

## Sticky Prices and Monetary Policy Shocks

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### **Abstract**

Models with sticky prices predict that monetary policy changes will affect relative prices and relative quantities in the short run because some prices are more flexible than others. In U.S. micro data, the degree of price stickiness differs dramatically across consumption categories. This study exploits that diversity to ask whether popular measures of monetary shocks (for example, innovations in the federal funds rate) have the predicted effects. The study finds that they do not. Short-run responses of relative prices have the wrong sign. And monetary policy shocks seem to have persistent effects on both relative prices and relative quantities, rather than the transitory effects one would expect from differences in price flexibility across goods. The findings reject the joint hypothesis that the sticky-price models typically employed in policy analysis capture the U.S. economy and that commonly used monetary policy shocks represent exogenous shifts.

*The views expressed herein are those of the authors and not necessarily those of the Federal Reserve Bank of Minneapolis or the Federal Reserve System.*

A large literature in macroeconomics holds that, because of sticky prices, changes in monetary policy temporarily affect the real quantities of goods and services produced. The magnitude and persistence of the effects should vary across goods in relation to their extent of price stickiness. We test this hypothesis using evidence on the importance of price rigidities across categories of consumption in the United States.

According to unpublished data on individual consumer prices collected by the Bureau of Labor Statistics (BLS) of the U.S. Department of Labor, the frequency of price changes varies dramatically across goods. Prices of newspapers, men's haircuts, and taxi fares change less than once every two years on average. At the other extreme, prices of gasoline, tomatoes, and airfares change more than once a month on average. We exploit this diversity. We classify goods by how frequently they display monthly price changes in the BLS microeconomic data. We then ask, If an expansionary monetary policy change occurs, do goods with flexible prices respond differently than goods with prices that rarely change? For example, when the Federal Reserve cuts interest rates unexpectedly, do flexible-price goods such as gasoline increase in price and fall in real quantity consumed compared to sticky-price goods such as film processing?

We find that they do not. The short-run responses of relative prices are opposite the predicted responses. Furthermore, the monetary policy shocks show persistent effects on both relative prices and relative quantities, not the transitory effects predicted. Our findings are inconsistent with the joint hypothesis that the sticky-price model well depicts the actual economy and that commonly used monetary policy shocks represent truly exogenous shifts.

### Stickiness of Consumer Prices

To construct the consumer price index (CPI), the BLS collects retail prices on more than 80,000 items a month. It collects prices on everything from broccoli to brain surgery. Bils and Klenow (2002) analyze some of the BLS data in detail, presenting evidence on 350 categories of goods and services. They find that differences in price flexibility are large and persistent across categories.

The accompanying table summarizes the evidence for broad categories of consumption over 1995–97. The first row shows that the median duration of prices across the 350 categories is 4.3 months. The next two rows show median durations separately for goods (about 30 percent of consumption) and services (about 41 percent of consumption). Prices are more flexible for goods (duration 3.2 months) than for services (7.8 months).

The next seven rows in the table show durations for the seven CPI major groups. At the flexible end are transportation prices (for example, new cars, airfares), with a median duration just under two months. At the sticky extreme are prices for medical care (drugs, physicians' services) and entertainment (admissions, newspapers, magazines, books), with median times between price changes of about 15 months and 10 months, respectively.

In the final two rows in the table, we distinguish between *raw* goods and *processed* goods and services. By raw goods we mean those with little value added beyond a primary input, for instance, gasoline or fresh fruits and vegetables.<sup>1</sup> As expected, raw goods display more price

flexibility (median duration 1.6 months) than do processed goods and services (5.7 months).

### A Sticky-Price Model

As described above, we wish to examine whether popular measures of monetary policy shocks have differential effects across types of consumption with varying underlying price flexibility. Here we use a simple general equilibrium model to illustrate how responses should vary with price stickiness. We build closely on the work of Chari, Kehoe, and McGrattan (2000). They model monopolistically competitive firms with staggered price-setting of a fixed duration. To their setup we add multiple consumer goods with prices fixed for different durations across the goods.

