hold in a standard business cycle model modified in the obvious way to include sticky prices.

In order to gain some intuition for why our results are so dramatically different from those of Taylor (1980) and Blanchard (1983), we modify our model so that it has exactly the same functional form as Taylor's model. His model essentially consists of two linear equations: a static money demand equation and a wage-setting equation. Wages are set as a function of both past and future wages and of the sum of future outputs. If we eliminate capital our model consists of a dynamic money demand equation and a price-setting equation. We make our model analogous to Taylor's by imposing his static money demand equation and linearizing our price equation around the steady state. Our linearized price-setting equation is identical to Taylor's wage-setting equation in that prices are set as a linear function of past and future prices and of the sum of future outputs.

The only difference between our modified model and Taylor's model is, thus, the magnitude of the coefficient on the sum of future outputs. In our model this coefficient is a simple function of the parameters of the underlying economy. We show that in the class of standard preferences there are no parameter values which generate persistence.

Beaudry and Devereux (1996), among others, suggest that it is possible to strengthen the propagation of shocks by altering agents' preferences to have zero income effects. We show that generating persistence requires implausibly large labor supply elasticities. Furthermore, such large labor supply elasticities lead to ridiculously large output movements in the impact period of the shock. Kimball (1995) suggests that persistence can be increased if intermediate goods producers face nonconstant elasticity of demand for their goods. We consider economies with such features and show they do not generate much persistence.

Rotemberg (1995) suggests that persistence can be increased if firms face upward-sloping marginal cost curves. One way of incorporating this feature is to assume that firms use specific factors which are inelastically supplied. We incorporate factor specificities in our model and show they do not substantially increase persistence. Basu (1995) suggests that adding an input-output structure can magnify the effect of monetary shocks. When we add this structure to our model, we find that for empirically plausible parameter values monetary shocks do not have persistent effects on output.

In Section 1 we describe our benchmark economy and define an equilibrium. In Section 2 we describe our choice of parameters, and in Section 3 we report our findings for the benchmark economy. In Section 4 we compare our results to Taylor's (1980). In Section 5 we add factor specificities, and in Section 6 we add an input-output structure to our benchmark economy.

1. A Benchmark Monetary Economy

Consider a monetary economy populated by a large number of identical, infinitely lived consumers. In each period t, the economy experiences one of finitely many events s_t. We denote by $s^t = (s_0, \ldots, s_t)$ the history of events up through and including period t. The probability, as of period zero, of any particular history s^t is $\pi(s^t)$. The initial realization s_0 is given.

In each period t the commodities in this economy are labor, a consumption-capital good, money, and a continuum of intermediate goods indexed by $i \in [0, 1]$. The technology for producing final goods from intermediate goods at history s^t is

$$(1) \qquad y(s^t) = \left[\int y(i, s^t)^{\theta} \, di \right]^{\frac{1}{\theta}}$$

where $y(s^t)$ is the final good and $y(i,s^t)$ is an intermediate good of type i. The technology for producing each intermediate good i is a standard constant returns to scale production function

$$(2) \qquad y(i,s^t) = F(k(i,s^t), l(i,s^t))$$

where $k(i,s^t)$ and $l(i,s^t)$ are the inputs of capital and labor.

Final goods producers behave competitively. In each period t they choose inputs $y(i,s^t)$, for all $i \in [0,1]$, and output $y(s^t)$ to maximize profits given by

$$(3) \qquad \max \; \overline{P}(s^{t-1})y(s^t) - \int P(i,s^{t-1})y(i,s^t)\,di$$

subject to (1), where $\overline{P}(s^{t-1})$ is the price of the final good at s^{t-1} and $P(i,s^{t-1})$ is the price of intermediate good i at s^{t-1}. The prices do not depend on s_t because date t prices in our economy are set before the realization of the date t shocks. Solving the problem in (3) gives the input demand functions

$$(4) \qquad y^d(i,s^t) = \left[\frac{\overline{P}(s^{t-1})}{P(i,s^{t-1})}\right]^{\frac{1}{1-\theta}} y(s^t).$$

The zero profit condition implies that

$$(5) \qquad \overline{P}(s^{t-1}) = \left[\int P(i,s^{t-1})^{\frac{\theta}{\theta-1}}di\right]^{\frac{\theta-1}{\theta}}.$$

Intermediate goods producers behave as imperfect competitors. They set prices for N periods and do so in a staggered fashion. In particular, in each period t fraction $1/N$ of these producers choose new prices $P(i,s^{t-1})$ before the realization of the event s_t. These prices are set for N periods, so for this group of intermediate goods producers,

$$(6) \qquad P(i,s^{t+\tau-1}) = P(i,s^{t-1})$$

for $\tau = 0,\ldots,N-1$. The intermediate goods producers are indexed so that producers indexed $i \in [0,1/N]$ set new prices in 0, N, $2N$, etc., while producers indexed $i \in [1/N,2/N]$ set new prices in 1, $N+1$, $2N+1$, etc., for the N cohorts of intermediate goods producers. At time t each producer in a cohort chooses prices $P(i,s^{t-1})$ to maximize discounted profits from periods t to $t+N-1$. That is, each solves

$$(7) \qquad \max_{P(i,s^{t-1})} \sum_{\tau=t}^{t+N-1} \sum_{s^\tau} Q(s^\tau|s^{t-1}) \left[P(i,s^{t-1}) - v(s^\tau)\overline{P}(s^{\tau-1})\right] y^d(i,s^\tau)$$

where $Q(s^\tau|s^{t-1})$ is the price of one dollar in s^τ in units of dollars at s^{t-1}, $v(s^t)$ is the unit cost of production at s^t, and $y^d(i,s^t)$ is given in (4). The unit cost of production is given by

$$(8) \qquad v(s^t) = \min_{k,l} \; r(s^t)k + w(s^t)l$$

subject to

$$(9)\qquad F(k,l) \geq 1$$

where $r(s^t)$ is the rental rate on capital and $w(s^t)$ is the real wage rate. The solution to the problem stated in (7) is

$$(10)\qquad P(i,s^{t-1}) = \frac{\sum_{\tau=t}^{t+N-1}\sum_{s^\tau} Q(s^\tau|s^{t-1})\overline{P}(s^{\tau-1})^{\frac{2-\theta}{1-\theta}}v(s^\tau)y(s^\tau)}{\theta\sum_{\tau=t}^{t+N-1}\sum_{s^\tau} Q(s^\tau|s^{t-1})\overline{P}(s^{\tau-1})^{\frac{1}{1-\theta}}y(s^\tau)}.$$

Implicit in this problem are the demands for capital and labor by the intermediate goods producers. (Note that these factor demands are the unit factor demands, which solve (8) and (9), multiplied by the level of output of the intermediate goods producer.) These factor demands, $k(i,s^t)$ and $l(i,s^t)$, of producer i in period t are made after the realization of the event s_t and thus depend on s^t. Profit maximization implies that

$$(11)\qquad \frac{F_l(k(i,s^t),l(i,s^t))}{F_k(k(i,s^t),l(i,s^t))} = \frac{w(s^t)}{r(s^t)}.$$

Notice that in what follows each intermediate goods firm has the Cobb-Douglas production function

$$(12)\qquad F(k(i,s^t),l(i,s^t)) = k(i,s^t)^\alpha l(i,s^t)^{1-\alpha}$$

and thus (11) can be written as

$$(13)\qquad \left(\frac{1-\alpha}{\alpha}\right)\frac{k(i,s^t)}{l(i,s^t)} = \frac{w(s^t)}{r(s^t)}.$$

It follows that the capital-labor ratios are equated across the intermediate goods firms, so for all $i \in [0,1]$,

$$(14)\qquad \frac{k(i,s^t)}{l(i,s^t)} = \frac{k(0,s^t)}{l(0,s^t)}.$$

Consumer preferences are given by

$$(15)\qquad \sum_{t=0}^{\infty}\sum_{s^t} \beta^t\pi(s^t)\,U(c(s^t),l(s^t),M(s^t)/\overline{P}(s^{t-1}))$$

where $c(s^t)$, $l(s^t)$, and $M(s^t)$ are consumption, labor, and nominal money balances, respectively. In each period $t = 0,1,\ldots$, consumers choose their time t allocations after the realization of the event s_t. The problem of consumers is to choose rules for consumption $c(s^t)$, labor $l(s^t)$, capital stocks $k(s^t)$, nominal money balances $M(s^t)$, and one-period nominal bonds $B(s^{t+1})$ to maximize

(15) subject to the sequence of budget constraints

$$(16)\qquad \overline{P}(s^{t-1})(c(s^t)+k(s^t))+M(s^t)+\sum_{s_{t+1}}Q(s^{t+1}|s^t)B(s^{t+1})$$
$$\leq \overline{P}(s^{t-1})(w(s^t)l(s^t)+[r(s^t)+1-\delta]k(s^{t-1}))$$
$$+M(s^{t-1})+B(s^t)+\Pi(s^t)+T(s^t),\quad t=0,1,\ldots.$$

