Short-Run Effects of Money When Some Prices Are Sticky

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Much of the literature in macroeconomics is concerned with the effects of monetary disturbances on the real economy, particularly the role of money in business cycles. Monetary shocks can have important real effects in "Keynesian" models because this class of models generally involves nominal rigidities in prices or wages. In sharp contrast, a broad neoclassical tradition in macroeconomics (including real business cycle theory) typically assumes prices are completely flexible, although there have been some recent attempts to combine these traditions, as in Kydland (1987), Cho and Cooley (1990), and King (1990).

While there is much evidence that certain types of goods have sticky nominal prices, there is also evidence of frequent price changes for other types of goods, such as the relatively homogeneous commodities sold on near-auction markets, food, automobiles (transactions prices), and computers. Typically, Keynesian macroeconomic studies postulate a sticky price level, so that a change in the nominal money supply is (in the short run) a change in the real money supply. These studies generalize from the evidence that *some* prices are sticky to the hypothesis that the *general price level* is sticky. In contrast, neoclassical studies often assume flexible prices, so that the price level adjusts immediately to changes in the nominal money supply. These studies typically ignore or discount the evidence that certain prices are sticky.

Studies presenting evidence that certain nominal prices are "sticky" include Stigler and Kindahl (1970), which found evidence of infrequent changes in transactions prices in product markets, and Carlton (1986), which extended the Stigler-Kindahl study and documented slow changes in nominal transactions

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prices for producers' goods even without long-term relationships between buyers and sellers and showed that delivery lags and other product characteristics often change before or in place of changes in nominal prices. Carlton's result (1989, p. 921) that the degree of price rigidity differs greatly across industries (with the average period between price changes ranging from 5.9 months for household appliances to 19.2 months for chemicals) is one motivation for our assumption below that sectors differ in their speed of price adjustment. Other papers include Cecchetti's (1986) study of stickiness in nominal magazine prices, Kashyap's (1991) study showing substantial price sluggishness in three major mail-order catalogs (even when new catalogs are published), Rees's (1961) study providing evidence that catalog prices and retail-store prices have similar properties, and Blinder's (1991) survey that found that most firms change nominal prices one time or less in a typical year. Other evidence for nominal price sluggishness includes the well-known fact that prices are seldom formally indexed to a price index and the fact that real exchange rates (exchange rate-adjusted ratios of price indexes across countries) vary much more under floating exchange rate systems than under pegged exchange rate systems (see Stockman [1983], Mussa [1986], and Baxter and Stockman [1989]). This evidence strongly suggests that the exchange rate system affects international relative-price variability, a fact that is easy to explain with models in which some prices are sticky and much harder to explain in flexible-price models. Related evidence appears in Engel (1991). On the other hand, many sectors of the U.S. economy appear to have very flexible prices—with nominal prices that often change weekly, daily, or every few minutes.

This article studies a hybrid model in which some nominal prices are sticky and others are flexible. This model turns out to have several interesting properties. Unexpected changes in the money supply change the relative prices of sticky-price and flexible-price goods, so the real effects of monetary disturbances can differ across sectors. With certain parameter configurations, the model has the ability to produce *endogenous* price sluggishness in the flexible-price sector because the equilibrium response of those prices to a change in money is small in the short run. With other parameter configurations, the response of flexible nominal prices to a monetary disturbance is sufficiently large that the change in real money balances is small, as are monetary effects on the real economy working through the standard Keynesian transmission mechanism. In that case, however, a monetary disturbance has large effects on relative prices and induces different responses of output in different sectors of the economy. Monetary shocks, in this way, may contribute to sectoral shifts in the economy. Nominal price sluggishness also affects the short-run response of the economy to real disturbances (e.g., to changes in technology), even in sectors of the economy with flexible prices.

Because there is currently no well-established theory to explain nominal price stickiness, we follow Svensson (1986), Lucas (1991), Lucas and

Woodford (1992) and Cho and Cooley (1990) in assuming that nominal prices in the sticky-price sector are set one period in advance.[1] (We assume that the *implications* of sluggish price adjustment are largely independent of the *source* of that sluggishness.) In contrast to those models, however, the economy we study also has a flexible-price sector with trading at Walrasian prices. An interesting feature of our more general theory (to coin a phrase) is that it encompasses the standard Keynesian model (in one of its guises) and the flexible-price neoclassical model as special cases.

We study two versions of the model. The first version is developed in the spirit of Barro and Grossman (1976): when nominal prices cannot adjust to clear markets, some agents are rationed and output is determined by the minimum of the quantity demanded and the quantity supplied. In this case positive money shocks result in excess demand, with households rationed, and negative money shocks result in excess supply, with producers constrained. The second version we study assumes that output is determined by the quantity demanded. This version of the model is more consistent with recent sticky-price literature such as Blanchard and Kiyotaki (1987), who assume monopolistic competition so that small, positive money shocks leave the sticky-price sector in a situation of demand-determined output and do not imply rationing of buyers as in the Barro-Grossman model. (Instead, firms supply more of the good as long as price exceeds marginal cost.) We show that the effects of positive money shocks differ across the two versions of the model, though the effects of negative money shocks are similar in both versions.

This article does not attempt to match closely the implications of the model with data. Instead, its purpose is to analyze the properties of a simple model with sticky- and flexible-price sectors and to examine how its properties depend on basic parameter values. Consequently, the analysis we present below focuses on the effects of isolated, exogenous monetary disturbances.

1. A SIMPLE COMPETITIVE EQUILIBRIUM MODEL

We begin with a simple flexible-price equilibrium model that we have also examined in Ohanian and Stockman (1994) and (in a two-country framework) in Stockman and Ohanian (1993). The model has two consumption goods, X and Y, and labor. We introduce money through a cash-in-advance constraint, intended to stand in for a more general transactions model of money. We assume, for simplicity, that there are complete asset markets. The representative household maximizes utility:

[1] In contrast to Lucas and Woodford, we simply assume the level at which nominal prices are predetermined in the sticky-price sector rather than deriving an endogenous distribution of prices.

$$\max E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{1}{(1-\rho)} \left[\alpha x_t^{(\sigma-1)/\sigma} + (1-\alpha) y_t^{(\sigma-1)/\sigma} \right]^{[\sigma/(\sigma-1)]\cdot(1-\rho)} - v(L_{Xt} + L_{Yt}) \right] \tag{1}$$

subject to the two constraints

$$n_{t-1} + \tau_t + P_{X,t-1} k_{X,t-1} L_{X,t-1}^{\delta} + P_{Y,t-1} k_{Y,t-1} L_{Y,t-1}^{\delta} - M_t + \nu_t (q_t + d_t) - \nu_{t+1} q_t = 0 \tag{2}$$

and

$$M_t - P_{Xt} X_t - P_{Yt} Y_t \geq 0 \tag{3}$$

each period. Equation (2) is a budget constraint for period t asset markets and (3) is the cash-in-advance constraint which applies to period t product markets (which immediately follow period t asset markets as in Lucas [1982]). The terms x and y refer to consumption of goods X and Y, L_X and L_Y refer to labor hours producing goods X and Y, $0 \leq \delta < 1$ is a parameter of the production function, k_X and k_Y are exogenous productivity parameters, n_{t-1} refers to the household's money holdings at the end of period $(t-1)$ product markets (which is the slack in inequality [3] from the previous period and equals *zero* in our equilibrium), τ refers to a lump-sum transfer of money to the household from the government, P_X and P_Y are nominal prices, M_t is the nominal money the household chooses as it leaves period t asset markets and enters period t product markets, and ν_t is a vector of other assets the household owns at the beginning of period t, with dividend vector d and ex-dividend price-vector q.[2]

Several important parameters that we will focus on later appear in (1) and (2). First, α is a parameter describing tastes. Because α helps determine the equilibrium share of good X in total output, we will vary it in "The Size of the Sticky-Price Sector" subsection of Section 2 to discuss changes in the relative sizes of the X and Y industries. Next, ρ is the inverse of the intertemporal elasticity of substitution; an increase in ρ means households are less willing to trade current consumption for future consumption (that is, they are willing to

[2] One can also think of k_X and k_Y as fixed levels of the capital stock. However, adding capital accumulation to the model would change its implications in several ways. The most obvious change would occur in the dynamics of adjustment to equilibrium following a disturbance. In addition, changes in the rate of capital accumulation would provide an additional margin of substitution for the economy that could tend to smooth consumption over time and thereby reduce the response of interest rates to exogenous disturbances. By abstracting from capital accumulation, the current article greatly simplifies the analysis. The benefit of this simplicity is that it facilitates understanding; the cost is that it may lead to slightly different quantitative results than a more complicated model with capital accumulation. We are currently extending the model to include capital and will report on the results in a forthcoming paper.

pay more for a more constant consumption stream). The subsection "The Size of Intertemporal Substitution" explains how the size of ρ affects our results. Third, σ is the elasticity of substitution between goods X and Y; a larger σ means the goods are better substitutes. The impact of the size of σ on our results is the subject of the subsection "The Size of Intratemporal Substitution." Finally, δ determines the curvature of the production function, with lower values of δ indicating higher degrees of diminishing returns to labor; the subsection "The Degree of Curvature in Production" discusses the impact of this parameter on our results.[3]

We assume that the cash-in-advance constraint (3) holds as an equality, $k_X = k_Y = 1$ for all t, and that $\tau \equiv 0$. The *flexible-price perfect foresight equilibrium* for this simple production economy satisfies

$$M_t^s = P_{Xt} L_{Xt}^{\delta} + P_{Yt} L_{Yt}^{\delta}, \tag{4}$$

$$P_{Xt}\lambda_t = \left[\alpha L_{Xt}^{\delta(\sigma-1)/\sigma} + (1-\alpha) L_{Yt}^{\delta(\sigma-1)/\sigma}\right]^{(1-\rho\sigma)/(\sigma-1)} \alpha L_{Xt}^{-\delta/\sigma}, \tag{5}$$

$$P_{Yt}\lambda_t = \left[\alpha^{(\sigma-1)/\sigma} L_{Xt}^{\delta} + (1-\alpha) L_{Yt}^{\delta(\sigma-1)/\sigma}\right]^{(1-\rho\sigma)/(\sigma-1)} (1-\alpha) L_{Yt}^{-\delta/\sigma}, \tag{6}$$

$$v = \beta P_{Xt} \delta L_{Xt}^{\delta-1} \lambda_{t+1}, \tag{7}$$

and

$$v = \beta P_{Yt} \delta L_{Yt}^{\delta-1} \lambda_{t+1}, \tag{8}$$

where M_t^s is the (exogenous and constant, because $\tau = 0$) money supply at the end of period t asset markets and λ is the current-value Lagrange multiplier on constraint (2). (It is easy to show that $\lambda = \gamma$, the multiplier on the cash-in-advance constraint, because of the first-order condition for the choice of M_t.) It is also easy to show that the nominal interest rate on a one-period nominal asset satisfies the usual pricing condition:

$$1 + i_t = \frac{\lambda_t}{\beta \lambda_{t+1}}. \tag{9}$$

2. EQUILIBRIUM WHEN SOME PRICES ARE STICKY

This section examines the implications of the basic model when prices in one sector are predetermined (for one period) at the expected market-clearing level. We assume for now that output is determined by the minimum of quantity demanded and quantity supplied. We return to this assumption later and modify it so that output is always demand determined.

[3] The other parameters in equation (1), β and v, have no important effects on our results.

We introduce short-term price stickiness into the model by assuming that sellers must choose $P_{X,t}$ one period in advance (that is, at the end of period $t-1$). We assume, however, that the nominal price of Y, P_Y, adjusts instantaneously to clear markets at each date. We examine the effects of a permanent, unanticipated change in the money supply starting from a nonstochastic steady-state equilibrium in which the money supply is constant and P_X is fixed at its expected equilibrium level. The money supply change occurs at the beginning of period t. Real variables dated at $t+1$ and later are unaffected by this change, but real variables at date t are affected because $P_{X,t}$ is predetermined.

