The Relative Price Effects of Monetary Shocks

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Abstract: We document the response of the individual components of the Producer Price Index (PPI) to commonly used measures of monetary shocks, and show that these responses are at variance with many widely-used "macro" models of monetary non-neutrality. Monetary shocks are shown to have large relative price effects, resulting in an increase in the dispersion of the cross-section distribution of prices. Furthermore, in response to a contractionary (expansionary) monetary shock, a substantial number of prices tend to rise (fall). Most of the existing models of monetary nonneutrality are not capable of replicating these types of relative price responses.

JEL Codes: E0, E3, E5

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1. Introduction.

Explaining the sources of monetary non-neutrality remains one of the great challenges of macroeconomics. There is a large body of evidence that suggests that changes in the nominal stock of money may have significant effects on the real economy in the short run. What remains controversial is the mechanism whereby these non-neutralities arise. On the one hand, it is argued that nominal wage or price rigidity of the sort emphasized by Keynes plays a key role. This idea has been explored extensively in recent research literature, with Goodfriend and King (1998) proposing a New Neoclassical Synthesis that combines insights from the real business cycle literature with Calvo (1983) style price setting to develop a framework for thinking about for monetary policy affects the real economy. An alternative strand of the recent literature eschews exogenously given wage and price rigidity, and instead argues that limited participation in financial markets is the key to understanding the real effects of money. Papers include Lucas (1990), Fuerst (1992), Christiano and Eichenbaum (1992), and more recently Alvarez and Kehoe (2002), Alvarez, Lucas and Weber (2001). A third strand of the recent literature has revived the idea of imperfect information as a source of nonneutrality. Models of this sort were pioneered by Lucas (1972) but the early variants proved less than satisfactory as accounts of persistent responses of real activity to nominal shocks. The newer models of Woodford (2003) and Mankiw and Reis (2002), for example, emphasize the importance of interaction between price setters with imperfect information about current economic conditions.

Our objective in this paper is to examine how the apparent non-neutralities of money are reflected in relative price movements. First, at its “microeconomic core” the non-neutrality of money has to be related to relative price changes. If economic agents react to purely monetary shocks (say by changing their consumption or labor supply decisions), then these changes would be reflected in relative price changes. Alternatively, relative price changes brought about by monetary shocks would also induce economic agents to alter their "real" behavior. Either way, real effects of monetary shocks would manifest themselves in relative price changes.

Second, examining the response of relative prices to monetary shocks may shed some light on alternative theories of monetary neutrality. For example, there is a literature that has documented the positive correlation between the mean of the cross-section distribution of price changes (aggregate inflation) and the skewness of this distribution. Ball and Mankiw (1995) have argued this positive correlation is consistent with menu cost pricing. On the other hand, Balke and Wynne (2001) have shown that flexible price models with sectoral interactions but money neutrality are also capable generating positive mean-skewness correlations. Where these models are likely to differ with respect to their predictions about price behavior is in the response of relative prices to purely monetary shocks. Similarly, one might expect that a nominal shock that is fully perceived would have very different implications for the pattern of relative price changes in an environment where firms are only allowed to change prices infrequently that would a comparably sized, but imperfectly perceived, shock in an environment where price changes are frequent.

In this paper, we examine the response of over 600, 8-digit level producer price indices to a "monetary shock". From these individual responses, the response of the entire cross-section distribution of prices can be constructed. What is evident from these responses is that monetary disturbances have substantial relative price effects. Not only is the mean of the cross-section distribution affected (as would be in the case of monetary neutrality), but also the dispersion of the cross-section distribution is substantially affected. Furthermore, the relative price effects are quite dramatic in the sense that in absolute terms, not just in relative terms, some prices rise and other prices fall. Like Barth and Ramey (2001), we find that a contractionary monetary shock tends to raise a substantial number of prices in the short-run. This suggests that the so-called price puzzle is prevalent in even very disaggregated price indices. At longer horizons, we find that the preponderance of prices fall in response to a contractionary monetary shock. Finally, we argue that simple "macro" models of relative price movements such as Lucas' 1972 paper or the more recent sticky-price or sticky information models are unlikely to generate the dramatic response of the cross-section distribution of price to monetary shocks observed in the data.

This paper is closely related to the recent paper by Bils, Klenow and Kryvtsov (2003). Bils, Klenow and Kryvtsov examine the response of the components of the Consumer Price Index (CPI) to standard measures of monetary shocks. They classify prices as flexible or sticky based on the frequency with which they change, and show that contrary to what we might expect, the prices of flexible goods tend to decline relative to the prices of sticky goods in response to an expansionary monetary shock. This finding is robust across different measures of monetary policy shocks, and across different subsamples.

2. Data preliminaries

Our primary source of data was monthly changes in the components of the PPI over the period 1959:1 to 2001:12. The indexes that make up the PPI are grouped according to various classification structures, the three most important of which are the industry, commodity and stage of processing. We use primarily the commodity classification, which organizes products by similarity of end use or material composition. The All Commodities PPI consists of fifteen major commodity groupings at the 2-digit level (for example, “01-Farm products”, “02-Processed foods and feeds” and so on). These major commodity groupings are further disaggregated into subgroups at the 3-digit level (for example “011-Fresh and Dry Fruits, Vegetables and Nuts”, “012-Grains” etc.), product classes at the 4-digit level (for example “0111-Fresh Fruits and Melons”, “0113-Fresh and Dry Vegetables” etc.), subproduct classes at the 6-digit level (for example, “011101-Citrus Fruits”, “011102-Other Fruits and Berries” etc.), and individual items at the 8-digit level (for example “01110101-Grapefruits”, “01110104-Lemons” etc.). The number of price series at the 2-digit level of aggregation is 14 for most of the sample period, increasing to 15 from 1969 on. At the highest (8-digit) level of disaggregation the number of series increases from 130 or so in 1959 to 1228 in 2001. It is possible to get price data at an even more disaggregated level, but only at the cost of frequent breaks in the price series: PPI disclosure rules prohibit the reporting of prices in an industrial category of there are fewer than three usable price quotes in that category (see U.S. Department of Labor (1997), p. 136).

In this paper, we focus on the cross-section distribution of log differences of 8-digit level PPI price indices. Because some price indices are available for only a limited number of observations, we include in our analysis only those price indices that have at least 172 observations. This leaves 616 price series of suitable length although not all of these series are available for the entire period. The number of available price series rise from 122 in 1959:1 to 616 in 2001:12.

Figure 1 plots the (smoothed) cross-section distribution of the sample averages of the 616 price change series.[1] These price changes are one-month changes in the logarithm of the individual 8-digit PPIs from 1959 through 2001. We take this distribution as representing the something like a steady-state cross-section distribution of price changes. For reference, we also plot a normal distribution that has the same mean and variance as this cross-section distribution of price changes. One of the characteristics of this cross-section distribution is that it negatively skewed and very leptokurtotic.

Figure 2 shows the various moments of the cross-section distribution of price changes over time. As evident from the figure, there is substantial variability in these summary statistics over the sample. Some of the variability is the result of changes in the number of price indices available. In particular, the number of price indices available increases from around 200 in 1980 to over 530 in 1984, and this gives rise to dramatic changes in the level of the variance, skewness, and kurtosis. Further, there is a substantial decline the time-variability of the mean of the cross-section distribution over this period as well. Despite the change in coverage over the sample, the unweighted mean of the distribution does the track broad movements in aggregate inflation over this period reasonably well, capturing the acceleration of inflation in the 1970s and the subsequent deceleration in the 1980s and 1990s.

[1] The distribution of price changes is smoothed using the Epanechnikov kernel in RATS.

3. Identifying Monetary Shocks

We are interested in characterizing the effects of pure monetary policy shocks on the cross-section distribution of prices. To measure these shocks we employ a standard VAR methodology of the sort employed in much of the recent monetary policy literature (see for example Christiano, Eichenbaum and Evans (1999) and Barth and Ramey (2001)). We estimate a five-variable system consisting of industrial production, IP_t, the personal consumption expenditures deflator, PCE_t, a commodity price index, $PCOM_t$, the nominal federal funds rate, FF_t, and the M2 measure of the money stock, $M2_t$. All data are monthly, and cover the period 959 through 2001. All variables except the federal funds rate are in natural logarithms. Finally, we include 12 lags of each variable in the VAR as well as a constant and seasonal dummy variables. As is standard, we use a Choleski decomposition to orthogonalize shocks; the ordering being: IP, PCE, PCOM, FF, and M2. As is standard, we take a positive, orthogonal shock to the fed funds rate as representing a contractionary monetary shock.

Figure 3 presents impulse responses of the variables in the system to a (one standard deviation) positive shock to the fed funds rate. The response of commodity prices and M2 money supply are what one might expect from a contractionary monetary shock--prices and the money supply fall. After a short delay, industrial production also falls in response to a contractionary shock. Only the aggregate price index, here measured by the personal consumption expenditures deflator, fails to react in the expected manner. This so-called price puzzle has been widely noted in the literature (Sims (1992), Christiano, Eichenbaum, and Evans (1999), Barth and Ramey (2001)).

4. Measuring the Response of the Cross-section distribution to Monetary Shocks

Because of changes in the coverage of the PPI over time, we will not use time series on the mean, variance, skewness and kurtosis of the cross-section distribution directly. Instead, to determine how the cross-section distribution of price changes responds to a monetary shock, we essentially build cross-sectional response price by price. For each of the 616, 8-digit level price series in the PPI we estimate an equation relating (the log of) the price to the macro variables present in the above VAR. In particular, we estimate an equation for each of our price indices of the form:

$$p_{it} = A_i x_t + B_i(L)p_{it-1} + C_i(L)Y_t + \varepsilon_{it}, \tag{1}$$

where p_{it} is the log of price index of good i, x_t is a vector of exogenous variables that includes a constant and seasonal dummy variables, and Y_t is the vector of macro variables used in identifying monetary shocks. $B_i(L)$ and $C_i(L)$ are lag polynomials.

To calculate the response of the price of good i to a monetary shock, we simply append the good i price equation to the macro VAR described in the previous section. This structure assumes no feedback from the individual 8 digit PPI to the macro variables in the model or to other 8-digit-level prices.[2] To determine the effects of monetary policy on the cross-section distribution of prices we simply calculate the response of each individual price series to a monetary shock. Once we have the response of each price, we can build the cross-section distribution at each point in time. We initialize the cross-section distribution to the average (or steady state) cross-section distribution of price changes described in Section 2.

[2] Barth and Ramey (2001) in their study of sectoral output and price responses to monetary shocks, and Davis and Haltiwanger (1997) in their study of industry level output responses to oil shocks employ similar restrictions.

Because the parameters of the VAR are estimated with some imprecision, we construct simulated distribution of impulse responses for each the 8-digit price indices in our sample. We do this by drawing parameters for the VAR from a normal distribution with a mean equal to the actual estimated parameters and variance/covariance equal to the parameter variance/covariance matrix. For each parameter vector draw, we calculate impulse responses for the 616 price indices. Finally, we use 1000 parameter vector draws to fill out the simulated distribution of impulse responses for each price.

5. Empirical Responses of 8-digit PPI Indices to Monetary Shocks

Figure 4 shows how a monetary shock affects the cross-section distribution at the 8-digit level of disaggregation after 2, 6 and 12 months. For reference we include the initial or steady state (horizon 0) cross-section distribution shown in Figure 1. Figure 5 provides an alternative view of what is happening to the cross-section distribution by plotting the cumulative distributions. What is clear from Figure 4 and 5 is that there is an increase in the dispersion (variance) of the cross-section distribution at these horizons as a result of a monetary shock. Furthermore, at short horizons (2 and 6 months) the distribution of price changes is also shifted towards the right, so that more price changes are above their sample average than below their sample average. Interestingly, while the distribution has shifted towards the right, there are still a substantial number of price changes that have fallen (relative to their sample average). At a horizon of 12, the distribution is no longer shifted to the right with the number of price changes above their sample average being roughly fifty percent, but the increased dispersion remains. After

24 months (not shown), the effect of a monetary shock on the cross-section distribution has for the most part disappeared, so that the cross-section distribution at a horizon of 24 months looks very similar to the initial cross-section distribution.

Changing our focus from the entire distribution to a select few moments of the distribution, Figure 6 shows the effect of a monetary shock on the (unweighted) mean, variance, skewness, and kurtosis of the cross-section distributions of price changes. Again, we start from the cross-section distribution implied by the sample averages of the individual price changes. We also display the (unweighted) mean of the accumulated change in the price levels of the PPI indices. Included on the graphs are the 10th and 90th percentiles from the Monte Carlo simulations of the impulse responses for these various statistics.

Perhaps the most striking result implied by Figure 6 is the dramatic increase in the variance of the cross-section distribution. Figures 4 and 5 suggest that this increase in dispersion is the result of some price changes increasing and others decreasing as a response to a monetary shock. While the response of skewness and kurtosis displays a good deal of variability, the general tendency is for these statistics to fall (in absolute value terms) as a result of a monetary shock. The increase in the variance and the decline in the skewness and kurtosis, as well as the plots of the cross-section distribution in Figures 4 and 5, suggest that the relative price effects of monetary shocks are widespread across prices and not isolated to the tails of the cross-section distribution. Note that the response of the mean of the cross-section distribution is qualitatively similar to that of the personal consumption deflator. This suggests that the so-called “price puzzle” that is found in aggregate price indexes is present at the level of individual prices as well.

Another way of characterizing the response of the cross-section distribution to a monetary shock is to examine the cumulative responses of the individual prices at different horizons. Figure 7 shows the cumulative responses (or changes from the initial steady state cross section distribution) of the individual prices at horizons of 1, 2, 6, 12, 24 and 60 months. As a reference point, we show the histogram for the cumulative response before the shock (horizon 0), which, of course, has all of the mass concentrated at zero. Examining the series of panels in the Figure, we observe how a monetary shock propagates through the cross section distribution over time. The initial increase in dispersion over the first year or so following the shock is readily apparent, and then with the passage of more time the distribution moves towards to the (lower) long-run price level. In terms of the cumulated changes this is reflected in a concentration of the mass on a new point below zero which is determined by the size of the (contractionary) monetary shock.

To further assess whether the increase in the variance of the cross-section distribution of price changes is the result of a few large price changes or is the result of widespread relative price changes, we simply count the number of prices whose response to a monetary shock is positive and negative for different horizons. To evaluate whether these changes are statistically "large", we consider two alternative ways to evaluate the statistical significance. The first counts the number of prices whose mean of the simulated distribution of responses is positive (or negative) at the 90% confidence level.[3] The second way we examine statistical significance is more stringent. Here we classify the response of a price to be positive (negative) if 90% of the simulated responses are

[3] Thus, a price is classified as having a positive response, if we can reject (one-sided) the null that the response is less than or equal to zero with a p-value of 10 percent.

positive (negative). Note that if the true probability of a positive simulated price response is .5 (i.e., on average the response is zero) then with 1000 simulations the probability that 90% of the simulated responses are positive is essentially zero.[4]

Figure 8 plots the number of prices whose mean price change and mean accumulated price change is positive (negative) at the 90% confidence level. For short horizons (say less than twelve months), the proportion of prices rising is slightly higher than the proportion of prices falling. As the horizon lengthens, the proportion of negative price responses is greater than positive responses. This is particularly true for the accumulated price effect or price level effect as the number of prices whose mean response is negative gradually rises as the horizon lengthens, approaching 75 percent as the horizon nears five years.

Figure 9 plots the number of prices whose response is positive (negative) using the more stringent definition of significant response, that is 90 percent of the simulated responses were positive (or negative). Again, at short horizons slightly more prices have a positive accumulated response than have a negative response. As the horizon lengthens, the proportion of goods whose accumulated price response is “negative” is substantially greater than the number of prices whose response is positive.

These results suggest that relative price movements are widespread and that at short horizons a substantial number of prices are moving in opposite directions. As we will discuss below, the fact that a substantial number of prices are rising while others are falling in response to a monetary shock poses problems for standard macro-models in which monetary shocks have relative price implications. At longer horizons, a greater proportion of goods prices respond as one might expect them to in response to a

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4 It is $6.7e^{-162}$.

contractionary monetary shock--they fall. These are suggestive that relative price effects of a monetary shock are lessened as the horizon lengthens.

6. Price responses by stage of processing and commodity group

To determine whether certain types of prices are more likely to respond positively (or negatively) to a monetary shock, we organize the 8 digit prices into different categories. First, we examine whether there are differences in the price response depending where the good is placed in the stage of processing, i.e. whether a good is classified as a finished, intermediate, or crude good. Of the 616 prices included in our analysis, the BLS classifies 508 of these prices into a stage of processing. For example, “Lemons” (fresh fruit) happen to be classified as a finished good as are “Beds, including bunk and water beds” (household furniture) and “Radio communication, fiber optics, and related equipment” (Communication and related equipment). Goods like “Confectionary materials-corn sweeteners” and “Softwood plywood-Southern, Sanded” were classified as intermediate goods. Goods like “Hard red winter wheat”, “Douglas fir logs, bolts and timber”, and “Gravel, construction” were classified as crude materials. Second, we classify goods by their 2-digit commodity grouping. For example, the PPI for “Lemons” (8-digit code 01110104) is classified as a “Farm Product” (2-digit code 01). This yields fifteen different commodity groups.

Figure 10 displays the proportion of prices classified by stage of processing whose simulated mean accumulated price response is significantly positive or negative while Figure 11 displays the proportion of prices in which 90% of the simulated accumulated responses were either positive or negative. Figures 10 and 11 suggest that at shorter horizons monetary shocks have greater relative price effects (in the sense that some prices rise and others fall) for final and to a lesser extent intermediate goods than for crude goods. It takes around 20 months for final goods and around 12 months for intermediate good before more prices have fallen than risen in response to a contractionary monetary shock. For crude goods, a disproportionately larger number of crude goods materials are falling than are rising and this remains the case for nearly all horizons. This suggests that contractionary monetary shocks are more likely to have the traditional effect, price falls, on crude goods prices than more processed goods in the short-term.

Table 1 displays the proportion of goods in the various commodity groupings whose prices are rising and falling according to the criterion that the mean (over the simulations) response of the price is significantly negative or positive. In the first month following a positive Fed Funds rate shock, the majority of commodity groups (11 out of 15) have more than half of their prices rising in response to the shock. In fact only in commodity group six (lumber and wood products) are a majority of prices falling at all horizons other than the initial period (horizon zero). However, by horizon six, in six of the fifteen commodity groups a majority of prices are falling. By the twenty-fourth month, twelve commodity groups have a majority of their prices falling and by the fifth year all but one commodity group have a majority of their prices falling (and in this sector the number of significant price declines exceeds the number of significant price increases). Fuels and related products (commodity group five), pulp, paper, and allied products (commodity group nine), and transportation equipment (commodity group fourteen) generally took longer than the other commodity groups before a majority of the prices in those groups had fallen.

7. Oil prices and Romer-Romer Monetary Policy Variables

Because identification of monetary shocks is not without controversy, we examine whether the major conclusions hold up for alternative specifications of the empirical model. First, because one might argue that monetary policy responds to variables that we have not already included in the basic VAR, we examine whether controlling for oil price changes alters the apparent relative price effects of monetary shocks. We do this by including the oil price variable proposed by Hamilton (1996) in the basic VAR and the individual price equations.[5] We still take innovations in the fed funds rate to represent a contractionary monetary shock.[6] Second, rather than taking innovations in the fed funds rate as the monetary policy indicator, we take the Romer and Romer ((1989) and (1994)) dates to correspond to a contractionary monetary intervention.[7] A contractionary monetary shock is then the effect of the Romer-Romer dummy "turning on".[8]

Figure 12 displays for the model that includes the Hamilton oil price variable the proportions of prices whose mean response to a contractionary monetary shock is significantly positive or significantly negative. Comparing Figure 12 with Figure 8 it is clear that including oil prices into the VAR does not change qualitatively the previous results—monetary shocks have strong relative effects even to the extent that some prices

[5] The Hamilton oil price variable is defined as $\max(0,\log(poil_t)-\max(\log(poil_{t-1}),\ldots,\log(poil_{t-12}))$.
[6] The oil price variable enters into the Choleski ordering before the Federal Funds Rate.
[7] The Romer dates are: 1947:10, 1955:9, 1968:12, 1974:4, 1978:8, 1979:10, and 1988:12.
[8] We include current and 12 lags of the Romer dummies in the every equation.

rise and others fall. Similarly, using the Romer dummies to capture contractionary monetary shocks does not change qualitatively the previous results (see Figure 13).

8. What can explain the Relative Price Effects of Monetary Shocks?

What kinds of economic environments could generate such profound relative price changes seen above? If money was neutral, then there would be no relative price effects of a monetary shock and only the mean of the cross-section distribution of price changes would be affected—all prices would increase proportionally. This is the prediction of a multi-sector flexible price classical model (see for example Balke and Wynne (2000)). To the extent that the cross-section distribution changes dramatically, as evident in the changes in the dispersion (variance) of the cross-section distribution seen above, this suggests that monetary shocks display substantial non-neutralities even at high levels of disaggregation. In this section, we consider three standard macro models in which monetary shocks have relative price implications. We argue that the absence of rich microeconomic interactions in these standard models makes them incapable of generating the type of relative price effects of monetary shocks documented above.

8.1 Nominal Misperceptions Model

In the nominal misperceptions model, firms (and consumers) cannot perfectly distinguish between relative price changes and aggregate price (see Lucas (1972) and 1973)). Here we use the model similar to that proposed by Barro (1976) and examined for its relative price effects by Hercowitz (1982).

Supply of and demand for market z's (log) output is given by:

$$y_t^s(z) = \alpha^s(z)[P_t(z) - E(P_t \mid \Omega(z,t))] + v_t + \varepsilon_t^s(z) \qquad (2)$$

$$y_t^d(z) = -\alpha^d(z)[P_t(z) - E(P_t \mid \Omega(z,t))] + [M_t - E(P_t \mid \Omega(z,t))] + \varepsilon_t^d(z), \qquad (3)$$

where $y_t(z)$ is log output in market z, $P_t(z)$ is (log) price in market z, $E(P_t \mid \Omega(z,t))$ is expected aggregate price level given information in market z at time t, M_t is log money supply, v_t is an aggregate supply shock, and $\varepsilon_t^s(z)$ and $\varepsilon_t^d(z)$ are market z supply and demand shocks. Because economic agents do not observe either the aggregate price level or the aggregate money supply directly, they must try to infer expected aggregate price level from observations of the price in their own market. Solving the signal extraction problem, Hercowitz (1982) shows the equilibrium price in market z is given by

$$P_t(z) = \tilde{M}_t + \theta(z)[\tilde{m}_t - v_t + \varepsilon_t(z)], \qquad (4)$$

$$\theta(z) = \frac{\sigma_m^2 + \sigma_v^2 + (\lambda(z)/\lambda)\sigma_\varepsilon^2}{\sigma_m^2 + \sigma_v^2 + (1/\lambda)\sigma_\varepsilon^2},$$

where $\tilde{M}_t$ is the anticipated money supply, $\tilde{m}_t$ is an unanticipated money shock, $\varepsilon_t(z) = \varepsilon_t^d(z) - \varepsilon_t^s(z)$ is market z excess demand shock, $\lambda(z) = 1/[\alpha^s(z) + \alpha^d(z)]$, and λ is the mean of $\lambda(z)$ over all markets.

Because $\theta(z)$ varies across markets, equation (3) does imply that monetary shocks will have relative price effects. However, because $\theta(z)$ is positive for every market, a monetary shock causes all prices to move in the same direction—relative price movements occur because some prices move more than others. This is in contrast to our empirical results in which we found the monetary shocks result in some prices falling and other prices rising, at least at short horizons.[9]

8.2 Sticky prices and Sticky information

The next two models build on the Dixit-Stiglitz (1977) model of monopolistically competitive price setting. The first model assumes that prices are not fully flexible. As a result, nominal prices do not increase proportionally to an increase in the money supply. There is a large literature on sticky prices; we consider a simple variant of the Calvo (1983) price setting model. In the second model, while prices are free to move each and every period, they do not always do so because new information about the economic environment arrives (or is processed) incompletely (see Sims (2003)). These so-called sticky information models have been suggested to yield more plausible dynamic behavior that the traditional Calvo-type sticky price model (see Woodford (2003) and Mankiw and Reis (2002)).

For both classes of models, the monopolistically competitive desired price is just a market-up over marginal cost. Assuming a CES aggregator for goods in the utility function and constant returns to scale production function with labor as the sole input, in equilibrium, firm i's desired (log) price is given by:

$$p_{i,t} = p_t + \eta y_t + z_{i,t}, \qquad (5)$$

where $p_{i,t}$ is the (log) of firm i's price, p_t is the aggregate (average) price level, y_t is aggregate output, and $z_{i,t}$ demand shock (a mark-up shock, say).[10] Given real money demand of $m_t - p_t = y_t$, we can rewrite desired price in market i as:

[9] Hercowitz (1982), on the other hand, did not find a statistically significant relationship between monetary shocks and price dispersion (variance of cross-section distribution).
[10] This discussion draws on Chapter 6 in Romer's (2001) textbook.

$$p_{i,t} = (1-\eta)p_t + \eta m_t + z_{i,t}\,. \qquad (6)$$

Note that a monetary shock, keeping aggregate price level fixed, will affect all desired prices in the same direction. If prices are perfectly flexible, normalizing the full information equilibrium output to be zero ($y_t = 0$ and $\sum_i z_{it} = 0$) yields an aggregate price level of $p_t = m_t$. Thus, for flexible prices and full information, all desired (and actual) prices move one-for-one with money shocks—there are no relative price effects.

8.2.1 Calvo-type sticky price model

We take as our benchmark sticky price model a variant of the model developed by Calvo (1983) that has become a workhorse in the sticky price literature. Assume that each month some fraction of firms get to reset the price of their output, while the remainder leave prices unchanged at previous levels. Let $(1-\psi)$ denote the probability that a firm will change its price in a given time period. This probability will also denote the fraction of firms that change prices each period while ψ will denote the fraction of firms that leave their price unchanged. Under this pricing regime, the average duration of a price set by a firm is $\psi/(1-\psi)$.

We assume that firms incur a quadratic cost by having a preset price that deviates from the price that would be chosen if it were free to adjust prices every period. If a firm gets to change its price at date t, it chooses a fixed price $\bar{p}_{i,t}$ to minimize

$$E_t \sum_{j=0}^{\infty} (\Psi\beta)^j (\bar{p}_{i,t} - p^*_{i,t+j})^2 \qquad (7)$$

where β denotes the discount factor and $p^*_{i,t+j}$ is the price that would be chosen in the absence of constraints on the frequency of price changes (equation (6) above). The optimal price $\overline{p}_{i,t}$ is given by

$$\overline{p}_{i,t} = \frac{\sum_{j=0}^{\infty} (\Psi\beta)^j E_t\, p^*_{i,t+j}}{\sum_{j=0}^{\infty} (\Psi\beta)^j} = (1-\Psi\beta) \sum_{j=0}^{\infty} (\Psi\beta)^j E_t\, p^*_{i,t+j}. \tag{8}$$

If firm changes its price in the current period it set its price equal to $\overline{p}_{i,t}$, otherwise its price is $p_{i,t-1}$.

This model implies that monetary shocks will have relative price effects. A monetary contraction will result in relative price changes as some firms change their price and others do not. However, those prices that are changing are moving in the same direction as desired prices are all moving in the same direction (see equation (6)) in response to a monetary shock. This contrasts with our empirical results above.

8.2.2 Sticky information model

The so-called sticky information models starts from the premise that it is difficult (or costly) for agents to gather and process information needed to make fully informed decisions (see for example, Sims (2003)). