Is There a Persistence Problem? Part 1: Maybe

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It would seem that staggered price adjustment must delay the economy's approach to market-clearing equilibrium following a monetary shock. But a key ingredient in this story is the assumption that each firm wants to keep its price close to the average price.

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The average post–World War II recession has lasted eleven months. This fact suggests that if monetary policy has contributed significantly to the business cycle, policy changes must have a prolonged impact on real economic activity. Although results from vector autoregression studies typically indicate monetary policy shocks have not, in fact, been a major source of postwar business-cycle fluctuations, these same studies suggest that money is *capable* of large and persistent output effects.[1]

Among economists who regard monetary policy as potentially important for real activity, there is little agreement about the underlying cause of monetary nonneutrality. However, one popular explanation for nonneutrality is sluggish price adjustment.[2] There are two major strands in this literature. The menu-cost strand assumes that firms must pay a small fixed cost whenever they change their prices. The individual firm must decide whether the gains from changing its price more than offset the cost. A key result is that even small menu costs can lead to large departures from market-clearing equilibrium in response to monetary policy shocks (Akerlof and Yellen 1985a, b; Mankiw 1985). In the second strand of the literature, firms are able to change their prices costlessly at predetermined intervals. This approach is sometimes motivated by the fact that many real-world prices are preset in contracts. An important result is that even if the interval between each individual firm's price adjustments is quite short, the average price level may react slowly to policy shocks if price adjustments are not synchronized across firms.[3] Sluggish adjustment of the average price level is sufficient to generate persistent movements in aggregate output.

How might frequent but staggered adjustment of individual prices lead to slow movement in the average price level? For concreteness, consider an economy with thirty identical firms, each of which changes its price once a month. Now suppose that the money supply doubles. The increase is a complete surprise and is expected to be a one-time event. Under these circumstances, in the absence of nominal rigidities, all prices would immediately double. There would be no other economic effects. More generally, if the thirty firms change prices synchronously, it would take fifteen days, on average (and never more than thirty days), for the price level to double and market-clearing equilibrium to be restored.[4] Suppose, instead, price adjustment is staggered, so that every day one of the thirty firms has the opportunity to change its price. Suppose further that each firm—perhaps out of fear of losing customers to competitors—doesn't want to stray far from the prevailing average price level. Suppose, in particular, that when it has a chance to adjust its price, each firm moves to a point somewhere between the prevailing average price and the long-run, market-clearing price. Because, on day 1, firm 1 sets a price below the long-run price, the new average price on day 1 will also be below long-run equilibrium. With each passing day, the firm free to reset its price will charge a little more than the previous firm but less than it would in market-clearing equilibrium. Hence, the average price remains below its long-run equilibrium level. In particular, after thirty days every firm's price will be higher but less than twice the original price. Price adjustment will still be incomplete.

It would seem that staggered price adjustment must delay the economy's approach to market-clearing equilibrium following a monetary shock. But a key ingredient in the above story is the assumption that each firm wants to keep its price close to the average price. Chari, Kehoe, and McGrattan (1996)—hereafter CKM—question this assumption. They argue it is very difficult to find plausible specifications of household tastes for which the assumption holds. Consequently, it is extremely difficult to obtain long-lasting output effects from policy shocks in a world with staggered price setting. CKM dub this difficulty "the persistence problem."

This article illustrates and explains CKM's results using a simple model economy.[5] The explanation that emerges from the analysis is as follows: In economies with sluggish price adjustment, a positive monetary shock drives up the demand for output, hence the demand for labor. Meantime, households, feeling wealthier, reduce the supply of labor. To clear the market, the wage rate must rise. At a higher wage, the price firms want to charge for their products increases. For realistic household tastes, the wage increase is so great that firms with the opportunity to respond raise their prices *more* than proportionately to the original money shock—not less than proportionately, as required to generate persistence.

Promising potential solutions to the persistence problem rely on labor-market frictions to short-circuit the wage increase that would otherwise accompany a monetary expansion. Some of these solutions will be examined in a subsequent issue of *Economic and Financial Review*.