First consider the excess-supply case. Suppose the money supply falls permanently by 1 percent at date t, with $P_{X,t}$ fixed for one period. When $P_{X,t}$ is above its equilibrium level, the quantity of X supplied exceeds the quantity demanded, so output of X will be *demand determined*. As a result, equation (7) (describing the supply of X) does not hold. That is, people would like to work more in the X industry and sell more of product X, but the price is predetermined at a level above the equilibrium, so the quantity demanded is insufficient to satisfy supply. Instead, sellers are rationed (equally in equilibrium). So we have equations (4)–(6) and (8) in the four variables $L_{X,t}, L_{Y,t}, P_{Y,t}$, and λ_t, (with λ_{t+1} taking its new steady-state value).

Because a change in the money supply has no steady-state effect on x, y, or L_X, equation (5) implies that the change in money has no effect on $P_{X,t+1}\lambda_{t+1}$ in the new equilibrium. But the fall in the money supply reduces $P_{X,t+1}$ by 1 percent, so it must raise λ_{t+1} by 1 percent.

Our first result is the following: a fall in the money supply reduces P_Y, and the percentage fall in P_Y is less than the percentage fall in the money supply if and only if the elasticity of substitution in consumption, σ, exceeds one. This means that if X and Y are good substitutes (relative to the Cobb-Douglas case of $\sigma = 1$), then exogenous price stickiness in the X sector causes *endogenous* price stickiness in the Y sector. The overall price level also adjusts sluggishly in this case.

Our second result is that a fall in the money supply causes a rise in the one-period nominal interest rate if and only if the degree of relative risk aversion, ρ, exceeds one, that is, if and only if the elasticity of intertemporal substitution $(1/\rho)$ is less than one.

Next, consider the excess-demand case. Suppose the money supply rises permanently by 1 percent at date t, with $P_{X,t}$ fixed for one period. When $P_{X,t}$ is below its equilibrium level, the quantity of X demanded exceeds the quantity supplied, so output of X is *supply determined*. As a result, equation (5) (describing the demand for X) does not hold. Instead, buyers are rationed (equally in equilibrium) and we have equations (4) and (6)–(8) in the (same) four variables $L_{X,t}, L_{Y,t}, P_{Y,t}$, and λ_t, (with λ_{t+1} taking its new steady-state equilibrium value).

Our first result for the excess-demand case is that the equilibrium response of P_Y to a rise in the money supply, is:

$$\frac{d \ln P_Y}{d \ln M} = 1 + \frac{s_X}{1 - s_X}, \tag{10}$$

where s_X is the share of good X in total spending. This means that a rise in the money supply raises the nominal price of Y by *more* than it would if the price of X were fully flexible and that this "overshooting" of P_Y is increasing in the share of the economy with sticky prices.

Our second result in the excess-demand case is that the overshooting of P_Y *necessarily* implies an inverse effect of money on interest rates. To see why, consider the pricing relationship for a one-period nominal bond:

$$\frac{1}{(1+i)} = \beta \, \frac{U_{y,t+1}}{U_{y,t}} \frac{P_{y,t}}{P_{y,t+1}}, \tag{11}$$

where $U_{y,t}$ denotes marginal utility of good y at date t. Two factors affect the nominal interest rate: the marginal rate of substitution between Y today and Y tomorrow and the rate of change of the nominal price of Y. In the excess-demand case, both factors tend to decrease the interest rate. First, note that households are rationed in purchasing X, so substitution into Y today raises the marginal rate of substitution, which reduces the interest rate. Second, $P_{y,t}$ overshoots the new equilibrium level, $P_{y,t+1}$, which results in (expected) deflation in the Y sector, which also tends to reduce the nominal interest rate.

As long as $\delta < 1$, which means that there are diminishing returns to labor, the changes in labor inputs in response to a positive money shock are

$$\frac{d \ln L_Y}{d \ln M} = \left(\frac{s_X}{1 - s_X}\right)\left(\frac{1}{1 - \delta}\right) \tag{12}$$

and

$$\frac{d \ln L_X}{d \ln M} = \left(\frac{-1}{1 - \delta}\right). \tag{13}$$

In this case a positive monetary disturbance moves labor from the sticky-price sector (X) to the sector with the rising relative price (Y). Because output is supply determined, it is interesting to note that the elasticity of substitution between the two goods does not affect the sectoral reallocation of labor between the X and Y industries.

Effects of a Fall in the Money Supply

The analytic results available for this model are limited, so we now turn to a numerical analysis of the model. Consider a permanent 1 percent fall in the money supply (from 10 to 9.9), starting from a steady-state equilibrium. Table 1 shows the results when $\alpha = 0.5,\ \sigma = 2,\ \delta = 0.64,\ v = 1,\ \beta = 0.96,$

Table 1 Baseline Model

Variable	Old SS	SR	New SS	Ratio
Labor in X	0.4869	0.4761	0.4869	−2.21
Labor in Y	0.4869	0.489	0.4869	0.43
Total labor	0.9738	0.9651	0.9738	−0.89
Output of X	0.6309	0.6219	0.6309	−1.42
Output of Y	0.6309	0.6326	0.6309	0.27
GNP	1.262	1.255	1.262	−0.58
Price of Y	7.925	7.858	7.846	0.15
CPI	7.925	7.891	7.846	0.58
Interest rate	4.167	4.771	4.167	0.60

and $\rho = 2$.[4] (We analyze permanent changes in the money stock to eliminate labor-supply responses that reflect temporary inflation tax considerations.)

The first column of Table 1 shows the variables: labor inputs in the X and Y industries, total labor, output in each industry (x and y) and total real GNP (evaluated at equilibrium prices and production shares), the nominal price of good Y (the nominal price of X in the old steady state and the short run equals the old steady-state price of good Y, and the new steady-state prices are also equal), the economy's consumer price index, and the nominal interest rate (in percent per period). The next column shows the old steady-state ("Old SS") levels of the variables, before the change in money. The "SR" column shows the short-run effects of the fall in money (while the nominal price of X is fixed at its previous level). The "New SS" column shows the new steady state. The column labeled "ratio" shows the percentage by which each variable in the short run exceeds its new steady-state level—except for the interest rate row in which the "ratio" shows the absolute *difference* between the interest rate in the short run and in the long run.