Here $\Pi(s^t)$ is the nominal profits of the intermediate goods producers, $T(s^t)$ is nominal transfers, and δ is the depreciation rate of capital. The initial conditions $k(s^{-1})$, $M(s^{-1})$, and $B(s^0)$ are also given. Each of the nominal bonds $B(s^{t+1})$ is a claim to one dollar in state s^{t+1} and costs $Q(s^{t+1}|s^t)$ dollars in state s^t. In terms of relating the prices in the intermediate goods producer's problem to these prices, note that for all $\tau > t$

$$(17)\quad Q(s^\tau|s^t)=Q(s^{t+1}|s^t)Q(s^{t+2}|s^{t+1})\cdots Q(s^\tau|s^{\tau-1}).$$

The first order conditions for the consumer can be written as

$$(18)\qquad -\frac{U_l(s^t)}{U_c(s^t)}=w(s^t)$$

$$(19)\qquad \frac{U_c(s^t)}{\overline{P}(s^{t-1})}-\frac{U_m(s^t)}{\overline{P}(s^{t-1})}=\beta\sum_{s_{t+1}}\pi(s^{t+1}|s^t)\frac{U_c(s^{t+1})}{\overline{P}(s^t)}$$

$$(20)\qquad U_c(s^t)=\beta\sum_{s_{t+1}}\pi(s^{t+1}|s^t)U_c(s^{t+1})[r(s^{t+1})+1-\delta]$$

and for all $\tau > t$,

$$(21)\quad Q(s^\tau|s^t)=\beta^{\tau-t}\pi(s^\tau|s^t)\frac{U_c(s^\tau)}{U_c(s^t)}\frac{\overline{P}(s^{t-1})}{\overline{P}(s^{\tau-1})}$$

where $U_c(s^t)$, $U_l(s^t)$, and $U_m(s^t)$ denote the derivatives of the utility function with respect to its arguments and $\pi(s^\tau|s^t)=\pi(s^\tau)/\pi(s^t)$ is the conditional probability of s^τ given s^t.

The nominal money supply process is given by

$$(22)\quad M(s^t)=\mu(s^t)M(s^{t-1})$$

where $\mu(s^t)$ is a stochastic process and $M(s^{-1})$ is given. New money balances are distributed to consumers in a lump-sum fashion by having transfers satisfy

$$(23)\quad T(s^t)=M(s^t)-M(s^{t-1}).$$

In terms of market clearing conditions, consider first the factor markets. Notice that the capital stock chosen by consumers in period $t-1$ for rental in period t is $k(s^{t-1})$ while the labor supply in period t is $l(s^t)$. In turn, each intermediate goods producer i chooses his factor demands after the realization of uncertainty s_t in period t, so the demands for capital and labor are $k(i, s^t)$ and $l(i, s^t)$. Factor market clearing thus requires that

$$(24) \quad k(s^{t-1}) = \int k(i, s^t)\, di$$

$$(25) \quad l(s^t) = \int l(i, s^t)\, di.$$

The resource constraint for this economy is

$$(26) \quad c(s^t) + k(s^t) = y(s^t) + (1 - \delta)k(s^{t-1}).$$

An *equilibrium* for this economy is a collection of allocations for consumers $c(s^t)$, $l(s^t)$, $k(s^{t-1})$, $M(s^t)$, $B(s^{t+1})$; allocations for intermediate goods producers $k(i, s^t)$, $l(i, s^t)$ for $i \in [0, 1]$; allocations for final goods producers $y(s^t)$ and $y(i, s^t)$ for $i \in [0, 1]$ together with prices $w(s^t)$, $r(s^t)$, $Q(s^\tau|s^t)$ for $\tau = t, \ldots, t + N - 1$, $\overline{P}(s^{t-1})$, and $P(i, s^{t-1})$ for $i \in [0, 1]$ that satisfy the following conditions: (i) taking prices as given, consumer allocations solve the consumer's problem; (ii) taking all prices but his own as given, each intermediate goods producer's price solves (7); (iii) taking the prices as given, the final goods producer's allocations solve the final goods producer's problem; (iv) the factor market conditions (24) and (25) and the resource constraint (26) hold; and (v) the money supply process and transfers satisfy (22) and (23).

In what follows we will focus on the symmetric equilibrium in which all the intermediate goods producers of the same cohort make identical decisions. Thus $P(i, s^t) = P(j, s^t)$, $k(i, s^t) = k(j, s^t)$, $l(i, s^t) = l(j, s^t)$, $y(i, s^t) = y(j, s^t)$ for all $i, j \in [0, 1/N]$ and so on for the N cohorts.

To compute an equilibrium, we begin by substituting out a number of variables and reducing the equilibrium to four equations: the resource constraint, a pricing equation, an Euler equation for money, and an Euler equation for capital. We begin with the resource constraint. Recall that the demand for intermediate good i is

$$(27) \quad y^d(i, s^t) = \left[\frac{\overline{P}(s^{t-1})}{P(i, s^{t-1})}\right]^{\frac{1}{1-\theta}} y(s^t)$$

and the production function for this good is

$$(28) \quad y(i, s^t) = F(k(i, s^t), l(i, s^t)).$$

Since each intermediate goods firm has the same capital-labor ratio, it follows that this ratio is also equal to the aggregate capital-labor ratio. Combining (27) and (28) and using the constant returns to scale assumption, we see that the relative labor allocations are given by

$$(29)\quad \frac{l(i,s^t)}{l(0,s^t)} = \left(\frac{P(0,s^{t-1})}{P(i,s^{t-1})}\right)^{\frac{1}{1-\theta}}.$$

Since all firms in a cohort make the same decision, we can write the market clearing condition for labor as

$$(30)\quad l(s^t) = \frac{l(0,s^t)}{N} + \frac{l(\frac{1}{N},s^t)}{N} + \cdots + \frac{l(1-\frac{1}{N},s^t)}{N}.$$

Using (29) in (30) gives

$$(31)\quad l(s^t) = l(0,s^t)H(s^{t-1})$$

where

$$(32)\quad H(s^t) = \left[\frac{1}{N} + \frac{1}{N}\left(\frac{P(0,s^t)}{P(\frac{1}{N},s^t)}\right)^{\frac{1}{1-\theta}} + \cdots + \frac{1}{N}\left(\frac{P(0,s^t)}{P(1-\frac{1}{N},s^t)}\right)^{\frac{1}{1-\theta}}\right].$$

Aggregate output in this economy is given by

$$(33)\quad y(s^t) = \left[\int [k(i,s^t)^{\alpha} l(i,s^t)^{1-\alpha}]^{\theta}\, di\right]^{\frac{1}{\theta}}.$$

Since the capital-labor ratios in all firms are equal, we can write (33) as

$$(34)\quad y(s^t) = \left(\frac{k(s^{t-1})}{l(s^t)}\right)^{\alpha} \left[\int l(i,s^t)]^{\theta}\, di\right]^{\frac{1}{\theta}}.$$

Using (29) and (31) in (34) gives

$$(35)\quad y(s^t) = \left(\frac{k(s^{t-1})}{l(s^t)}\right)^{\alpha} \frac{l(s^t)G(s^{t-1})}{H(s^{t-1})}$$

where

$$(36)\quad G(s^t) = \left[\frac{1}{N} + \frac{1}{N}\left(\frac{P(0,s^t)}{P(\frac{1}{N},s^t)}\right)^{\frac{\theta}{1-\theta}} + \cdots + \frac{1}{N}\left(\frac{P(0,s^t)}{P(1-\frac{1}{N},s^t)}\right)^{\frac{\theta}{1-\theta}}\right]^{\frac{1}{\theta}}.$$

Substituting (35) into (26) gives the resource constraint we use in our computations.

We can now develop the pricing equation. We first express unit cost in terms of the aggregate allocations. To do so we solve the maximization problem in (8) and (9) and use (14) and (18) to get

$$(37)\quad v(s^t) = -\frac{1}{(1-\alpha)}\frac{U_l(s^t)}{U_c(s^t)}\left(\frac{l(s^t)}{k(s^{t-1})}\right)^{\alpha}.$$

Also, using (5), we can write the aggregate price level as

$$(38) \quad \overline{P}(s^{t-1}) = \left[\frac{1}{N}P(s^{t-1})^{\frac{\theta}{\theta-1}} + \cdots + \frac{1}{N}P(s^{t-N})^{\frac{\theta}{\theta-1}}\right]^{\frac{\theta-1}{\theta}}.$$

Using (35), (37), and (38) in (10), we obtain the pricing equation we use in our computations. Finally, we rewrite the Euler equations for money and capital, (19) and (20), using (38) to substitute for $\overline{P}(s^{t-1})$ and using (13), (14), and (18) to substitute for $r(s^t)$.