Consumers have momentary utility given by

$$(1) \quad U(c, m, l) = [\eta/(\eta-1)] \ln[\omega c^{1-1/\eta} + (1-\omega)m^{1-1/\eta}] + \psi \ln(1-l)$$

where  $c$  is a constant elasticity of substitution consumption aggregate,  $m$  is real money balances,  $l$  is labor supply, and the time endowment is one. Time subscripts are implicit. Following Chari, Kehoe, and McGrattan (2000), we set  $\omega = 0.94$  based on the empirical ratio  $m/c$  (M1 to nominal consumption),  $\eta = 0.39$  based on the interest elasticity of money demand (from regressing  $\log m/c$  on the nominal three-month Treasury bill rate), and  $\psi = 1.5$  so that steady-state  $l$  is one-fourth.

The consumption aggregate is given by

$$(2) \quad c = [(\int_0^1 c_f(i)^\theta di)^{1/\theta}]^{1/2} [(\int_0^1 c_s(j)^\theta dj)^{1/\theta}]^{1/2}$$

where  $c_f(i)$  is production of flexible-price good  $i$  by a monopolistic competitor and  $c_s(j)$  is production of sticky-price good  $j$  by a monopolistic competitor. As shown, each sector has a continuum of firms of measure one. The Cobb-Douglas specification across sectors makes the nominal shares of the flexible-price and sticky-price goods constant. We could relax this specification to allow an elasticity of substitution different from one; this would not affect the qualitative predictions presented. For simplicity, we have given the two sectors equal weight in consumption. We assume  $\theta = 0.9$  so that the elasticity of substitution between varieties within each sector is 10. This means firms desire a price markup of 11 percent above marginal cost, in line with Basu and Fernald's (1997) evidence.

Firm production technologies are the product of labor and random-walk productivity  $a$ :

$$(3) \quad c_f(i) = a l_f(i) \text{ for all } i, c_s(j) = a l_s(j) \text{ for all } j.$$

Labor is mobile across firms and sectors. Clearing of the labor market requires

$$(4) \quad \int_0^1 l_f(i) di + \int_0^1 l_s(j) dj = l.$$

We assume the money supply evolves exogenously according to a random walk with drift. This case is helpful for illustration because the ultimate price change is the same size as any money innovation.

For both sectors, any firm setting its price in period  $t$  does so before observing the current-period shocks. After prices are set, the current shock is realized and all firms

produce to satisfy the quantity demanded at their preset prices. In the flexible-price sector, prices are preset for two periods, the 90th percentile of price flexibility in the BLS data analyzed by Bils and Klenow (2002). In the sticky-price sector, prices are preset for 15 periods, the 10th percentile in the BLS data. In each sector, price-setting is staggered evenly. (One-half of the flexible-price sector firms set their prices before a given period; the other half, before the next period. One-fifteenth of the sticky-price sector firms set their prices before a given period; one-fifteenth, before the next period; and so on.) Firms set their prices to maximize expected discounted profits over the period in which their prices will be fixed. Their information set includes the entire distribution of preset prices of other firms in their own sector and in the other sector. If prices were preset for only one period, firms would set prices equal to the steady-state markup over their expected nominal marginal cost.

Charts 1 and 2 present equilibrium responses to a permanent 1 percent increase in the money supply. Chart 1 shows that the price levels of both goods increase the month of the shock and then rise toward 1 percent thereafter. The ascent is quicker in the flexible-price sector because only one additional cohort needs to respond with higher prices. In contrast, in the sticky-price sector the price gradually rises for 15 months following the shock. Chart 2 shows that the boost to the quantity consumed is likewise longer-lasting for the sticky-price sector. Chart 3 drives home the implications for the *relative* prices and quantities of flexible-price versus sticky-price goods.

Below we estimate empirical responses of prices to commonly used measures of monetary policy disturbances. The empirical responses will clearly fail to match the predictions in Charts 1–3. This failure could reflect a rejection of the sticky-price model or, alternatively, a lack of exogeneity in the popular measures of monetary policy disturbances. In an attempt to sort out these causes, we also examine responses in the model and in the data to a second type of shock, namely, disturbances to productivity.

Charts 4 and 5 show model responses to a permanent 1 percent increase in the productivity index  $a$ . The responses of prices and quantities are rapid in the flexible-price sector. In the sticky-price sector it takes 15 months for the effects on prices and quantities to be fully felt. Chart 6 illustrates the implications for *relative* prices and quantities.