With the parameter values in Table 1, the sticky-price sector (X) represents one-half of output in the economy. Half of all labor is employed in the sticky-price sector. A permanent 1 percent fall in the money supply is neutral in the long run (with a 1 percent fall in nominal prices and no effects on real variables). But in the short run, with p_X predetermined, real GNP falls about 0.58 percent. This fall in total GNP masks major differences across sectors:

[4] The value of β in Table 1 is appropriate if prices in the X sector are sticky for about one year. If, instead, they are sticky for about one quarter, then a more appropriate level of β is 0.99. An unexpected change in the money supply of about 1 percent *per quarter* with prices sticky for one quarter has nearly the same effects as an unexpected change of about 1 percent *per year* when prices are sticky for a year.

output in the sticky-price sector falls 1.4 percent, while output in flexible-price industries rises 0.27 percent.[5] The fall in money reduces the nominal price of *Y*, which raises the relative price of *X*. This leads to a fall in the quantity of *X* demanded and creates excess supply in the *X* industry. Output of *X* is determined by the minimum of the quantity demanded and the quantity supplied, so output of *X* falls. But consumers substitute (partly) into purchases of *Y*, so output of *Y* rises. Notice that the nominal price of *Y* falls by almost exactly the amount it would fall if the price of *X* were flexible (it falls by almost 1 percent—to about one-seventh of 1 percent above its new steady-state level). Because the nominal price of *Y* responds almost proportionally to the change in the money supply while the nominal price of *X* is fixed and because each sector represents one-half of the economy's output, the CPI falls about halfway to its new long-run level.

As in standard Keynesian models, the fall in the money supply has a short-run "liquidity effect" on the nominal interest rate. In Table 1, the interest rate rises 60 basis points from 4.17 percent to 4.77 percent in the short run. This increase is slightly higher than the estimates reported by Christiano and Eichenbaum (1992), who estimate that a lower bound for the liquidity effect is that a 1 percent fall in the money supply raises the federal funds rate by about 27–53 basis points (within one to two quarters). Because expected inflation is negative (the CPI is expected to fall another 0.6 percent), this represents a rise in the real interest rate (measured in terms of the output bundle) of about 120 basis points. Notice that the liquidity effect occurs despite the introduction of money through a cash-in-advance constraint, which (when binding as in these examples) builds in a zero interest elasticity of the demand for money. Ohanian and Stockman (1994) examine the question of how much price stickiness is necessary to generate a liquidity effect of money on interest rates of realistic size and find that only a small sticky-price sector can be sufficient to produce interest rate effects of the magnitude found in the data.

Table 1 provides an initial answer to one of our central questions: Are nominal prices in flexible-price sectors "sluggish" in response to monetary and real disturbances—so that relative prices remain close to their equilibrium levels—or do nominal prices in flexible-price sectors change more than proportionally to monetary disturbances—so that the overall price level adjusts to equate the supply of and demand for money? The answer provided by Table 1 is a compromise between these two possible responses: P_Y is not endogenously sluggish, but neither does it change more than proportionally to the monetary disturbance. As a result, the overall price level exhibits a degree of sluggishness

[5] Because the capital stock and technology are fixed in this experiment, the marginal product of labor rises in the sticky-price sector (as employment in that sector falls) and rises in the flexible-price sector (as employment in that sector rises).

at the same time the monetary disturbance contributes to a change in relative prices.[6]

The Size of Intertemporal Substitution

Raising the degree of relative risk aversion from two to three (i.e., lowering the elasticity of intertemporal substitution from one-half to one-third) raises labor effort and output (and lowers nominal prices) in the steady state. However, Table 2 shows that the *responses* of the economy to a fall in the money supply are virtually unchanged, except for a larger liquidity effect on the interest rate. With $\rho = 3$, a 1 percent fall in the money supply raises the nominal interest 121 basis points in the short run, roughly double the response when $\rho = 2$. The other responses of the economy are virtually unaffected. A reduction in the elasticity of intertemporal substitution raises the size of the liquidity effect for a simple reason. A fall in the money supply raises the interest rate in the short run because households become cash constrained: with the smaller money supply, P_X fixed at its old level, and P_Y roughly at its new equilibrium level, households cannot afford to buy as many consumption goods as they did before the fall in money or as many as they will buy after all nominal prices adjust. Households attempt to smooth consumption intertemporally by borrowing. The equilibrium real interest rate is bid up as all households attempt to borrow. The higher real interest rate induces households to accept the temporary reduction in consumption. However, the smaller the elasticity of intertemporal substitution, the larger the increase in the real interest rate required to induce households to accept the temporarily low level of consumption. So increases in ρ raise the interest rate response to a monetary disturbance.

The Size of Intratemporal Substitution

We have assumed that outputs of the two sectors are substitutes in the sense that the elasticity of substitution σ exceeds one. Now suppose that $\sigma = 0.5$ rather than 2. Table 3 shows that reducing the elasticity of substitution from two to one-half has several effects on the economy's response to a monetary disturbance. First, output in the flexible-price sector now *falls* along with

[6] The effects of increases in productivity in this model differ from the effects in either standard Keynesian models or neoclassical models. Suppose productivity rises permanently by 1 percent in each sector: output is 1 percent higher for each level of labor input. In the long run, this reduces nominal prices and employment in each sector and raises output in each sector, with no permanent effect on the interest rate. (Labor input is constant in response to a productivity change if we assume log utility, in which case income and substitution effects are offsetting.) But with the nominal price P_X fixed in the short run, the relative price of X rises as the nominal price of Y falls. As a result, an economy-wide rise in productivity can *reduce* output in the sticky-price sector in the short run. It also raises output in the flexible-price sector more in the short run than in the long run and temporarily raises nominal and real interest rates.