We are interested in a stationary equilibrium and thus restrict the stochastic processes for the growth of the money supply to be Markov. A stationary equilibrium for this economy consists of stationary decision rules which are functions of the state of the economy. Intuitively, the state at t must record the $N-1$ intermediate goods prices in addition to the capital stock and the rate of growth of the money supply. At any date t there are N prices prevailing for intermediate goods, namely, those set at the beginning of period t, those set at the beginning of period $t-1$, and so on up through those set in period $t-(N-1)$. It should be clear that all we need to record is these prices and not the index identifying the producers. Thus from now on we drop the dependence on i, and we let $P(s^{t-1})$ denote the prices set at the beginning of period t, $P(s^{t-2})$ denote the prices set at the beginning of period $t-1$, and so on. Since the money supply is growing over time, these prices are nonstationary. We normalize prices by dividing them by the money stock. Thus our state is

$$(39) \quad x_t = \left[\frac{P(s^{t-2})}{M(s^{t-1})}, \ldots, \frac{P(s^{t-N})}{M(s^{t-1})}, k(s^{t-1}), \mu(s^t), \mu(s^{t-1})\right].$$

The decision variables for period t are aggregate consumption in t, $c(s^t)$; aggregate labor supply in t, $l(s^t)$; and the normalized price of the cohort of intermediate goods producers that are setting their prices at the beginning of period t, $P(s^{t-1})/M(s^{t-1})$. We substitute out the end of period capital stocks using the resource constraints, and we end up with three equations: the pricing equation, the Euler equation for money, and the Euler equation for capital. We linearize these equations around the steady state and use standard methods to obtain linear decision rules. For $N=1$ and 2 we checked the accuracy of the linear decision rules against nonlinear decision rules obtained by the finite element method. (See McGrattan 1996.)

2. Calibration of the Benchmark Economy

We consider a utility function of the form

$$(40) \quad U(c, l, \frac{M}{\overline{P}}) = \left[\left(bc^{\nu} + (1-b)(M/\overline{P})^{\nu}\right)^{\frac{1}{\nu}}(1-l)^{\psi}\right]^{1-\sigma}/(1-\sigma).$$

The stochastic process for the growth rate of the money stock is given by

$$(41)\quad \log \mu_t = \rho \log \mu_{t-1} + (1-\rho)\log \overline{\mu} + \epsilon_t$$

where ϵ is a normally distributed i.i.d. mean zero shock with standard deviation σ.

Table 1

Parameter Values

Preferences	$b = 0.73,\ \nu = -17.52,\ \psi = 3,\ \sigma = 5$
Technology	$\alpha = 0.33,\ \delta = 1 - 0.9^{\frac{1}{4}},\ \theta = 0.9$
Money Growth	$\bar{\mu} = 1.06^{\frac{1}{4}},\ \rho = 0.57,\ \sigma = 0.00193$
Discount Factor	$\beta = 0.96^{\frac{1}{4}}$

The parameter values that we use are reported in Table 1. Consider first the preference parameters. The discount factor β, the share parameter ψ, and the curvature parameter σ are all standard from the business cycle literature (see, for example, Chari, Christiano, and Kehoe 1994). To obtain a and ν we drew on the money demand literature. Our model can be used to price a variety of assets including a nominal bond which costs one dollar at s^t and pays $R(s^t)$ dollars in all states s^{t+1}. The first order condition for this asset can be written as

$$(42)\quad U_m(s^t) = U_c(s^t)\left(\frac{R(s^t)-1}{R(s^t)}\right).$$

Using our specification of utility the first order condition can be rewritten as

$$(43)\quad \log \frac{M(s^t)}{\overline{P}(s^{t-1})} = -\frac{1}{1-\nu}\log\frac{b}{1-b} + \log c(s^t) - \frac{1}{1-\nu}\log\left(\frac{R(s^t)-1}{R(s^t)}\right).$$

We use Mankiw and Summers' (1986) money demand regressions to obtain ν. We set $-1/(1-\nu)$ equal to their estimate of the interest elasticity of money demand (-0.054) and obtained $\nu = -17.52$. To obtain b we set $M(s^t)/(\overline{P}(s^{t-1})c(s^t))$ equal to the average ratio of M1 to quarterly nominal consumption expenditures in the postwar period (1.2), and we set $R(s^t)$ equal to the average quarterly yield on three-month Treasury bills in the postwar period (that is, $R(s^t) = 1.0495^{\frac{1}{4}}$). Substituting these values into (43) yielded $b = 0.73$.

Consider next the technology parameters. We set the capital share parameter $\alpha = 0.33$ as is standard in the real business cycle literature. We calibrate θ as follows. We consider a steady state of our model with $\overline{\mu} = 1$. Let the real profits of intermediate goods producers in the steady state be denoted by Π. In the steady state $\Pi = y - vy$, where y is output and v is unit cost. From the pricing equation it follows that in a steady state $v = \theta$, so that

$$(44) \quad \frac{\Pi}{y} = 1 - \theta.$$

To obtain an estimate of Π/y we use the price-cost margin data of Domowitz, Hubbard, and Petersen (1986). They measure the price-cost margin as (*value added* $-$ *payroll*)/(*value added* $+$ *cost of materials*). The average price-cost margin across a sample of manufacturing industries is approximately 1/4. In the steady state of our model, (*value added* $-$ *payroll*) $= \Pi + (r+\delta)k$, where r and k are the steady state rental rate on capital and the capital stock, respectively. Jorgenson, Gollop, and Fraumeni (1987) show that the cost of materials is approximately equal to value added in U.S. manufacturing. Using these facts we obtain

$$(45) \quad \frac{\Pi + (r+\delta)k}{y} = \frac{1}{2}.$$

In the steady state of our model, $r + \delta = 0.14$ and $k/y = 2.8$. Using these numbers in (44) and (45), we obtain $\theta = 0.9$ (that is, a markup of about 11%).

Finally, the parameters governing the stochastic process for money growth were obtained from running a regression of the form (41) on data on M1 from 1959:3 through 1995:2 obtained from Citibase. We obtained $\bar{\mu} = 1.06^{1/4}$ and $\rho = 0.57$. We set σ so that the volatility of output in the benchmark economy is the same as in the data. We obtained $\sigma = 0.00193$.

3. Findings for the Benchmark Economy

The main question addressed in this section is whether the contract multiplier arising from staggered price setting generates persistence in output. We address this question by examining how much output changes following a monetary shock after all firms have had the opportunity to change their prices. For comparison purposes, we examine how much output changes following a monetary shock in a version of our model with no staggering.

Taylor (1980) shows that a version of his model is consistent with the persistence of unemployment in the United States. In his preferred version the length of the wage contracts is one year and one-fourth of all wage setters set their wages each quarter. Our benchmark model mimics Taylor's preferred version by setting $N = 4$ and setting the length of a period to be a quarter of a year. Thus prices are set for a year at a time and one-fourth of all price setters set their price each quarter. We focus on the impulse responses to a monetary shock. Figures 1 and 2 illustrate the response of the benchmark economy to a one time shock to the innovation in the log of the money growth rate at the beginning of the first year. We choose the size of the innovation so that in one year the money supply increases by 7%, which is one percentage point higher than its steady state growth rate of 6%.

In Figure 1 we plot the percentage deviations of output, consumption, and employment from their steady state values. For example, our measure of output is $100(y_t - y)/y$, where y_t is output in period t and y is steady state output. This shock to money growth leads to a 3.3% increase in output and a 1.7% increase in consumption in the period of the shock. One year after the shock output is below its steady state level. In Figure 2 we plot standardized measures of the money supply and the price level, namely, $M(s^t)/\overline{\mu}^t$, $P(s^t)/\overline{\mu}^t$. One year after the shock the price level has risen by roughly the same amount as the increase in the money supply. These figures show that staggered price setting does not lead to persistent movements in output.

For comparison purposes, in Figure 3 we plot the percentage deviations of output, consumption, and employment from their steady state values for a version of our economy with no staggering. We assume that the length of a period is one year and that all monopolists set prices at the beginning of each year. We adjust parameters so that a period is interpreted as one year (that is, $\beta = 0.96$, $\delta = 0.1$, $\bar{\mu} = 1.06$, and $\rho = 0.57^4$). From Figures 1 and 3 it should be clear that the contract multiplier does not increase persistence.

Taylor (1980) and Blanchard (1983) conjectured that, holding constant the length of time that prices are fixed, increasing the amount of staggering increases the persistence of output fluctuations. We investigate this conjecture as follows. We consider economies with $N = 12$ and $N = 52$. In these economies we adjust parameters so that a period is interpreted as a month and a week, respectively (that is, $\beta = 0.96^{\frac{1}{N}}$, $\delta = 1 - 0.9^{\frac{1}{N}}$, $\bar{\mu} = 1.06^{\frac{1}{N}}$, and $\rho = 0.57^{\frac{4}{N}}$). We keep the length of time over which prices are fixed at one year. Figure 4 illustrates the response of output for $N = 4, 12$, and 52 to a one time shock to the innovation in the log of the money growth rate at the beginning of the first year. This figure shows that increasing the amount of staggering has no effect on the persistence of output responses. Thus the Taylor-Blanchard conjecture does not hold in a business cycle model modified in the obvious way to include sticky prices.