### Evidence on Responses to Shocks

We match the BLS categories of consumption to available time series on prices and quantities consumed from the Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce. The data span the period from January 1959 to June 2000. Although we can allocate most of the BLS categories to BEA time series, in many cases the BEA categories are broader than the BLS categories. The match results in 123 categories covering 67.3 percent of overall consumer spending (versus the 71.2 percent of spending covered by the 350 BLS categories).<sup>2</sup>

Do flexible-price versus sticky-price goods respond differently to shocks? We consider variables that have been suggested as measures of monetary policy innovations, such as shocks to the federal funds rate, as well as shocks to aggregate productivity as measured by the rate of growth in total factor productivity (TFP).

Let  $p_{it}$  equal the natural log of the price of good  $i$  in period  $t$ . We look for the effect of an aggregate shock on relative values of  $p_{it}$  by estimating the following:

$$(5) \quad p_{it} = \lambda_i \sum_{j=0}^n \beta_j x_{t-j} + \phi_{it}$$

where

$$(6) \quad \phi_{it} = \alpha_i + \gamma_i t + \mu_i + \varepsilon_{it}.$$

The variable  $\lambda_i$  denotes the frequency of price changes for good  $i$  as measured in the 1995–97 BLS panel analyzed by Bils and Klenow (2002). That is,  $\lambda_i$  represents the percentage of months a price in category  $i$  differs from the same item's price in the preceding month. (In the model of the preceding section, this equals the inverse of the duration of prices.) The variable  $x_t$  denotes shocks, such as innovations to the federal funds rate. The good-specific error  $\phi_{it}$  has several components. The  $\alpha_i$  and  $\gamma_i t$  components represent  $i$ -specific levels and trends of prices. We also allow for monthly seasonal dummies specific to each good  $i$ . The  $\mu_i$  term is the error common to all goods but specific to time period  $t$ . The  $\varepsilon_{it}$  term denotes the error specific to good  $i$  in period  $t$ .

We specify  $\varepsilon_{it}$  as the autoregressive process

$$(7) \quad \varepsilon_{it} = (\rho_1 + \omega_1 \lambda_i) \varepsilon_{it-1} + (\rho_2 + \omega_2 \lambda_i) \varepsilon_{it-2}$$

so that the degree of persistence in  $\varepsilon_{it}$  can vary with the observed frequency of price changes  $\lambda_i$ . Estimation is by Cochrane-Orcutt methods, iterating on the  $\beta$ ,  $\rho$ , and  $\omega$  parameters. Observations are weighted by the share of good  $i$  in the CPI. To estimate the effects of an  $x_t$  shock on good  $i$ 's consumption ( $c_{it}$ ), we replace  $p_{it}$  in equation (5) with  $c_{it}$ .

Following Christiano, Eichenbaum, and Evans (1999), hereafter CEE, we examine empirical responses to innovations in each of the following: the federal funds rate, nonborrowed reserves, and the ratio of nonborrowed to total reserves. These have been proposed as measures of monetary policy, with a negative innovation in the federal funds rate suggesting more expansionary monetary policy and a positive innovation in nonborrowed/total reserves or nonborrowed reserves suggesting the same. We take the innovations to these series estimated by CEE from a seven-variable vector autoregression (VAR).<sup>3</sup> Charts 7–9 show the responses of the fed funds rate, personal consumption deflator, and nonfarm employment to a one percentage point drop in the fed funds rate. These responses are taken straight from the CEE estimates. A fed funds rate drop is associated with higher prices and higher employment over time. Although not seen in the first 20 months, the estimates imply that employment eventually heads back down.

Responses of relative prices and relative quantities to a federal funds rate innovation appear in Charts 10 and 11. The shock here is equal to a one percentage point drop in the fed funds rate. Because a drop signals expansionary monetary policy, we should see an initial rise in relatively flexible prices. The charts show the responses implied for goods at the 90th percentile of price flexibility relative to the responses implied for goods at the 10th percentile of price flexibility. We calculated these implied responses by multiplying the difference in frequencies of price changes at the 90th percentile (48.5 percent) versus the 10th per-

centile (6.1 percent) by the values for  $\beta_j$  that we estimated using (5). The charts plot  $(\lambda_{90} - \lambda_{10})\beta_j$  against  $j$ , where  $j$  denotes months since a one percentage point decrease in  $x_t$  (fed funds rate innovations). The charts also include shaded areas depicting 95 percent confidence bounds for the impulse responses. (These confidence intervals do not reflect the fact that the innovations to the fed funds rate are generated as a residual to an estimated regression.)