Table 2 Baseline Model, $\rho = 3$

Variable	Old SS	SR	New SS	Ratio
Labor in X	0.718	0.7078	0.718	−1.42
Labor in Y	0.718	0.7199	0.718	0.27
Total labor	1.436	1.428	1.436	−0.58
Output of X	0.5959	0.5827	0.5959	−2.21
Output of Y	0.5959	0.5985	0.5959	0.43
GNP	1.192	1.181	1.192	−0.89
Price of Y	6.964	6.905	6.894	0.15
CPI	6.964	6.934	6.894	0.58
Interest rate	4.17	5.38	4.17	1.21

Table 3 Baseline Model, $\sigma = 0.5$

Variable	Old SS	SR	New SS	Ratio
Labor in X	0.4869	0.4814	0.4869	−1.13
Labor in Y	0.4869	0.4856	0.4869	−0.28
Total labor	0.9738	0.967	0.9738	−0.70
Output of X	0.6309	0.6263	0.6309	−0.73
Output of Y	0.6309	0.6298	0.6309	−0.18
GNP	1.262	1.256	1.262	−0.45
Price of Y	7.925	7.838	7.846	−0.10
CPI	7.925	7.881	7.846	0.46
Interest rate	4.167	4.64	4.167	0.47

output in the sticky-price sector. Second, output in the sticky-price sector falls much less when $\sigma = ½$ than when $\sigma = 2$. The reason for these differences is straightforward. When a fall in the money supply reduces the nominal price of Y but not the price of X, households substitute out of consumption of X into consumption of Y. When X and Y are good substitutes, there is a large increase in the demand for Y and a large decrease in the demand for X, which raises equilibrium output of Y and causes output of X to fall by a large amount. If, however, the goods are complements in the sense that an increase in consumption of one of the goods raises the marginal utility of the other good, then the fall in equilibrium consumption of Y reduces the marginal utility of consuming X. Instead of rising, the demand for X falls and equilibrium output of X also falls. The fall in demand for Y is smaller in this case, and equilibrium output of Y falls less than it would if X and Y were good substitutes. This also explains why, with $\sigma = ½$, the price of Y falls more (overshooting its new equilibrium level), whereas if $\sigma = 2$, P_Y falls only partway to its new equilibrium level.

The Degree of Curvature in Production

Table 4 presents the results of the same experiment as in Table 1, but with $\delta = 0.9$ rather than $\delta = 0.64$. This means that the economy experiences only a small degree of diminishing returns to labor. The assumption that $\delta = 0.64$ is more appropriate based on long-run studies of aggregate production functions, but some time-series estimates suggest a higher value of δ in the short run. While the steady state of the economy with $\delta = 0.9$ differs from that presented in Table 1, the *response* of the economy to a monetary disturbance is similar. Total employment falls less, because changes in employment do not so quickly result in diminishing returns. Employment in the sticky-price sector falls less for the same reason. Because output of the flexible-price good rises more in this case, the price P_Y falls less.

Table 4 Baseline Model, $\delta = 0.9$

Variable	Old SS	SR	New SS	Ratio
Labor in *X*	0.6429	0.6324	0.6429	−1.64
Labor in *Y*	0.6429	0.646	0.6429	0.48
Total labor	1.286	1.278	1.286	−0.58
Output of *X*	0.6719	0.662	0.6719	−1.47
Output of *Y*	0.6719	0.6748	0.6719	0.43
GNP	1.344	1.337	1.344	−0.53
Price of *Y*	7.441	7.37	7.367	0.05
CPI	7.441	7.406	7.367	0.53
Interest rate	4.167	4.715	4.167	0.55

The Size of the Sticky-Price Sector

Now consider changing the relative sizes of the two sectors of the economy. Table 5 takes the same parameter values as in Table 1 except $\alpha = 0.2$ rather than 0.5. This implies that the sticky-price sector is about 21 percent of aggregate GNP and accounts for 11 percent of employment. A permanent 1 percent fall in money reduces the nominal price of *Y* by almost 1 percent immediately and reduces employment in the sticky-price sector by 2.86 percent and output by 1.8 percent in the short run. Real GNP falls 0.1 percent and total employment falls 0.23 percent, as output in the flexible-price sector rises 0.07 percent. The liquidity effect (inverse effect of money on interest rates) in Table 5 is smaller than in Table 1, but reaches the lower end of the range estimated by Christiano and Eichenbaum (1992) if the elasticity of intertemporal substitution is reduced to one-third instead of one-half (that is, if $\rho = 3$ rather than 2), in which case the interest rate rises 31 basis points in the short run. The fall in α also raises the percentage response of labor in the sticky-price sector to a monetary

Table 5 Baseline Model, $\alpha = 0.2$

Variable	Old SS	SR	New SS	Ratio
Labor in X	0.1015	0.09862	0.1015	−2.86
Labor in Y	0.7797	0.7806	0.7797	0.11
Total labor	0.8813	0.8792	0.8813	−0.23
Output of X	0.2313	0.2271	0.2313	−1.84
Output of Y	0.8528	0.8534	0.8528	0.07
GNP	1.025	1.024	1.025	−0.10
Price of Y	10.380	10.280	10.270	0.04
CPI	9.754	9.665	9.656	0.10
Interest rate	4.167	4.324	4.167	0.16

disturbance, because it reduces the absolute size of that sector. Similarly, it reduces the percentage response of labor in the flexible-price sector because it raises the absolute size of that sector. With a smaller sticky-price sector, households are less cash constrained by a fall in the money supply, so the interest rate response is smaller. And the smaller the sticky-price sector, the smaller the effect of that sector on the nominal price P_Y. Ohanian and Stockman (1994) examine these issues in greater detail and show that a change in the money supply can have a substantial "liquidity effect" on nominal and real interest rates in the short run even if only a small fraction of the economy has sluggish prices.

Costly Time-to-Move Labor Across Industries

The results discussed above involve substantial short-run movements of labor across industries in response to monetary shocks. Because labor is often costly to reallocate across industries in the short run, we now modify the model so that rapid labor mobility is costly. We assume it takes one period to move labor across sectors unless the worker pays a utility cost of moving equal to

$$v_2\left(\frac{ly}{ly + lx} - \frac{lyss}{lyss + lxss}\right)^2 + v_2\left(\frac{lx}{ly + lx} - \frac{lxss}{lyss + lxss}\right)^2, \qquad (14)$$

where *lxss* and *lyss* are the original steady-state levels of employment in the X and Y industries and v_2 is a nonnegative parameter. We assume $v_2 = 10$ and the same parameters as in Tables 1 and 3. Tables 6 and 7 present the results of this experiment.