4. Some Intuition

In this section we develop some intuition for why we do not get persistence. To do so we consider a stripped down version of the model that we can solve analytically for the equilibrium. In this version we abstract from capital and impose a static money demand equation. We show that in order to get persistence the equilibrium wage rate must change very little when consumption changes. We show that for the class of preferences in our benchmark model the equilibrium wage changes by so much that we cannot get persistence.

Consider a version of our model without capital and with $N = 2$. Suppose that the utility function is given by (40), as in the benchmark economy. We set $\overline{\mu} = 1$ so that the average rate of growth of the money supply is zero. We log-linearize our pricing equation around the deterministic steady state. We let $x_t = \log P(s^{t-1})$, $p_t = \log \overline{P}(s^{t-1})$, $w_t = \log w(s^t)$, and $y_t = \log c(s^t)$. Consider the pricing equation (10). If we set $\beta = 1$ in this equation and linearize it around the deterministic steady state, we get

$$(46) \quad x_t = \frac{1}{2}x_{t-1} + \frac{1}{2}E_{t-1}x_{t+1} + E_{t-1}w_t + E_{t-1}w_{t+1}.$$

Log-linearizing the labor supply equation (18) around the deterministic steady state gives

$$(47) \quad w_t = \gamma y_t$$

where $\gamma = (1 + \frac{\theta b}{\psi})$. We simply impose a static money demand equation given by

$$(48) \quad y_t + p_t = m_t.$$

The price level p_t is a weighted average of the individual prices,

$$(49) \quad p_t = \frac{x_t}{2} + \frac{x_{t-1}}{2}$$

and m_t is an exogenously given stochastic process.

Notice that if we substitute (47) into (46), the resulting system of equations is the same as that in Taylor (1980). (In his original article, Taylor focused on real shocks. The subsequent literature, including West 1988 and Blanchard 1990, focuses on monetary shocks.) The only difference between our price-setting equation and Taylor's wage-setting equation is that our value of γ depends on the underlying preferences and technology while for Taylor γ is a structural parameter.

The system of equations (46)–(49) can be solved to determine how money shocks are divided into movements in prices and movements in output. From (48) it follows that large movements in output require small movements in the price level. But from (46) and (47) it follows that large movements in output have small effects on the price level only if γ is small. To see how γ influences the division of money shocks into price and output movements, we solve the model for x_t, p_t, and y_t. Substituting for y_t in (46) using (48) and (49) we obtain

$$(50) \quad E_{t-1}x_{t+1} - 2\frac{1+\gamma}{1-\gamma}x_t + x_{t-1} = -\frac{2\gamma}{(1-\gamma)}E_{t-1}(m_t + m_{t+1}).$$

We can use standard methods to write x_t as

$$(51) \quad x_t = ax_{t-1} + \frac{2a\gamma}{1-\gamma} E_{t-1} \sum_{i=0}^{\infty} a^i (m_{t+i} + m_{t+1+i})$$

where a is the root with absolute value less than 1 which solves the quadratic $a^2 - \phi a + 1 = 0$ and $\phi = 2(1+\gamma)/(1-\gamma)$. This root is

$$(52) \quad a = \frac{1-\sqrt{\gamma}}{1+\sqrt{\gamma}}.$$

Now suppose that m_t is a random walk. Then after simplifying we can write

$$(53) \quad x_t = ax_{t-1} + (1-a)m_{t-1}.$$

Substituting for x_t in (49) we obtain

$$(54) \quad p_t = ap_{t-1} + \frac{1}{2}(1-a)(m_{t-1} + m_{t-2}).$$

Finally, substituting for p_t in (48) we obtain

$$(55) \quad y_t = ay_{t-1} + (m_t - m_{t-1}) + \frac{1}{2}(1-a)(m_{t-1} - m_{t-2}).$$

As should be clear, the persistence properties of output with respect to money shocks depend critically on the value of a and, therefore, on the value of γ.

When $\gamma = 0$, $a = 1$, x does not respond at all to money shocks, and $y_t = m_t$. Here a shock to m of Δ at time $t-1$ leads to a permanent increase in output starting at $t-1$.

When $\gamma = 1$, $a = 0$, so that

$$(56) \quad x_t = m_{t-1}$$

$$(57) \quad p_t = \frac{1}{2}(m_{t-1} + m_{t-2})$$

$$(58) \quad y_t = m_t - \frac{1}{2}(m_{t-1} + m_{t-2}).$$

Here a shock to m of Δ at time $t-1$ leads to no increase in x_{t-1} since this variable is chosen before the realization of m_{t-1}. This shock leads to an increase of Δ in x_t, x_{t+1}, x_{t+2}, and so on. In terms of aggregate prices, the shock leads to no increase in p_{t-1}, an increase of $\Delta/2$ in p_t, and an increase of Δ in aggregate prices in all subsequent periods. Likewise for output: the impulse leads to an increase of Δ in y_{t-1}, an increase of $\Delta/2$ in y_t, and no increase for all subsequent periods. Thus with $\gamma = 1$ output increases for only two periods, which is exactly the length of the price stickiness.

Indeed, if $\gamma > 1$, then output is necessarily below its steady state level two periods after a monetary shock.

The difference between our results and Taylor's can be traced to differences in the values of γ used in the two models. (For other analyses which emphasize the link between γ and persistence, see West 1988 and Blanchard 1990.) Taylor shows that a choice of $\gamma = 0.05$ is consistent with the persistence properties of the U.S. data. Recall that in our model

$$(59) \quad \gamma = 1 + \frac{\theta b}{\psi}.$$

In our model, because γ is necessarily greater than 1, positive monetary shocks cannot lead to positive output movements beyond the length of price stickiness. (For our calibrated model $\gamma =$ 1.22.) Furthermore, the persistence properties of output are highly nonlinear in γ, so that increasing γ to a small amount above 0.05 reduces persistence sharply. To see this, consider Figure 5 in which we plot the impulse responses following a monetary shock for different values of γ: 1.22 (the value of γ for our calibrated model), 0.25, and 0.05. This figure illustrates that even with values of γ as low as 0.25 output movements are not very persistent.

So far we have focused on $N = 2$ and a random walk process for the money supply. Similar results hold for larger values of N and more general stochastic processes for the money supply.

It should be clear from (47) that the labor supply equation determines γ. We investigated implications for γ for utility functions of the form

$$(60) \quad U(c, l, M/\bar{P}) = U\left[V(c) + G(l) + W(M/\bar{P})\right]$$

where V, G, and W are increasing concave functions. Log-linearizing the labor supply equation (18), we obtain

$$\gamma = \phi + 1/\xi$$

where $\phi = cV''(c)/V'(c)$ and $\xi = G'/G''l$ is the labor supply elasticity evaluated at the steady state. With these preferences it is possible to obtain values of γ as small as Taylor's value of 0.05 as long as ϕ is small enough and ξ is large enough. For example, values of $\phi = 0$ and $\xi = 20$ yield $\gamma = 0.05$. These calculations suggested that preferences with zero income effects and high labor supply elasticities offer a promising route to persistence. (Blanchard and Fischer 1989 and Blanchard 1990 point to the importance of high labor supply elasticities in generating persistence.) Labor economists are generally agreed (see Pencavel 1986) that labor supply elasticities are at most 1. With a labor supply elasticity of 1, $\gamma \geq 1$ and we cannot get persistence.

It turns out that if we assume a labor supply elasticity large enough to get γ down to 0.05, the model generates ridiculously large output effects in the impact period. We modified our benchmark economy to have preferences of the form (60) with $V(c) = c^{1-\phi}/(1-\phi)$, $G(l) = -\kappa l^{(1+1/\xi)}/(1+1/\xi)$, $W(m) = bm^{\omega}/\omega$ and with $U(x) = x^{1-\sigma}/(1-\sigma)$, with $\phi = 0.03$, $\kappa = 1.5$, $\xi = 50$, $b = 0.025$, $\omega = 0.97$, and $\sigma = 5$. With these parameters $\gamma = \phi + 1/\xi = 0.05$. We computed impulse responses following a shock which raises the growth rate of the money supply by 1% after one year. In the impact period of the shock, output rises by almost 30%. After the impact period, output is roughly 0.7% above its steady state value and declines slowly to its steady state. The large response of output is due to the fact that the labor supply is implausibly elastic and the within period utility over consumption is close to linear. These features imply that very small changes in wage rates are associated with huge changes in consumption and employment.

In a recent paper Kimball (1995) suggests that monetary shocks can have persistent effects on output if the monopolists face demand curves with nonconstant elasticity. He argues that if the elasticity of demand for a firm's product rises as that firm's relative price rises, firms will be reluctant to raise prices following a monetary shock, and this will lead to persistent movements in output. We examine this argument in our model by modifying the final goods technology to be of the Stone-Geary form:

$$(61) \quad y(s^t) = \left[\int \left[y(i,s^t) + \bar{y}\right]^{\theta} di\right]^{\frac{1}{\theta}} - \bar{y}$$

where $\bar{y}$ is a positive constant. One interpretation of this production function is that consumers are endowed with $\bar{y}$ units of each type of intermediate good and $y(s^t)$ is market production of the final good. The demand functions for the intermediate goods produced in the market are

$$(62) \quad y^d(i,s^t) = \left[\frac{\overline{P}(s^{t-1})}{P(i,s^{t-1})}\right]^{\frac{1}{1-\theta}} (y(s^t) + \bar{y}) - \bar{y}.$$

The elasticity of demand for good i is

$$\frac{1}{1-\theta}\left[1 - \bar{y}/(y^d(i,s^t) + \bar{y})\right]^{-1}.$$

Since $y^d(i,s^t)$ is decreasing in $P(i,s^{t-1})$ and $\bar{y}$ is positive, it follows that the elasticity of demand is increasing in $P(i,s^{t-1})$. Indeed, by making $\bar{y}$ large relative to $y^d(i,s^t)$, we can make the derivative of the elasticity with respect to the relative price arbitrarily large. Thus this functional form has the properties that Kimball argues is important.

It can be shown that a log-linearized version of the price setting equation is

$$(63) \quad x_t = \frac{1}{2}x_{t-1} + \frac{1}{2}E_{t-1}x_{t+1} + \beta_1 E_{t-1}(y_t + y_{t+1}) + \beta_2 E_{t-1}(w_t + w_{t+1})$$

where y_t is the log of market output at t, w_t is the log of real wages at t,

$$\beta_1 = \frac{(1-\theta)\bar{y}}{\theta(y+\bar{y})+(2-\theta)\bar{y}}$$

and

$$\beta_2 = \frac{\theta(y+\bar{y})+(1-\theta)\bar{y}}{\theta(y+\bar{y})+(2-\theta)\bar{y}}$$

where y is the steady state level of output. Since

$$(64) \quad w_t = (1+\frac{\theta b}{\psi})c_t$$

we can rewrite (63) as

$$(65) \quad x_t = \frac{1}{2}x_{t-1} + \frac{1}{2}E_{t-1}x_{t+1} + \gamma E_{t-1}(y_t + y_{t+1})$$

where $\gamma = \beta_1 + (1+\theta b/\psi)\beta_2$. Nonconstant elasticities of this form cannot lead to much persistence in output. For example, if we suppose that $y = \bar{y}$, and we use our calibrated parameters for θ and ψ, we obtain $\gamma = 0.84$. One interpretation of $y = \bar{y}$ is that the value of market output equals the value of home production. Even with the extreme assumption that market output is 0, we obtain $\gamma = 0.61$, which is still much too high to generate persistence. In view of this feature we do not report impulse responses for this model.

5. Factor Specificities

In this section we assume that each intermediate good is produced using a specific factor in addition to labor and capital. Each of these specific factors is inelastically supplied. The motivation for including these specificities is that they can potentially lead to greater persistence in output. With factor specificities, when a monopolist raises prices, the monopolist's output and hence his unit costs fall, if economy wide factor prices are held fixed. This feature implies that increases in economy wide wage rates will raise a monopolist's prices by a smaller amount than in an economy without specificities. Thus, following a monetary shock, all monopolists will raise their prices by a smaller amount and output movements will be larger and more persistent.

The technology for producing intermediate good i is given by

$$(66) \quad y(i,s^t) = F(k(i,s^t), l(i,s^t))$$

where F has decreasing returns to scale. We also introduce a type of capital specificity by having adjustment costs in changing the capital employed in producing each intermediate good. Specifically, the law of motion for capital used in producing good i is given by

$$(67) \quad k(i,s^t) = (1-\delta)k(i,s^{t-1}) - \phi\left(\frac{x(i,s^t)}{k(i,s^{t-1})}\right)k(i,s^{t-1}) + x(i,s^t)$$

where the adjustment cost function is given by

$$\phi(\frac{x}{k}) = \left(\frac{x}{k} - \delta\right)^2.$$

The problem of monopolist i is to choose $P(i, s^{t-1})$ and $l(i, s^\tau)$, $x(i, s^\tau)$, and $k(i, s^\tau)$ for $\tau = t, ..., t+N-1$ to maximize

$$(68) \quad \sum_{\tau=t}^{t+N-1} \sum_{s^\tau} Q(s^\tau | s^{t-1}) \left[P(i, s^{t-1}) y^d(i, s^\tau) - w(s^\tau)\bar{P}(s^{\tau-1}) l(i, s^\tau) - \bar{P}(s^{\tau-1}) x(i, s^\tau)\right]$$

subject to (67), where $y^d(i, s^\tau)$ is given by (4). The rest of the economy is the same as in Section 1.

We computed the impulse response functions for a version of our benchmark economy modified to include factor specificities. We let

$$F(k(i, s^t), l(i, s^t)) = k(i, s^t)^{\alpha_1} l(i, s^t)^{\alpha_2}$$

with $\alpha_1 = 2/9$ and $\alpha_2 = 4/9$. In Figure 6 we plot the impulse responses of output following a monetary shock in our economy with staggering and $N = 4$. As is clear from the figure, output has essentially returned to its steady state level one year after the shock. For comparison purposes, we also plot the impulse response in a version of the economy with no staggering ($N = 1$) with parameters adjusted as before. Clearly, staggering does not increase persistence.

Some intuition for why this version of the model does not generate persistence can be gained by analyzing a version of this model without capital. The production function for producing intermediate goods is given by

$$y(i, s^t) = l(i, s^t)^{1-\alpha}.$$

To make this analysis parallel to the analysis of the benchmark model without capital, it is convenient to split up the monopolist's problem into two parts. In the first part, the problem is to choose $P(i, s^{t-1})$ to maximize

$$(69) \quad \sum_{\tau=t}^{t+N-1} \sum_{s^\tau} Q(s^\tau | s^{t-1}) \left[P(i, s^{t-1}) - v(i, s^\tau)\bar{P}(s^{\tau-1})\right] y^d(i, s^\tau)$$

taking $v(i, s^\tau)$ as given. Here $v(i, s^\tau)$ can be interpreted as the price of one unit, of an input which can be converted into the intermediate good in a one-to-one fashion. In the second part, the problem is to choose $l(i, s^t)$ to maximize

$$v(i, s^t) l(i, s^t)^{1-\alpha} - w(s^t) l(i, s^t).$$

The first order condition for this problem is

$$(70) \quad v(i,s^t) = \frac{w(s^t)}{(1-\alpha)} l(i,s^t)^{\alpha}.$$

This way of writing the monopolist's problem requires an additional equilibrium condition,

$$(71) \quad y^d(i,s^t) = l(i,s^t)^{1-a}.$$

Substituting $l(i,s^t)$ from (71) into (70) and using the definition of $y^d(i,s^t)$ gives

$$(72) \quad v(i,s^t) = \frac{w(s^t)}{(1-\alpha)} \left(\frac{\bar{P}(s^{t-1})}{P(i,s^t)} \right)^{\frac{\alpha}{(1-\alpha)(1-\theta)}} y(s^t)^{\frac{\alpha}{1-\alpha}}.$$

It should be clear that the pricing equation is identical to that in the benchmark model. Now suppose $N=2$, $\bar{\mu}=1$, and $\beta=1$. As before, let $x_t = \log P(s^{t-1})$, $p_t = \log \overline{P}(s^{t-1})$, $y_t = \log c(s^t)$. Let $h_{1t} = \log v(i,s^t)$ for those intermediate goods producers who set prices at t, and let $h_{2t} = \log v(i,s^t)$ for those intermediate goods producers who set prices at $t-1$, and let $w_t = \log w(s^t)$. The log-linearized pricing equation is

$$(73) \quad E_{t-1}x_t = \frac{1}{2}x_{t-1} + \frac{1}{2}E_{t-1}x_{t+1} + E_{t-1}h_{1t} + E_{t-1}h_{2t+1}.$$

Log-linearizing (72) gives

$$(74) \quad h_{1t} = w_t + \frac{\alpha}{(1-\alpha)(1-\theta)}\left[-\frac{1}{2}x_t + \frac{1}{2}x_{t-1}\right] + \frac{\alpha}{(1-\alpha)}y_t$$

and

$$(75) \quad h_{2t+1} = w_{t+1} + \frac{\alpha}{(1-\alpha)(1-\theta)}\left[-\frac{1}{2}x_t + \frac{1}{2}x_{t+1}\right] + \frac{\alpha}{(1-\alpha)}y_{t+1}.$$

Log-linearizing the labor supply equation (18) around the deterministic steady state gives

$$(76) \quad w_t = (1+\theta b/\psi)y_t.$$

Substituting (74)–(76) into (73) gives

$$(77) \quad x_t = \frac{1}{2}x_{t-1} + \frac{1}{2}E_{t-1}x_{t+1} + \gamma E_{t-1}\left(y_t + y_{t+1}\right)$$

where

$$\gamma = \frac{1+\theta b/\psi + \alpha/(1-\alpha)}{1+\alpha/\left[(1-\alpha)(1-\theta)\right]}.$$

With our calibrated numbers $\theta = 0.9$, $\psi = 3$, $b = 0.73$, and $\alpha = 0.33$ we get $\gamma = 0.29$. This value of γ is too high to generate the observed level of persistence in output. If, however, θ is close enough to 1, then γ can be made arbitrarily close to 0. For example, if $\theta = 0.99$, then $\gamma = 0.03$, which is close to Taylor's value.