According to Chart 10, prices for flexible goods actually decrease relative to prices for sticky goods in the first eight months after the innovation. After eight months the flexible prices are up relative to the sticky ones, but at this point the effects on relative prices should be fading rather than building. (See Chart 3 from the sticky-price model.) In Chart 11 we see no impact of a drop in the federal funds rate on the relative quantity consumed for the first year, followed by a fall in real consumption of flexible-price goods relative to sticky-price goods. Neither the initial nor subsequent responses match those predicted by the model. (Again, see Chart 3.) Charts 12 and 13 provide the implied *levels* of price and consumption responses for the 90th and 10th percentiles of price flexibility.<sup>4</sup> The level responses likewise do not match those predicted for flexible-price and sticky-price goods.

We find similar patterns when we define monetary policy shocks in terms of the other two measures employed by CEE—innovations to nonborrowed reserves and to the ratio of nonborrowed to total reserves. Our results are also robust across subsamples such as 1982–2000 rather than the full 1959–2000 sample. When we added commodity prices (already a variable in the VAR used to identify monetary policy innovations) as a control to equation (5), this too had little effect on the patterns.

We see two possible interpretations of our results. One is that the staggered sticky-price model in the preceding section is not a good description of how price stickiness affects responses to exogenous monetary policy shocks. Another interpretation is that the measures of monetary policy shocks are not orthogonal to persistent shocks to flexible-price versus sticky-price goods. In this latter interpretation, the responses we are estimating are a mixture of the effects of real shocks and the effects of monetary policy shocks. Put more succinctly, we reject the joint hypothesis of sticky-price models and these popular means of identifying monetary policy (for example, innovations to the federal funds rate).

In an attempt to address where the rejection comes from, we lastly examine how relative prices and consumption across the 123 goods respond to an aggregate supply shock as measured by the rate of growth in TFP. We construct quarterly TFP growth based on real GDP from the BEA, hours worked and employment from the BLS, and the physical capital stock from the BEA. We construct a monthly series for TFP growth by interpolating monthly growth rates within each quarter, conditioning on monthly data for industrial production and hours.<sup>5</sup> Our series for TFP growth extends from April 1964 to June 2000. Consistent with prior work, TFP growth shows no significant serial correlation. For this reason, we treat TFP's growth rate as a permanent innovation to productivity ( $a$ ).

Responses to a 1 percent TFP shock for flexible-price versus sticky-price goods are presented in Charts 14 and 15. As predicted by the model (and shown in Chart 6), the

price of the flexible good decreases over the first several months, and this relative price effect gradually erodes in a little over a year. In contrast, the shifts in relative quantities consumed are smaller than predicted and not statistically clear. Charts 16 and 17 present response of prices and real consumption *levels* to a TFP shock. For both prices and quantities, the estimated responses bear little resemblance to the model predictions in months 10 through 20. (See Charts 4 and 5.) Given that the match between the model and data responses to TFP shocks is mixed, we continue to interpret the evidence from Charts 10–17 as a rejection of the joint hypothesis of the sticky-price model and the method for identifying disturbances to monetary policy.

The model sketched in the preceding section treats the differences in price flexibility across goods as exogenous. Could this explain the discrepancy between the model's predictions and the empirical impulse responses presented here? Suppose instead that prices change more frequently for goods with more volatile idiosyncratic shocks, as in Willis' (2000) state-dependent model. We conjecture that the response of flexible-price and sticky-price sectors to an aggregate impulse in such a model would be qualitatively the same as if the price flexibility differed exogenously across sectors. Our reasoning is that a firm changing its price in response to a large idiosyncratic shock will also take into account the current value of the aggregate shock process. What is crucial for our inference, we believe, is not that price flexibility be exogenous across goods, but that the aggregate shocks we consider be uncorrelated with idiosyncratic shocks hitting the flexible-price and sticky-price sectors.

## Conclusions

We find that popular measures of monetary policy shocks (innovations to, respectively, the federal funds rate, nonborrowed reserves, and the ratio of nonborrowed to total reserves) are followed by anomalous movements in the prices and quantities consumed of flexible-price versus sticky-price goods. Most striking, monetary policy shifts seem to be followed by very persistent movements in relative prices and relative quantities. Based on this, these measures of monetary policy shocks do not appear to act like purely nominal (monetary) disturbances do in staggered-pricing models.

Our results reject the joint hypothesis of sticky-price models and popular monetary policy identification schemes. We stress more generally that, in identifying monetary policy shocks, the inferred innovations should not be related to long-run movements in relative prices or quantities of flexible-price versus sticky-price goods.

\*The authors are grateful to Jeff Campbell, V. V. Chari, Chris Phelan, Richard Rogerson, Art Rolnick, and Jenni Schoppers for helpful comments.

<sup>1</sup>The set of raw goods consists of gasoline, motor oil and coolants, fuel oil and other fuels, natural gas, electricity, meats, fish, eggs, fresh fruits, fresh vegetables, and fresh milk and cream. Unlike the BLS food and energy categories, the set does not include meals purchased in restaurants or foods the BLS classifies as processed.

<sup>2</sup>When aggregating BLS categories, we weight categories by their relative importance in the December 1997 CPI.

<sup>3</sup>We refer to CEE's *monthly* VAR, which involves nonfarm employment, the consumption deflator, commodity prices, the nominal federal funds rate, nonborrowed reserves, total reserves, and M1. This is the ordering of the variables CEE use in their Cholesky decomposition of residuals to obtain orthogonal fed funds rate innovations. Because gross domestic product (GDP) data are not available monthly, CEE use the

monthly consumption deflator and monthly nonfarm employment in place of the quarterly GDP deflator and real GDP.

<sup>4</sup>We estimated these level responses by replacing the time dummies in equation (6) with current and lagged federal funds rate innovations. The interactions of these innovations with  $\lambda_t$  were, as before, included in (5).

<sup>5</sup>More exactly, we require that relative growth rates of TFP within a quarter exhibit the same relation between growth rates in TFP and growth rates in industrial production and hours that we observe in quarterly data.

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## Duration of Prices by Category of Consumption, 1995–97

Category	Median Duration (months)	Share of the CPI (percent)
All Items*	4.3	71.2
Goods	3.2	30.4
Services	7.8	40.8
Food	3.4	17.1
Home Furnishings	3.5	14.9
Apparel	2.8	5.3
Transportation	1.9	15.4
Medical Care	14.9	6.2
Entertainment	10.2	3.6
Other	6.4	7.2
Raw	1.6	12.0
Processed	5.7	59.2

\* The data exclude shelter, which represents the remaining 28.8 percent of the CPI.

Source: Bureau of Labor Statistics, U.S. Department of Labor, via Bils and Klenow 2002

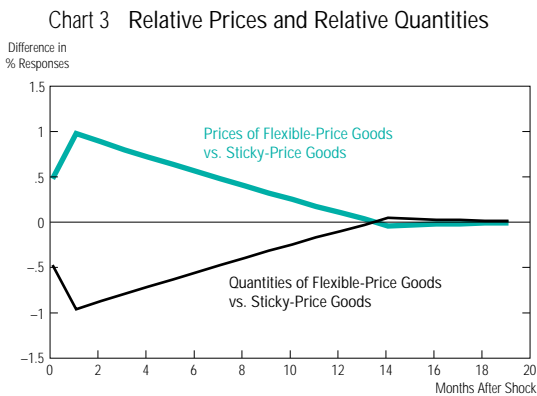
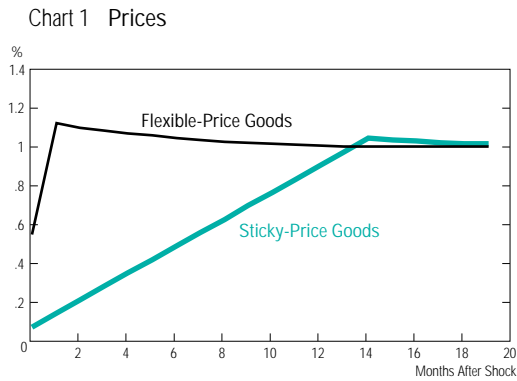
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Charts 1–6

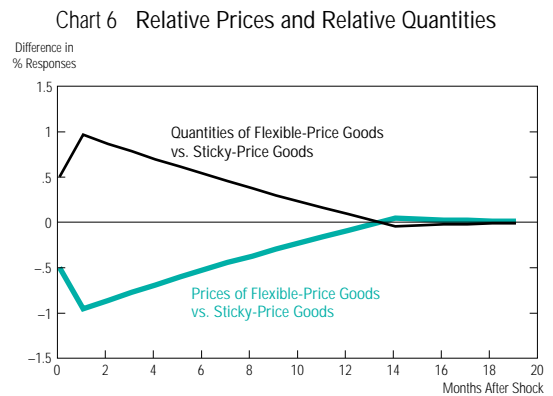
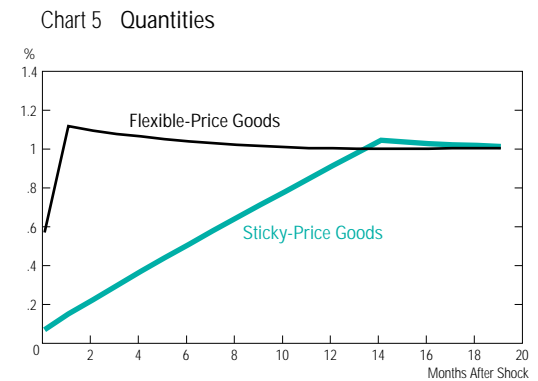
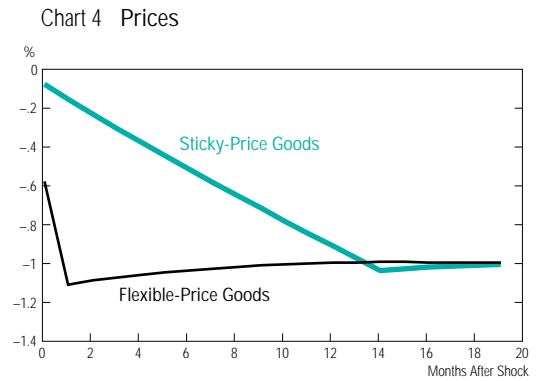
Responses to Shocks Predicted by a Sticky-Price Model

Percentage Changes in Prices and Quantities Consumed of Goods With Flexible and Sticky Prices in the 20 Months After an Unexpected, Permanent 1% Increase in the Money Supply or in the Productivity Index

Charts 1–3 Responses to a Money Supply Shock



Charts 4–6 Responses to a Productivity Shock

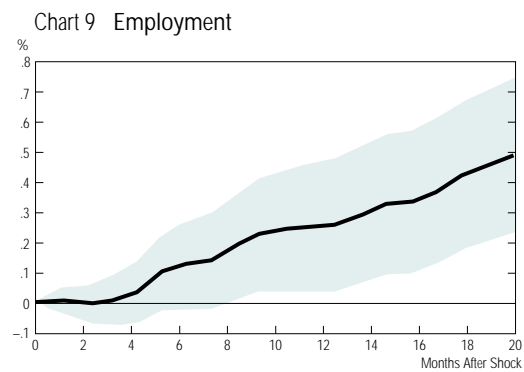
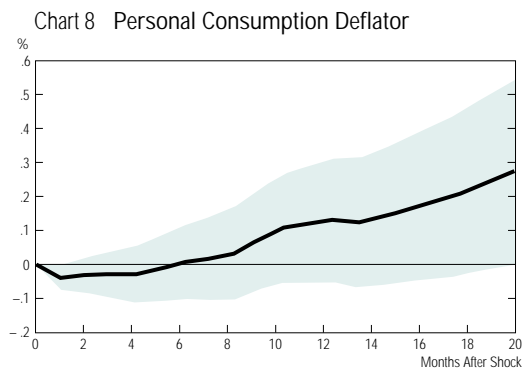
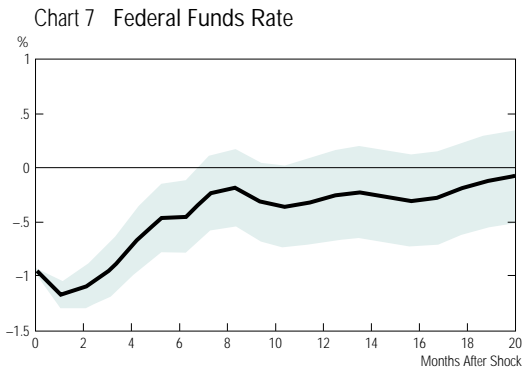


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Charts 7–9

## How One Measure of Monetary Policy Shocks Affects Indicators of Aggregate U.S. Economic Activity

Percentage Changes in Aggregate U.S. Indicators in the 20 Months After an Unexpected, One Percentage Point Drop in the Federal Funds Rate, as Predicted by a Vector Autoregression; Responses and 95% Confidence Bounds



Source: Christiano, Eichenbaum, and Evans 1999

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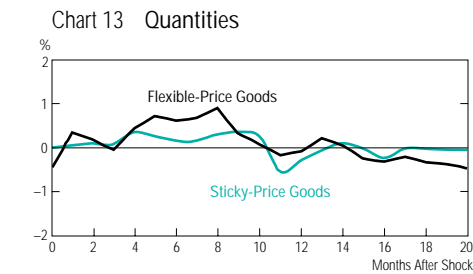
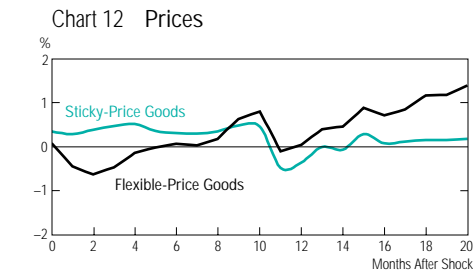
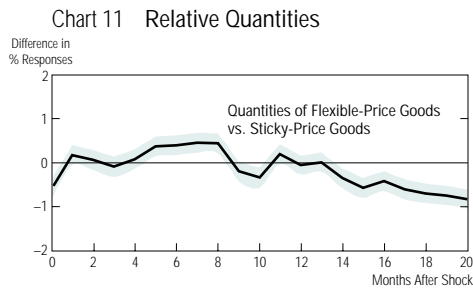
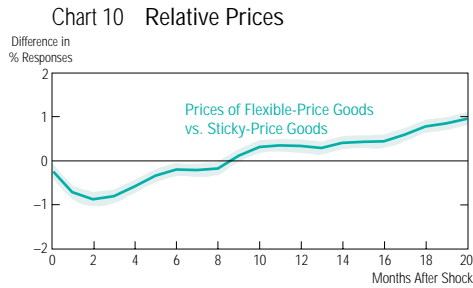


Charts 10–17

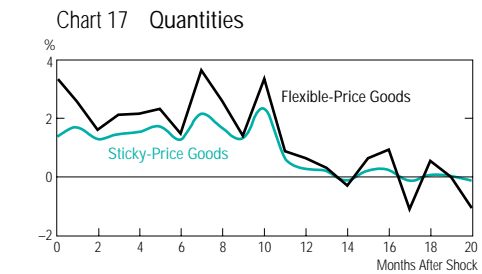
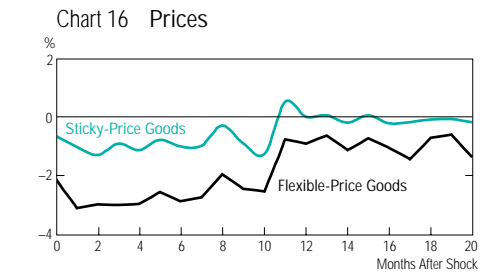
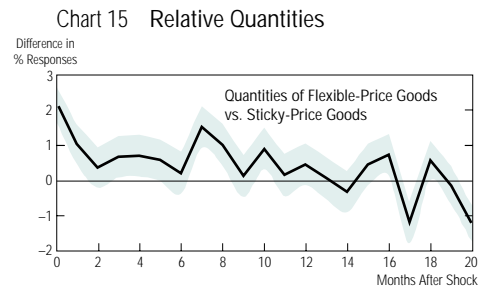
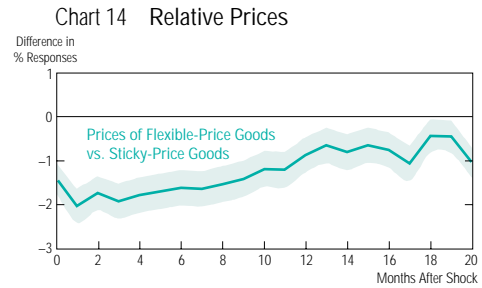
The Responses to Shocks Estimated in U.S. Data

Percentage Changes in Prices and Quantities Consumed of Goods With Flexible and Sticky Prices in the 20 Months After a One Percentage Point Drop in the Fed Funds Rate or a 1% Increase in Total Factor Productivity; Responses and 95% Confidence Bounds

Charts 10–13 Responses to a Fed Funds Rate Shock



Charts 14–17 Responses to a Productivity Shock



Source of Basic Data: Christiano, Eichenbaum, and Evans 1999