A MODEL ECONOMY

Household Decision Making

Households are assumed to be identical, so we need only look at the decisions of a representative household. Suppose this household has a utility function of the form

$$U(C, L) = (C^{1-\sigma} - 1)/(1 - \sigma) - L^{1+1/\xi}/(1 + 1/\xi) \tag{1}$$

each period, where C and L are the levels (not logged) of output consumed and labor supplied and where σ and ξ are both positive constants.[6] Assuming a competitive labor market, household utility maximization requires that the marginal rate of substitution between leisure and consumption equal the real wage: $-U_L/U_C = W/P$, where W and P denote the money wage and average price of output, respectively. For the utility function given above, this condition yields a log-linear labor-supply relationship:[7]

$$l = \xi(w - p) - \sigma\xi c. \tag{2}$$

The supply of labor is increasing in the real wage (with elasticity ξ) and decreasing in household consumption (with elasticity $\sigma\xi$), reflecting households' reduced willingness to work as their wealth rises. Realistic values for σ and ξ are 0.5 and 0.25, respectively.[8]

Finally, we assume that households' desired money balances are determined by their consumption expenditures:

$$m - p = c. \tag{3}$$

Firm Decision Making

The output market is monopolistically competitive. Firms are identical except for the timing of their pricing decisions. CKM assume each firm's price can be changed only at certain times. These times are staggered across firms. Holding the price of a product fixed over an interval might make sense if price changes are costly per se. The costs associated with printing and/or publicizing price lists are germane. These are the sorts of costs emphasized in the menu-cost literature. We assume, instead, that each firm chooses a price *path*. It is this path that is adjusted only at discrete times, staggered across firms. For example, each firm's executives might meet quarterly to reevaluate their pricing plans. Predictable changes in demand for the firm's product or in production costs might lead the executives to decide, at a particular meeting, to schedule a series of, say, price increases stretching over coming months. Presetting a price path this way makes sense if menu costs are small relative to the costs of gathering and processing information about current and future demand and cost conditions.

Allowing executives the flexibility of choosing a price path rather than a fixed price greatly simplifies their decision making. Further simplification is achieved by assuming there are no durable goods (and, in particular, no capital investment) and that the monetary policy shock is a one-time, completely unexpected event. These conditions do not alter the essential character of the persistence problem.[9]

I begin by considering the decision making of a particular firm—firm f, say. Under the above assumptions, as soon as it has a chance to respond to the policy shock, firm f selects the price it will charge for its product in each future period. The price in any particular period only affects the firm's profit in that period. Hence, to maximize its profits, the firm chooses a price path that will equate marginal cost to marginal revenue, period by period.

Marginal cost depends on factor prices, the production technology, and (in general) how much output is produced. I adopt the simplest possible production technology:

$$y_f = l_f, \tag{4}$$

where y_f is the amount of output that firm f produces using l_f units of labor. It follows that the firm's marginal cost schedule is horizontal and that its height equals the prevailing wage rate, w.

Marginal revenue depends on the demand schedule the firm faces and on the firm's production level. I assume a constant elasticity of substitution between the products of different firms, so that the demand for firm f's output is given by

$$y_f = y - (p_f - p)/(1 - \Theta), \tag{5}$$

where y and p are the average aggregate output level and price level, respectively; p_f is the price charged by firm f; and $0 < \Theta < 1$. Equation 5 says the higher firm f's price is relative to the economywide-average price, the lower the firm's sales will be relative to economywide-average sales.[10] Perfect competition is obtained in the limit as $\Theta \rightarrow 1$. I assume the firm is small enough that it takes y and p as given. In this case, the firm's marginal revenue is easily shown to be $p_f + \theta$.[11]

Recall that, given the opportunity, firms equate marginal cost and marginal revenue period by period. In the present case, this means setting price as a markup over the wage rate:

$$p_f = \mathrm{w} - \theta. \tag{6}$$

It follows that what occurs in the labor market is critical for determining whether output prices adjust slowly toward long-run equilibrium or tend to overshoot.

Closing the Model

With each firm's production tightly linked to its hiring, a similarly tight link exists between average aggregate output and average aggregate labor hours:

$$y = l. \tag{7}$$

Also, absent a government sector and capital investment, all output must be consumed:

$$y = c. \tag{8}$$

There is some ambiguity about how the quantity of output is determined outside of market-clearing equilibrium. I assume that firms adjust their production to match their sales. This behavior is sensible as long as each firm's output price exceeds the marginal cost of production (w).

Once each firm has responded to the policy shock, Equations 4, 5, and 6 will apply to all. Hence, all firms will charge the same price, hire the same amount of labor, and produce the same amount of output in long-run, market-clearing equilibrium. With this result in mind, a little algebraic manipulation of Equations 2, 3, 4, 6, 7, and 8 establishes that

$$y^* = c^* = l^* = \theta\xi/(1 + \sigma\xi), \tag{9}$$

$$w^* = m + \theta - \theta\xi/(1 + \sigma\xi), \tag{10}$$

and

$$p^* = m - \theta\xi/(1 + \sigma\xi), \tag{11}$$

where an asterisk indicates a variable is evaluated in long-run, market-clearing equilibrium. Note that long-run equilibrium output, consumption, and labor are all independent of the money supply, as are the long-run levels of the real wage and real money balances. The long-run, market-clearing *nominal* wage and *nominal* price of output are proportional to the money supply.

SHORT-RUN PRICE ADJUSTMENT

Individual Firms

When they first have a chance to respond to a monetary policy shock, do firms move only part way toward the long-run, market-clearing price level—as required for persistence? Or do they, instead, overshoot long-run equilibrium? We have already established that firms seek to maintain a constant markup over the wage rate (*Equation 6*). So whether individual firms' prices adjust gradually or overshoot is determined by how strongly the wage rate responds to an unexpected change in the money supply. If the wage rate responds less than proportionately, so will the price charged by any firm free to adjust its price. If the wage rate responds more than proportionately, the prices individual firms charge will overshoot long-run equilibrium.

To determine how the wage responds to monetary shocks, we need only substitute from Equations 3, 4, and 8 into the labor-supply relationship (*Equation 2*):

$$w = p + (1/\xi + \sigma)(m - p). \tag{12}$$

Equation 12 says that the real wage rate varies in the same direction as the real money supply. In fact, for reasonable parameter values, the real wage can be expected to increase about 4.5 percent for each 1 percent increase in real money balances. (Recall that $\sigma \approx 0.5$ and $\xi \approx 0.25$.) Since, with staggered price setting, the economywide-average price level is essentially fixed immediately following a money-supply shock, Equation 12 also says that a sudden 1 percent increase in the *nominal* money supply will trigger an immediate 4.5 percent increase in the *nominal* wage. Thus, the nominal wage overshoots its long-run equilibrium level.

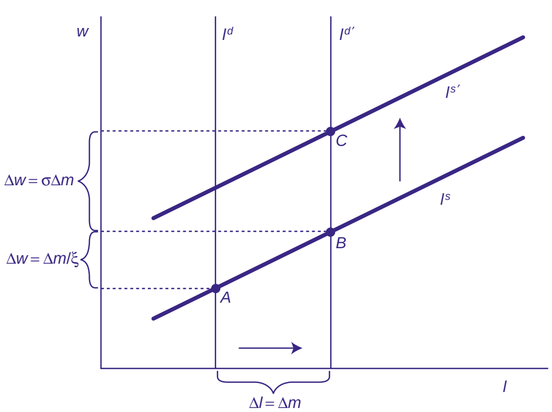
Figure 1 illustrates the labor market's initial response to a monetary shock. In the figure, the labor-supply schedule has slope $1/\xi$ (*Equation 2*). The labor-demand schedule is drawn as a vertical line because in the short run firms are assumed to adjust production to match their sales and aggregate sales are determined solely by the money supply (*Equation 3*). The pre-shock equilibrium is point A. When the money supply suddenly increases, the labor-demand schedule shifts to the right by the same amount. If this were the end of the story, the economy would move to point B, where the (log) wage is $\Delta m/\xi$ higher than before. But the increase in their real money balances makes households feel wealthier, so the labor-supply schedule shifts up by $\sigma\Delta m$. The net result is that the economy ends up at point C. Employment rises by the same amount as the money supply: $\Delta l = \Delta m$. The wage rises by substantially more than the money supply: $\Delta w = (1/\xi + \sigma)\Delta m$.

Since the wage rate rises by more than the money supply, there is a tendency for individual firms' prices to overshoot the long-run equilibrium price level, p^*. To see this overshooting, use Equation 12 to eliminate the wage rate from Equation 6 and use Equation 11 to eliminate the money supply. These substitutions yield

$$\begin{aligned} p_f &= p + (1/\xi + \sigma)(p^* - p) \\ &= p^* + (1/\xi + \sigma - 1)(p^* - p). \end{aligned} \tag{13}$$

Hence, an increase in the market-clearing price (p^*) relative to the prevailing average aggregate price level (p) leads to overshooting by firms that are free to change their prices if, and only if, $1/\xi + \sigma > 1$. Empirical estimates of ξ and σ suggest this overshooting condition is likely to be satisfied.

Figure 1
Short-Run Effects of an Increase in the Money Stock



Micro-overshooting and Aggregate Persistence

Figures 2 and 3 show how the price charged by firms that have had a chance to reevaluate their pricing (p_f) and the overall average price level (p) vary over time in response to an unexpected doubling of the money supply, under alternative assumptions about the value of the "overshooting parameter," $\omega \equiv 1/\xi + \sigma$. The policy shock is assumed to hit at time $t = 0$, when all firms are charging the price $p(0)$. The length of the unit time interval is chosen so that at $t = 1$, every firm has had a chance to reset its price path. Thus, t is not only an index of time but also measures the fraction of firms that have had a chance to respond to the monetary policy change. Suppose, for example, that firms reset their price paths every three months, so that the unit time interval is ninety-one days. After one month ($t = 1/3$), one-third of all firms will be charging $p_f(1/3)$ and two-thirds of firms will still be charging $p(0)$; after two months ($t = 2/3$), two-thirds of all firms will be charging $p_f(2/3)$, and only one-third will still be charging $p(0)$; and so on. (For further details, see the box entitled "The Analytics of Short-Run Price Adjustment.")

When $\omega = 1$, Figure 2 says that firms with

Figure 2
An Individual Firm's Price Response to a Money-Supply Increase

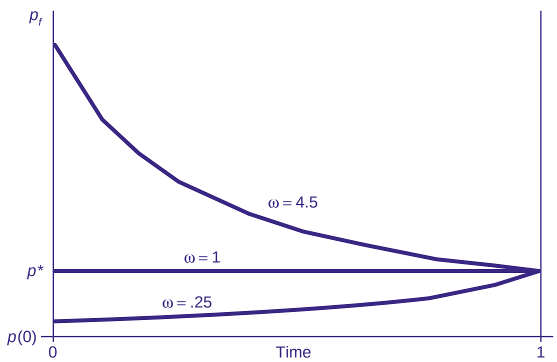
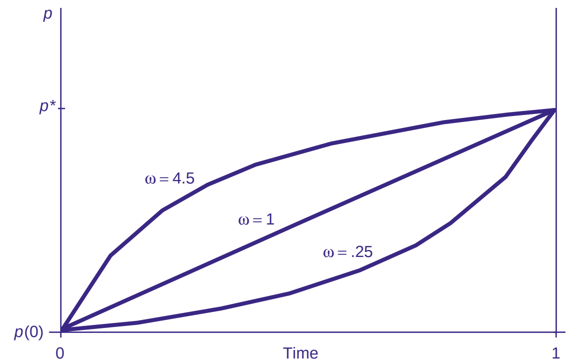


Figure 3
Response of the Aggregate Price Level to a Money-Supply Increase



a chance to adjust their price paths immediately increase their prices from $p(0)$ all the way to p^* and hold them there. As a result, the average price level rises steadily from $p(0)$ to p^* as more and more firms respond to the policy change (*Figure 3*). Price adjustment is neither front-loaded nor back-loaded. It is half complete at $t = ½$.

When $\omega < 1$, firms with a chance to adjust their price paths don't find it desirable to deviate much from the prices other firms charge. Consequently, they set a price path that starts off low—close to $p(0)$—and increases gradually as more and more firms are free to respond to the money-supply shock. The path of the average price level is similar: most of the adjustment occurs near the end of the period. When $\omega = 0.25$, for example, price adjustment isn't half complete until $t = 0.8$.

Finally, when $\omega > 1$, the real wage initially rises so sharply in response to the money-supply shock that firms with an opportunity to raise their prices do so with a vengeance: $p_f(0)$ is well above p^*. As the average price level increases, cutting into the demand for output, marginal production costs fall. So does $p_f(t)$. Adjustment of the average price level is front-loaded in this case. When $\omega = 4.5$, for example, price adjustment is half complete at $t = 0.18$.

Staggered Price Setting: Part of the Solution or Part of the Problem?

Is aggregate price adjustment slower in an economy where the pricing decisions of individual firms are staggered than in an otherwise identical economy in which these decisions are synchronized? For concreteness, suppose firms reevaluate their price paths quarterly (that is, once every ninety-one days). A positive money-supply shock suddenly hits, increasing the market-clearing price level from $p(0)$ to p^*. With synchronized decision making, aggregate price adjustment is an all-or-nothing proposition: either all firms charge $p(0)$ or all firms charge p^*. If the policy shock's timing is random relative to that of price adjustment, the probability that all firms will move to p^* the same day as the shock is 1/91. The probability that all firms will move to p^* the first day *after* the shock is also 1/91, so the probability that firms will move to p^* within two days of the shock is 2/91. More generally, the probability that all firms will be charging p^* within N days of the policy shock is $N/91$, for $N = 1, 2, \ldots, 91$. Hence, the expected aggregate price level, as a function of time, is

$$E[p(t)] = p(0) + t[p^* - p(0)], \qquad (14)$$

where $t = N/91$ is the fraction of the quarter that has passed since the money supply increased. Equation 14 says that the expected price level is $p(0)$ at the instant the policy shock hits and rises linearly to p^* one quarter later.

Figure 4
Staggering May Speed or Slow the Price Level's Response to a Money-Supply Increase

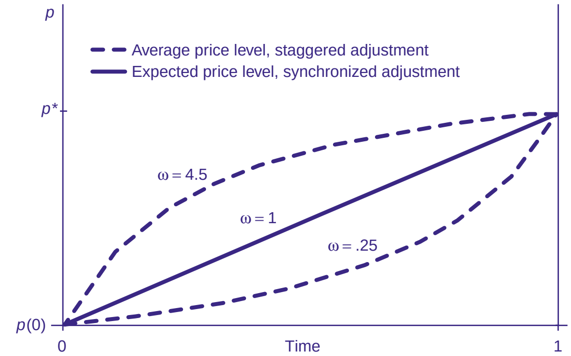


Figure 4 plots the expected aggregate price level under synchronous price adjustment. For comparison, it also reproduces plots of the average aggregate price level from Figure 3, for various values of the overshooting parameter, ω. These latter plots assume, of course, that pricing decisions are staggered across firms. It is apparent that when $\omega = 1$, the rate of aggregate price adjustment is the same, on average, whether price decisions are staggered or not. When $\omega < 1$, aggregate price adjustment is slower when decisions are staggered than when they are synchronized. However, in the most realistic case ($\omega > 1$), staggered price adjustment reduces persistence.