First, compare Table 6 to Table 1: the costly time-to-move assumption results in a much smaller increase in employment and output in the flexible-price sector; output in that sector is roughly constant (rising only 0.02 percent). Total labor supply falls more than in Table 1, as does GNP. Nominal prices in the flexible-price sector fall less than in Table 1: P_Y remains 0.32 percent above its new equilibrium level in the short run. If the *equilibrium* price response in the flexible-price sector is small, as in this case, studies such as Blinder (1991) that search for "menu costs" or similar reasons for "price-stickiness" in these markets would fail to uncover them because that price sluggishness would reflect an equilibrium response to the fact that *other* nominal prices are sticky. In fact, it is interesting that Blinder's survey found little or no evidence of "menu costs" in changing prices. Instead, firms reported that the reason they change nominal prices infrequently is that they are concerned about their product price relative to those of their "competitors." If we interpret "competitors" to include goods in the sticky-price sector, this observation may be consistent with the results in Table 6.[7]

Next, compare Table 7 to Table 3: the costly time-to-move assumption results in a much smaller fall in employment and output in the flexible-price sector; output in that sector is roughly constant (falling only 0.02 percent rather than 0.18 percent). Total labor supply falls less than in Table 3, as does GNP. Nominal prices in the flexible-price sector fall more than in Table 3: P_Y falls 1.3 percent and overshoots its new equilibrium level by 0.3 percent. The time-to-move assumption in this case reduces the response of interest rates by about 10 basis points. As before, the size of the liquidity effect is governed by the size of intertemporal substitution: if it is one-third rather than one-half, the nominal interest rate rises twice as much as in Tables 6 and 7.

Sticky Wages with Flexible Prices

We have assumed up to now that nominal stickiness in the X sector occurs mainly in product markets. We now modify the model so that nominal rigidities in the X sector have their origin in labor markets. We assume nominal wages in the X sector are predetermined for one period, while nominal product prices in both sectors (and nominal wages in the Y sector) are flexible. Table 8 presents the results of the same experiment as in Table 1 (with the same parameter values), but with sticky wages rather than sticky prices. We assume the nominal wage rate in the X sector is set one period in advance equal to the expected nominal marginal product of labor, which equals the steady-state marginal product multiplied by the *original* steady-state nominal price, P_X. In this sticky-wage economy, employment in the X industry is demand determined in the case of negative money shocks and supply determined in the case of positive money shocks.

[7] It is interesting that most of the reasons given by firms for sluggish nominal prices in Blinder's study deal with *relative* prices. For example, some firms said that price is only one component of an overall package that matters to buyers; others spoke of implicit contracts and so on. These reasons by themselves are not sufficient to explain sticky *nominal* prices. But if some nominal price is exogenously fixed, then these reasons could help explain the "spread" of stickiness to other nominal prices.

Table 6 Baseline Model, $v_2 = 10$

Variable	Old SS	SR	New SS	Ratio
Labor in *X*	0.4869	0.4768	0.4869	−2.08
Labor in *Y*	0.4869	0.4871	0.4869	0.03
Total labor	0.9738	0.9638	0.9738	−1.03
Output of *X*	0.6309	0.6225	0.6309	−1.34
Output of *Y*	0.6309	0.631	0.6309	0.02
GNP	1.262	1.253	1.262	−0.66
Price of *Y*	7.925	7.871	7.846	0.32
CPI	7.925	7.898	7.846	0.67
Interest rate	4.167	4.859	4.167	0.69

Table 7 Baseline Model, $\sigma = 0.5$, $v_2 = 10$

Variable	Old SS	SR	New SS	Ratio
Labor in *X*	0.4869	0.4818	0.4869	−1.05
Labor in *Y*	0.4869	0.4868	0.4869	−0.03
Total labor	0.9738	0.9686	0.9738	−0.54
Output of *X*	0.6309	0.6267	0.6309	−0.67
Output of *Y*	0.6309	0.6308	0.6309	−0.02
GNP	1.262	1.257	1.262	−0.35
Price of *Y*	7.925	7.822	7.846	−0.31
CPI	7.925	7.873	7.846	0.35
Interest rate	4.167	4.531	4.167	0.36

The results in Table 8 differ slightly from those in Table 1, but the main differences are quantitative rather than qualitative. Wage and price stickiness have similar results because the main effect of wage stickiness is to keep the marginal cost of production constant in nominal terms in the short run. This reduces the effect of money on equilibrium nominal product prices in the *X* sector. As a result, the economy resembles a sticky-product-price economy but with *some* nominal price movement, and equilibrium responses to money are smaller than in the sticky-product-price economy. Wage stickiness results in less aggregate labor movement—and less sectoral reallocation than does price stickiness. Total labor falls 0.50 percent in the sticky-wage economy, while it fell by 0.89 percent in the sticky-price economy. Employment in each sector changes by only about half as much in the sticky-wage case as in the sticky-price case. The sticky wages endogenously generate sluggish nominal prices: P_Y, the price of output in the sticky-wage sector, falls immediately by an amount equal to 44 percent of its long-run fall. In this sense, wage stickiness induces

Table 8 Baseline Model with Sticky Wages

Variable	Old SS	SR	New SS	Ratio
Labor in *X*	0.4869	0.4809	0.4869	−1.23
Labor in *Y*	0.4869	0.4881	0.4869	0.24
Total labor	0.9738	0.969	0.9738	−0.50
Output of *X*	0.6309	0.6259	0.6309	−0.79
Output of *Y*	0.6309	0.6319	0.6309	0.15
GNP	1.262	1.258	1.262	−0.32
Price of *X*	7.925	7.89	7.846	0.56
Price of *Y*	7.925	7.852	7.846	0.09
CPI	7.925	7.871	7.846	0.32
Interest rate	4.167	4.502	4.167	0.3352

partial price stickiness. This induced price stickiness is even more pronounced if goods *X* and *Y* are less substitutable; Table 9 shows the results of a 1 percent fall in money in the sticky-wage model when $\sigma = 0.5$ (as in Table 4). In this case the short-run fall in P_X is only 28 percent of its long-run fall.

As $\delta \rightarrow 1$, the sticky-price and sticky-wage economies become equivalent. This occurs because a linear production function (with marginal-cost pricing of factors) implies that competitive payments to labor exhaust production. The relative similarity between the sticky-price and sticky-wage economies is consistent with Lucas' (1989) conjecture that the effect of money shocks on sticky-price and sticky-wage economies should be similar.

Table 9 Baseline Model with Sticky Wages, $\sigma = 0.5$

Variable	Old SS	SR	New SS	Ratio
Labor in *X*	0.4869	0.483	0.4869	−0.81
Labor in *Y*	0.4869	0.486	0.4869	−0.20
Total labor	0.9738	0.9689	0.9738	−0.50
Output of *X*	0.6309	0.6277	0.6309	−0.52
Output of *Y*	0.6309	0.6301	0.6309	−0.13
GNP	1.262	1.258	1.262	−0.32
Price of *X*	7.925	7.902	7.846	0.72
Price of *Y*	7.925	7.84	7.846	−0.07
CPI	7.925	7.871	7.846	0.32
Interest rate	4.167	4.503	4.167	0.34

Increases in the Money Supply

Increases in the money supply have qualitatively different effects on the economy because it generates *excess demand* in the sticky-price sector (because increases in nominal prices in the flexible-price sector reduce the relative price of sticky-price goods). As a result, output in the sticky-price sector is determined by the *quantity supplied* rather than the quantity demanded. Table 10 shows the effects of a permanent 1 percent rise in the money supply (from 10 to 10.1), starting from a flexible-price steady state and with the same parameter values as in Table 1.

Table 10 Baseline Model with Money Rising One Percent

Variable	Old SS	SR	New SS	Ratio
Labor in *X*	0.4869	0.4736	0.4869	−2.73
Labor in *Y*	0.4869	0.5002	0.4869	2.73
Total labor	0.9738	0.9738	0.9738	0.00
Output of *X*	0.6309	0.6199	0.6309	−1.75
Output of *Y*	0.6309	0.6419	0.6309	1.74
GNP	1.262	1.262	1.262	0.01
Price of *Y*	7.925	8.082	8.004	0.97
CPI	7.925	8.004	8.004	−0.01
Interest rate	4.167	2.304	4.167	−1.86

Table 10 shows that a 1 percent rise in the money supply causes the nominal price of *Y* to overshoot its new steady-state value. The price of *Y* rises nearly 2 percent in the short run in response to the 1 percent increase in money. This overshooting of the price of *Y* leads the overall price level to respond rapidly to the increase in the money supply: nearly all of the long-run response of the CPI to the increase in money occurs immediately. The model therefore implies that the overall price level responds much more rapidly to a rise in the money supply than a fall (even though the price of *X* is assumed to be sticky upwards as well as downwards). It is interesting to note that this result is consistent with empirical work presented by Fischer (1981) that inflation is positively associated with periods of high relative-price variability. Also, Cody and Mills (1991) (among others) find that spot commodity prices are important predictors of future inflation in U.S. data. This is consistent with the two-sector model economy in that the immediate sharp increase in the price of flexible goods is a "leading indicator" of future changes in prices of sticky goods. Finally, this asymmetric response of prices is consistent with the widely held view that prices are more sticky in a downward direction than in an upward direction. Our model, however, generates this result even though individual prices are either flexible or sticky in *both* directions. This shows how an observer who looks only at the overall price level rather than individual prices could mistakenly conclude that some underlying friction allows prices to rise but not to fall.

While an increase in money raises output and employment in the flexible-price sector, it reduces output and employment in the sticky-price sector.

Aggregate GNP rises only slightly and total labor supply is fixed: the increase in money induces sectoral reallocation of employment and output. The increase in money also causes a large fall in the interest rate: the interest rate falls 186 basis points in response to the 1 percent rise in money. This result suggests that there may be an asymmetry in the size of the liquidity effect of money on interest rates depending on whether the money supply rises or falls. There is also an asymmetry with respect to the effects of intertemporal substitution on the size of the liquidity effect: when the money supply rises, the elasticity of intertemporal substitution has very small effects on the size of the liquidity effect.

Table 11 shows the effects of adding time-to-move labor to Table 10, with $v_2 = 10$. In this case a 1 percent increase in money has little effect on output or employment in either sector, though it again causes considerable overshooting of P_Y and a large (though smaller) liquidity effect: the nominal interest rate falls 105 basis points in response to a 1 percent rise in money. Notice that this interest rate response is smaller than without the time-to-move assumption; in contrast, we found above that adding the time-to-move assumption reduced the inverse effect of money on interest rates in response to negative monetary disturbances.

Table 11 Baseline Model with Money Rising One Percent, $v_2 = 10$

Variable	Old SS	SR	New SS	Ratio
Labor in X	0.4869	0.4864	0.4869	−0.10
Labor in Y	0.4869	0.4874	0.4869	0.10
Total labor	0.9738	0.9738	0.9738	−0.00
Output of X	0.6309	0.6305	0.6309	−0.06
Output of Y	0.6309	0.6313	0.6309	0.06
GNP	1.262	1.262	1.262	0.00
Price of Y	7.925	8.083	8.004	0.99
CPI	7.925	8.004	8.004	−0.00
Interest rate	4.167	3.114	4.167	−1.05

Increases in the Money Supply with Monopolistic Competition

A number of recent papers have studied economies with sticky prices and firms that have market power (Blanchard and Kiyotaki 1987; Mankiw 1985; Svensson 1986). In these papers, an increase in the money supply does not necessarily lead to rationing of consumers (as in our version of the Barro-Grossman model with excess demand). Instead, firms willingly supply output equal to the quantity demanded, provided that the fixed product price exceeds the marginal cost of production. (If marginal cost does exceed price, consumers are rationed and output is supply determined.) While the implications of a negative money shock are similar in both setups (in either case, firms would like to sell more than is demanded at the fixed price), the effect of an unexpected increase in the money supply differs across these two sticky-price models.

This section discusses the effects of an increase in money in our model economy modified so that output in the *X* industry is always determined by quantity demanded. This amounts to assuming that the *X* sector is monopolistically competitive, with price exceeding marginal cost. Rather than solving for the explicit equilibrium of a monopolistic-competition model, we can consider an experiment in which steady-state P_X is set above its market-clearing level. In this case, a small positive money shock leads to an expansion in output in the *X* industry. The results of this experiment are nearly identical, with a change in sign, to the results reported earlier for reductions in the money supply (creating a case of excess supply).

Increases in money have strikingly different effects on the economy depending on whether output in the sticky-price sector is demand determined (as it is here) or supply determined (as in the experiments reported earlier). In both cases, there is a sectoral reallocation of labor. In the supply-determined case discussed earlier, a positive money shock causes labor to move from the sticky-price sector (*X*) to the flexible-price sector (*Y*), which has a rising nominal (and relative) price. With monopolistic competition (where output is demand determined even in the case of a positive money shock), labor moves in the opposite direction: labor flows from the flexible-price sector to the sticky-price sector. In addition, fluctuations in output and interest rates due to monetary shocks in the monopolistic competition case are symmetric (in contrast to the asymmetric results reported above) because demand determines production regardless of the sign of the disturbance.

Without taking a stand on the market structure in sticky-price industries in the U.S. economy, these models suggest some interesting tests. Do monetary disturbances affect industries identically? Do they have asymmetric effects on the economy, depending on whether the disturbances are positive or negative? What are the characteristics of the sectoral flow of labor over the business cycle? Kretzmer (1989) provides evidence related to the first question: he finds that monetary shocks affect different industries differently. Using unanticipated-money regressions for individual industries, his evidence suggests that output and employment initially *decline* in response to a positive money shock in almost 40 percent of the industries.[8] This finding could be consistent with either of the market structures discussed above; to distinguish between the two structures, we would need to know whether the industries that contract in response to a positive money shock are sticky-price or flexible-price industries. Cover (1992) and Thoma (1992) present aggregate evidence on the second question:

[8] See Kretzmer's Table 2 (p. 288). He reports that 13 of 30 impact coefficients in his hours equations and 11 of 30 impact coefficients in his output equations are negative.

they find that positive and negative money shocks affect the economy differently. In particular, it appears that negative money shocks precede economic declines, but positive money shocks do not suggest significant increases in future output. This is consistent with our two-sector model with output determined by the short side of supply and demand, but not with the two-sector monopolistic-competition model. (Ball and Mankiw [1992] modify a one-good monopolistic-competition model so that positive trend inflation combined with menu costs triggers price adjustments that depend on the sign of the monetary shock.)

Comparison of Results to a One-Sector Model

It is interesting to contrast the implications of this two-sector model to those of a one-sector model. Recall that a one-sector model is a *special case* of our model, with the parameter $\alpha = 1$. The utility function becomes

$$U = \frac{c^{1-\rho} - 1}{1 - \rho} - vL, \tag{15}$$

where L is labor supply. Perhaps the most interesting comparisons are the effects of money on interest rates. If money falls unexpectedly and permanently, output is demand determined and (assuming the cash-in-advance constraint binds) output and consumption fall proportionally with the decrease in money. The interest rate is

$$\left[\frac{P_t}{P_{t+1}}\right]^{\rho-1} \frac{1}{\beta} = 1 + i. \tag{16}$$

With $\rho = 2$, the interest rate rises one for one with the fall in money. That is, a 1 percent fall in the money supply raises the nominal interest rate 1 percent, which is more than in the two-sector model. In the excess-demand case (resulting from an unexpected permanent increase in money), the differences are even more striking. In the one-sector model, labor supply falls in percentage terms by $\frac{1}{1-\delta} d \ln m$, which implies that output also falls proportionally to the change in money in the excess-demand case. Because money has increased, the cash-in-advance constraint clearly does not bind. As a result, the interest rate falls to zero for *any* increase in money.

3. CONCLUSIONS

There is considerable evidence that the nominal prices of some goods change very infrequently, while nominal prices of other goods change on a daily basis. This article presents a simple two-sector monetary economy with production in which the degree of price flexibility differs by sector. In the excess-demand/excess-supply setup, the model predicts that unanticipated monetary shocks cause (1) asymmetric changes in output and employment that depend on whether money has increased or decreased, (2) changes in relative prices over the cycle, (3) sectoral reallocation of labor, and (4) a significant liquidity effect of money on interest rates. In a related paper (Ohanian and Stockman 1994) we show that only a small amount of price stickiness is needed in this economy to generate a liquidity effect of reasonable size. The asymmetric effects of money in the model are consistent with recent empirical studies (Cover 1992; Thoma 1992), and the model is also consistent with the finding reported by Fischer (1981) that periods of significant inflation are associated with high relative-price variability. The model also reproduces the empirical finding documented by Cody and Mills (1991) that changes in the prices of flexible-price goods (spot commodities) predict future aggregate price changes and the empirical finding by Kretzmer (1989) that output and employment in a significant fraction of U.S. industries decline initially in response to a positive money shock. In the case that X and Y are good substitutes, the model also has the interesting implication that the price level is "sticky" downwards as an equilibrium phenomenon.

In our continuing work, we hope to show that even very short-term price stickiness can set into motion forces that lead to longer-lasting effects on real interest rates, output and employment, and nominal price changes. To study this, we are currently studying the effects of adding capital to the basic model described here. Our extension of this model to a two-country world in Stockman and Ohanian (1993) examines the effects of monetary disturbances on domestic and world interest rates, exchange rates, and domestic and foreign output, and shows that the effects of monetary disturbances are highly non-linear in open economies. In future work we intend to use the model to study the effects of alternative exchange rate systems, devaluations, and optimal currency areas.

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