While high enough values of θ can lead to substantial persistence they also lead to extremely counterfactual implications regarding the distribution of output across firms in our economy. To see this, note that relative outputs of monopolists i and j are given by

$$\frac{y(i,s^t)}{y(j,s^t)} = \left[\frac{P(j,s^t)}{P(i,s^t)}\right]^{\frac{1}{1-\theta}}.$$

For example, with $\theta = 0.99$ a 1% difference in relative prices implies a 270% (1.01^{100}) difference in relative outputs.

6. Adding an Input-Output Structure

In a recent paper Basu (1995) suggests that adding an input-output structure to the static sticky price model can magnify the effect of monetary shocks. In his model intermediate goods producers must purchase the composite final good to produce their own intermediate good. One reason to suppose that adding this structure might lead to persistent output movements is as follows. Suppose that the percentage change in wage rates and rental rates is the same in the models with and without the input-output structure. Then, in the model with the input-output structure, the percentage change in the marginal cost of producing intermediate goods is smaller because some factor prices have not changed. In this section we investigate whether adding an input-output structure to our model can lead to persistent movements in output following a monetary shock. When we add this structure to our model, we find that for empirically plausible parameter values monetary shocks do not have persistent effects on output.

We incorporate an input-output structure in our model as follows. The intermediate good i is produced according to the following production function:

$$(78) \quad y(i,s^t) = (F(k(i,s^t), l(i,s^t)))^{1-\eta} q(i,s^t)^{\eta}$$

where $q(i,s^t)$ is the amount of the final good used as an input by intermediate goods producer i. The final good is produced according to the production function

$$(79) \quad y(s^t) = \left[\int y(i,s^t)^{\theta}\, di\right]^{\frac{1}{\theta}}.$$

The resource constraint for this economy is given by

$$(80) \quad c(s^t) + q(s^t) + k(s^t) - (1-\delta)k(s^{t-1}) = y(s^t)$$

where $q(s^t) = \int q(i, s^t)\, di$ is the aggregate amount of the final good used as an input. The unit cost of production of intermediate goods firms is now

$$(81) \quad v(s^t) = \min_{k,l,q} \; r(s^t)k + w(s^t)l + q$$

subject to

$$(82) \quad F(k,l)^{1-\eta} q^{\eta} = 1.$$

The rest of the model is identical to the one in Section 1. The only parameter we have added is η, which is the share of intermediate goods costs in total costs.

Adding the input-output structure requires that we recalibrate θ. In a steady state of our model with $\bar{\mu} = 1$, the real profits of intermediate goods producers are $\Pi = y - vy$, where y is gross output and v is unit cost. From the pricing equation it follows that in a steady state $v = \theta$, so that

$$(83) \quad \frac{\Pi}{y} = 1 - \theta.$$

Recall that Domowitz, Hubbard, and Petersen (1986) obtained a price-cost margin of 1/4. In the steady state of this model, we obtain

$$(84) \quad \frac{\Pi + (r+\delta)k}{y} = \frac{1}{4}.$$

Recall from Section 2 that gross output is twice as large as value added, the ratio of the capital stock to value added is 2.8, and $r + \delta = 0.14$. It follows that $(r+\delta)k/y = 0.196$, and thus Π/y is about 0.05. Using this value for Π/y in (83) we get $\theta = 0.95$.

We set η as follows. Let $x = F(k,l)$ denote the composite capital-labor good used in producing intermediate goods, and let u denote its unit cost of production. In a steady state,

$$(85) \quad \frac{q}{y} = \left(\frac{q}{x}\right)^{1-\eta}.$$

Cost minimization implies that

$$(86) \quad \frac{q}{x} = \frac{\eta}{1-\eta} u$$

and

$$(87) \quad v = \frac{1}{1-\eta} \left(\frac{1-\eta}{\eta}\right)^{\eta} u^{1-\eta}.$$

In a steady state, the pricing equation implies that $v = \theta$. Using this relation in (85)–(87) gives

$$(88) \quad \frac{q}{y} = \eta\theta.$$

Since gross output is twice value added and $\theta = 0.95$, we obtain $\eta = 0.53$.

We calculate impulse responses to a monetary shock for this model in exactly the same way as we did in the benchmark model. Figure 7 illustrates the response to a one time innovation in the growth rate of money. It is clear that adding the input-output structure has no effect on the persistence properties of output. For comparison purposes, we also plot the impulse response in a version of the economy with no staggering ($N = 1$) with parameters adjusted as before. Clearly, staggering does not increase persistence.

To give some intuition for why adding the input-output structure does little to help generate persistence, we compare a version of the model without capital to Taylor's model. With an input-output structure the formula for γ is now

$$(89) \quad \gamma = \frac{(1-\eta)[\psi(1-\eta\theta) + \theta b(1-\eta)]}{\psi(1-\eta\theta) + \eta\theta b(1-\eta)(1-\theta)/(1-\eta\theta)}.$$

Recall that when η equals zero, $\gamma = 1 + \theta b/\psi$ is necessarily larger than 1. When η is positive, γ may be less than 1 and it is theoretically possible that monetary shocks have persistent effects on output. Substituting $\theta = 0.95$, $\eta = 0.53$, $b = 0.73$, and $\psi = 3$ into (89), we find that $\gamma = 0.54$. This value of γ is too large to generate much persistence.

7. Conclusion

At some level, generating monetary business cycles which last, say, three years is a trivial task in a sticky price model. To do so we need only assume that prices are exogenously sticky for three years in the sense that firms are prohibited from changing their prices for three years at a time. We find assumptions like these implausible. The task we undertook in this paper was to develop a model in which prices are exogenously sticky for a short period of time, but endogenously sticky for a long period of time. Prices would be endogenously sticky if firms choose not to change prices very much when they can do so. This endogenous stickiness gives rise to a contract multiplier. We found that the contract multiplier in standard new Keynesian models is small. This research suggests that we should look elsewhere for mechanisms to generate persistence following monetary shocks.

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Figure 1. Impulse Responses of Output, Consumption, and Employment in Benchmark Economy

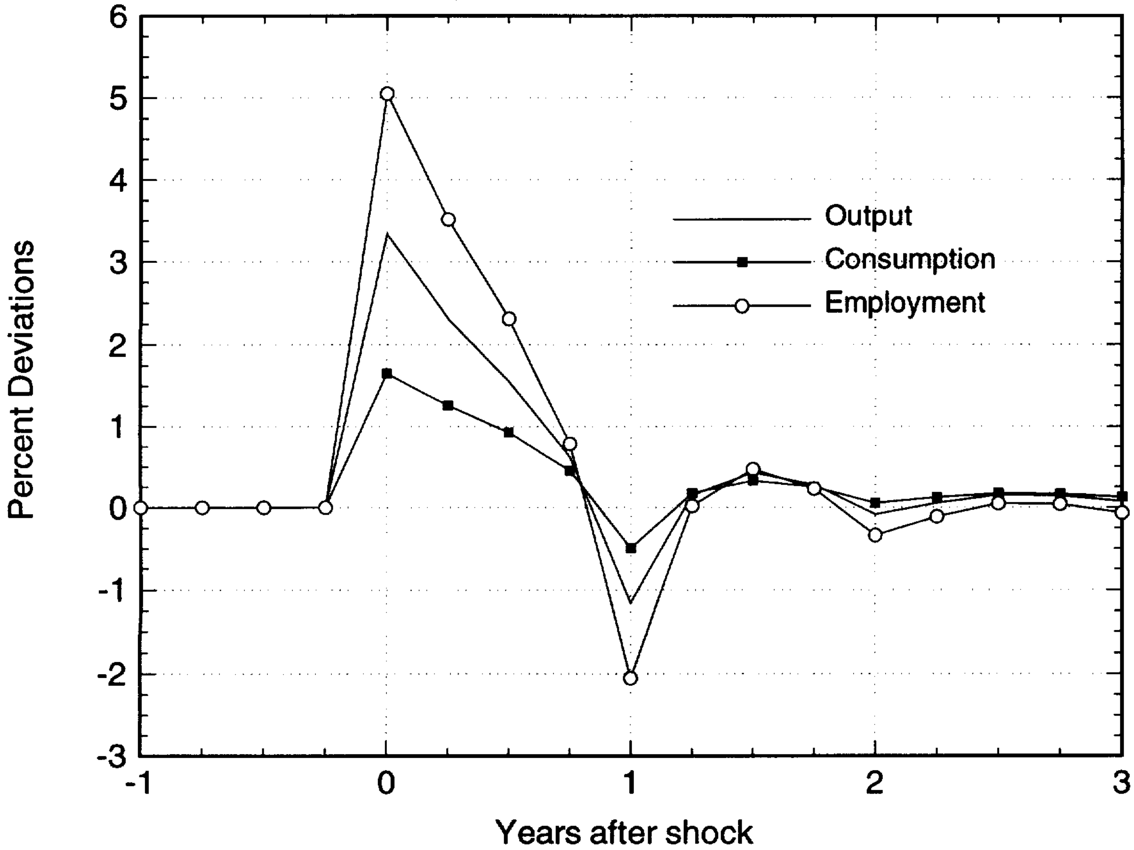

Figure 2. Impulse Responses of Money and Prices in Benchmark Economy

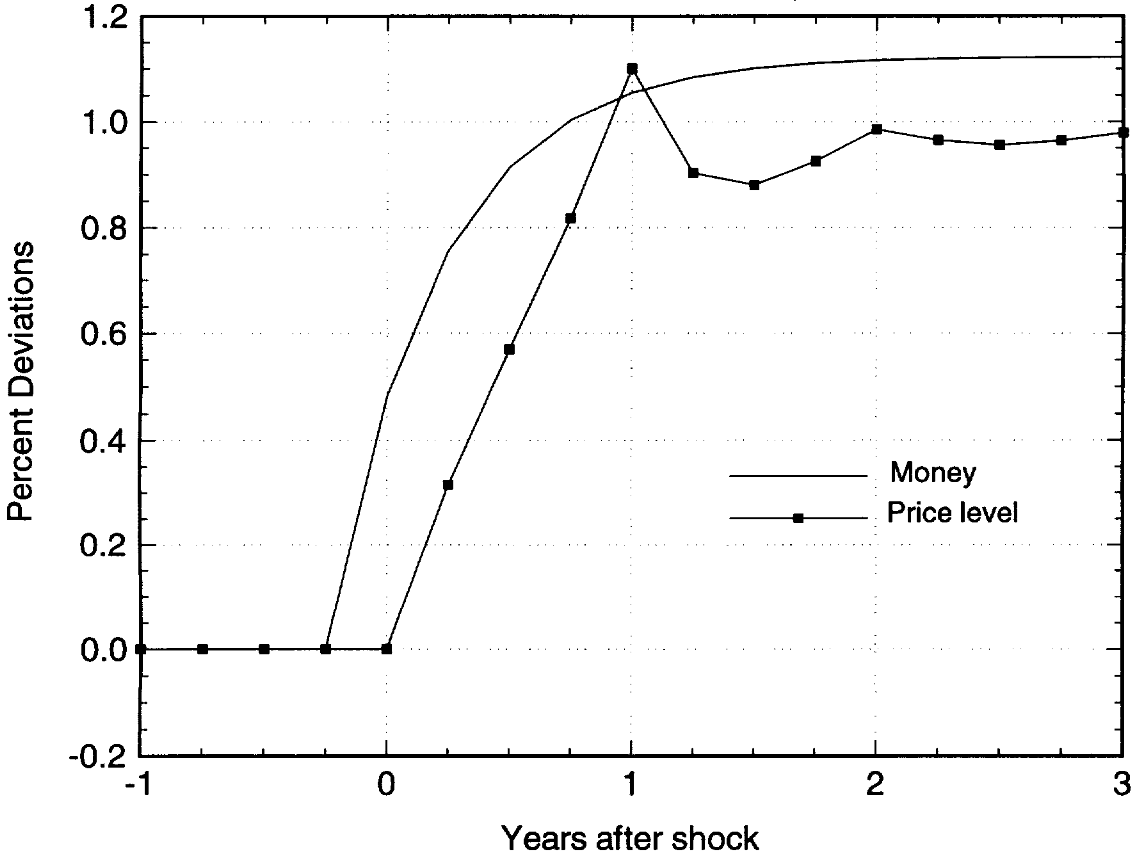

Figure 3. Impulse Responses of Output, Consumption, and Employment in Economy without Staggering

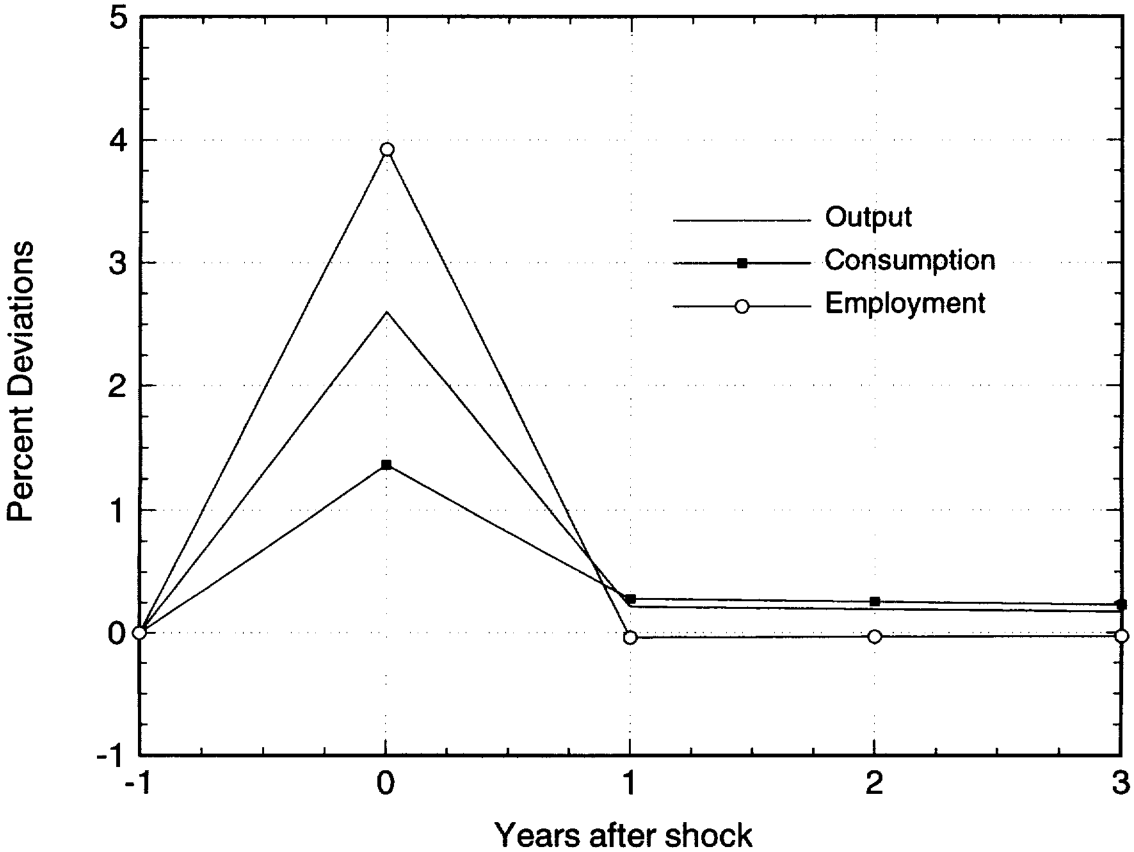

Figure 4. Impulse Responses of Output in Economies with N = 4, 12, and 52

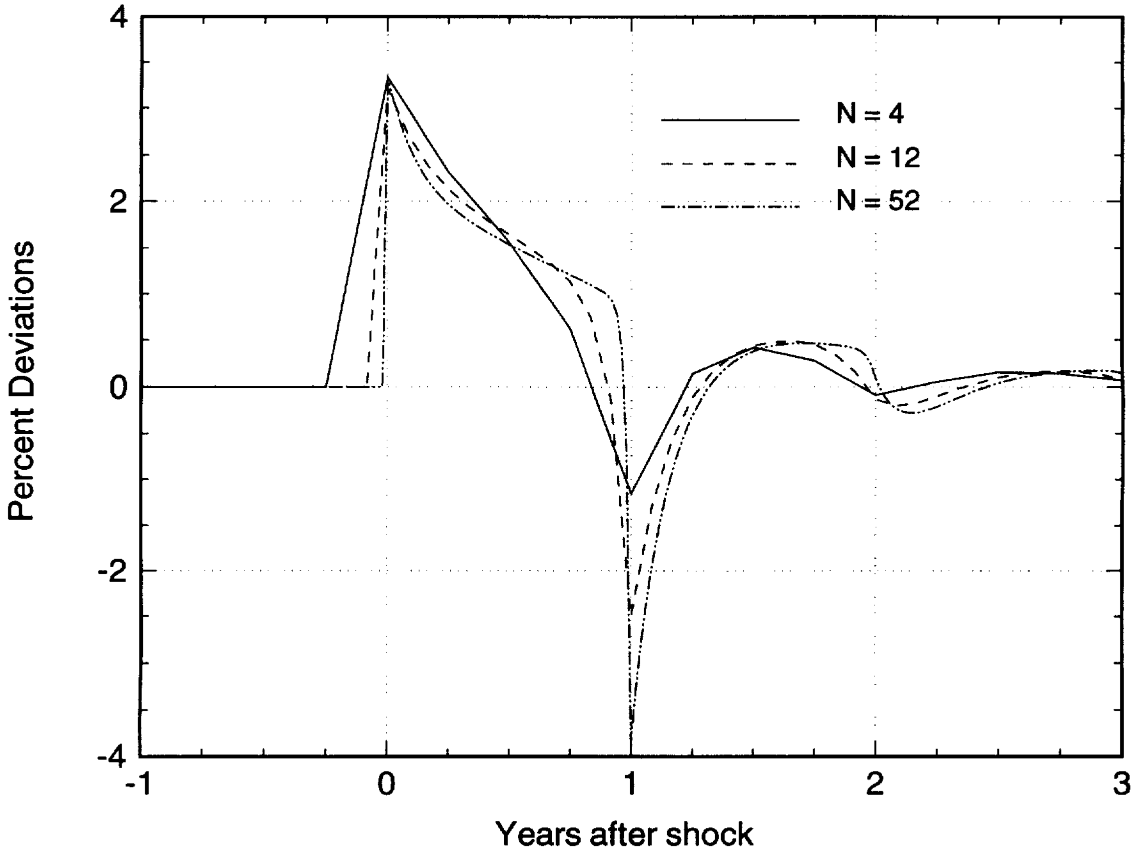

Figure 5. Impulse Responses of Output for Alternative γ's

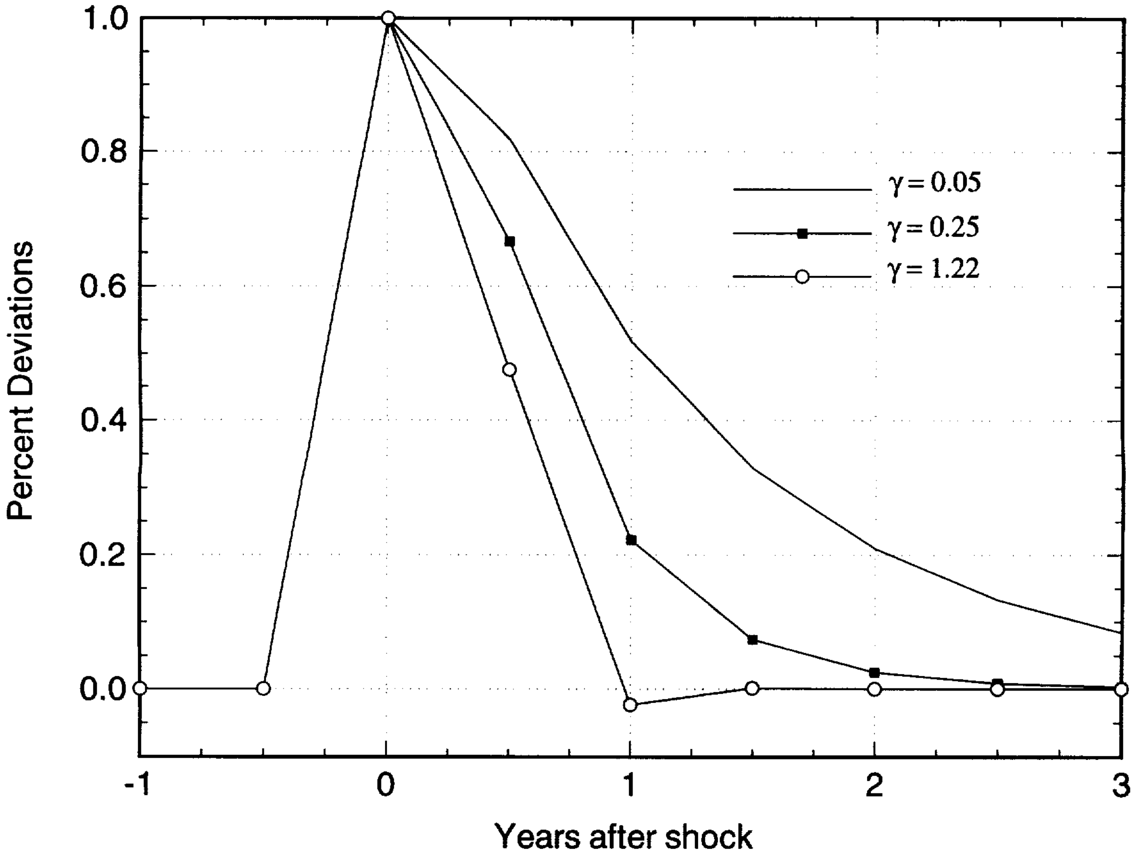

Figure 6. Impulse Responses of Output in Economy with Factor Specificities

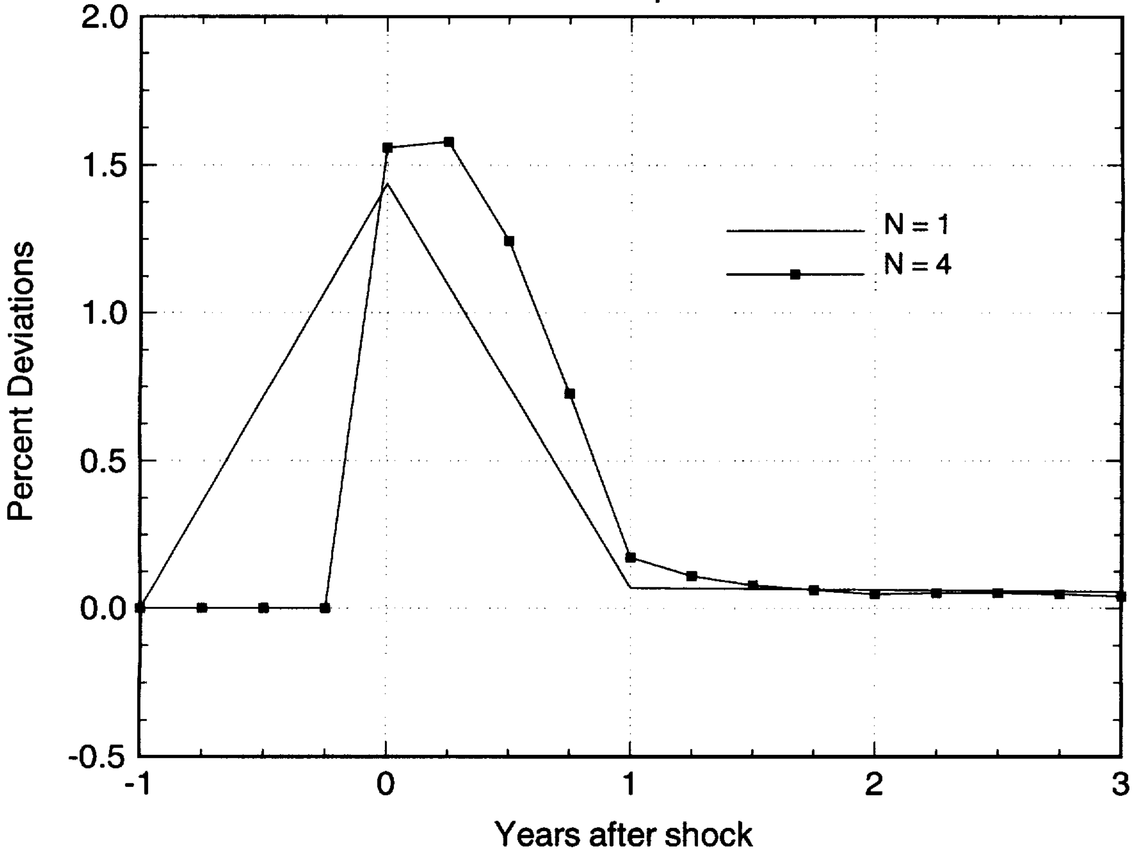

Figure 7. Impulse Responses of Output in Economy
with Input-Output Structure