DISCUSSION

At first glance, staggered price setting seems to provide a simple explanation for monetary policy's persistent effects on the real economy. In principle, staggering allows aggregate price adjustment to be slow even if individual firms reevaluate their prices frequently. However, this result is valid only if firms that are free to react to a policy change don't want their prices to differ much from the prices others charge. Chari, Kehoe, and McGrattan forcefully argue that in the real world, the typical household's labor-supply schedule is sufficiently inelastic and wealth-sensitive that the wage rate must rise sharply following a monetary injection, if aggregate labor supply and labor demand are to be equated. This rise in the wage rate drives up firms' marginal production costs and gives firms with the opportunity to do so a powerful incentive to increase prices. So firms do *not* act as though they want to stay close to the prices others charge but instead as though they want to move away from those prices. As a result, aggregate price adjustment is actually swifter when pricing decisions are staggered than when they are synchronized.

Should we, therefore, write off staggered contracts as a possible solution to the persistence problem? There are at least two reasons to think that doing so would be premature. First, models in which staggered price contracts reduce persistence have counterfactual implications in other areas—suggesting these models fail to capture some important features of real-world economies. For example, CKM-style contracting models predict that a money-induced inflation will always be "cost push": the wage rate always rises first in response to a monetary injection, cutting into profit margins. Only gradually do output prices respond.[12] In the real world, there is no clear lead–lag relationship between wages and prices (Mehra 1990). CKM-style models are also arguably unrealistic in predicting that monetary policy changes will have markedly different effects on different firms, depending on the timing of their pricing decisions. For example, these models predict that an unexpected increase in the money supply, although it increases aggregate output, will cause some firms' sales (those of firms able to raise their prices quickly) to fall.[13] Moreover, according to these models, the firms whose sales fall the most will have the highest profits.

Another reason not to write off staggered contracts as a possible solution to the persistence problem is that the CKM results are sensitive to frictions in the labor market. The idea

The Analytics of Short-Run Price Adjustment

This box details the connection between individual firms' pricing decisions and the evolution of the aggregate price level following a money-supply shock. It formalizes the notion that the more advantageous individual firms find it to stay close to the aggregate price level, the slower that level responds to policy shocks.

Without any loss of generality, we can define a unit time interval as the period between each firm's pricing decisions. For example, if each firm decides once per quarter how its price will vary over the coming three months, our unit time interval is one quarter. I assume the timing of different firms' pricing decisions is staggered uniformly over the unit interval, so that the same fraction of firms pick a price path on the first day of the quarter as on the last day of the quarter, or on any other day during the quarter. I also assume each firm is infinitesimally small relative to the economy. (This condition is consistent with the requirement that each firm takes the prevailing average price as given.) Finally, for simplicity, I assume the preshock market-clearing equilibrium is one in which the money supply (and, hence, each firm's price) is constant. I denote this initial price level by $p(0)$.

Because each firm picks a price path rather than a fixed price level, at any point t during the unit interval following a money-supply shock, there are only two different prices in the marketplace. Firms that have not had a chance to reset their price paths charge $p(0)$. From Equation 13, firms that *have* had a chance to reset their price paths charge a price [$p_f(t)$] that is a weighted average of the prevailing aggregate price level [$p(t)$] and the long-run, market-clearing price level (p^*):

$$p_f(t) = \omega p^* + (1 - \omega)p(t), \tag{B.1}$$

where $\omega \equiv 1/\xi + \sigma > 0$. Since pricing decisions are staggered uniformly over the unit interval, the average price level at time t is[1]

$$p(t) = tp_f(t) + (1 - t)p(0). \tag{B.2}$$

Equations B.1 and B.2 are readily solved for $p_f(t)$ and $p(t)$ as functions of $p(0)$ and p^*:

$$p_f(t) = p(0) + \left[\frac{\omega}{(\omega - 1)t + 1}\right]\left[p^* - p(0)\right]; \tag{B.3}$$

$$p(t) = p(0) + \left[\frac{\omega t}{\omega t + (1 - t)}\right]\left[p^* - p(0)\right]. \tag{B.4}$$

Figures 2 and 3 show plots of $p_f(t)$ and $p(t)$ for different values of ω.

NOTE

[1] Equation B.2 is a linear approximation of the exact formula, which, from Note 10, is

$$p(t) = [(\Theta - 1)/\Theta]\ln\{t\cdot\exp[p_f(t)\Theta/(\Theta - 1)] + (1 - t)\cdot\exp[p(0)\Theta/(\Theta - 1)]\}.$$

that staggered contracts can contribute to persistence in the presence of labor market frictions is explored in Part 2 of this article, which will appear in an upcoming issue of *Economic and Financial Review*.

NOTES

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1 See, for example, Leeper, Sims, and Zha (1996). For evidence on how much monetary policy shocks have contributed to the business cycle, one must look at historical decomposition results. For evidence on the *potential* influence of monetary policy shocks, impulse-response functions are relevant. It is possible, of course, that if policymakers tried to vigorously exploit their potential influence, private agents would adapt their behavior in such a way that policy effects would be diminished.

2 Other explanations include price confusion (Lucas 1972, 1973) and asset-market imperfections (Lucas 1990; Fuerst 1992; Christiano and Eichenbaum 1992, 1995). For an overview of the literature, see Gordon (1990).

3 See Blanchard (1983). The argument was originally formulated in the context of overlapping wage contracts (Taylor 1980).

4 In making this statement, I implicitly assume that the model economy has only nondurable goods.

5 By no means is the analysis presented here exhaustive. CKM's benchmark model is considerably more realistic than that developed below, and CKM explore several variants of the benchmark model to establish that their results are robust to plausible changes in specification. Variants considered include models with endogenous capital accumulation, inelastically supplied specific factors of production, and intermediate producer goods. Here, as many complicating factors as possible are stripped from the CKM analysis, to highlight the basic mechanisms driving their results.

6 The assumption that utility this period depends only on current consumption and current hours of work is standard but open to question. See Hall (1998).

7 Throughout, lowercase letters denote the logarithms of their uppercase counterparts. I assume the number of households and firms is equal, eliminating the need to distinguish between, for example, average output per firm and average output per household.

8 For evidence supporting this calibration of household tastes, see Pencavel (1986), Attanasio and Weber (1994), and Ogaki and Reinhart (1998). In principle, labor indivisibilities (Rogerson 1988) and non-time-separable preferences (Hall 1998) can increase the wage elasticity of the labor supply (ξ). The larger ξ is, the weaker the CKM argument.

9 However, when firms choose a price path rather than a fixed price level, an upper bound is placed on persistence: price adjustment will always be complete by the time every firm has had a chance to respond to the policy shock. If there are thirty firms, each of which can adjust its price path once per month, aggregate price adjustment cannot take more than one month. When firms choose a fixed price level, price adjustment can, in principle, take longer than one month.

10 A demand curve of this form is consistent with household utility maximization if the output variable, C, that enters the representative household's utility function is a composite of the goods different firms produce. In particular, if there is a continuum of firms indexed by $f \in [0, 1]$, Equation 5 is obtained if

$$C \equiv [\int C_f^{\Theta} df\,]^{1/\Theta},$$

and

$$P \equiv [\int P_f^{\Theta/(\Theta-1)} df\,]^{(\Theta-1)/\Theta},$$

where C_f is the amount of firm f's output consumed by the household (Blanchard and Kiyotaki 1987). Similarly,

$$Y \equiv [\int Y_f^{\Theta} df\,]^{1/\Theta},$$

and

$$L \equiv [\int L_f^{\Theta} df\,]^{1/\Theta}.$$

11 Since $0 < \Theta < 1$, we know $\theta \equiv ln(\Theta) < 0$.

12 According to Equation 6, the wage rate varies one-for-one with p_f. With this in mind, a comparison of Figures 2 and 3 shows the wage rate rises sharply relative to the price level in response to a monetary injection (especially when $\omega > 1$). Alternatively, subtract Equation B.3 from Equation B.4.

13 Equations 5 and 13 (with a little help from Equations 3, 8, and 11) imply that $y_f - y^* = (p^* - p)(1 - \Theta - \omega)/(1 - \Theta)$, where y_f is the output of a firm that has had a chance to respond to the policy shock. The necessary and sufficient condition for y_f to fall below y^* is $\Theta + \omega > 1$. A sufficient condition, obviously, is $\omega > 1$.

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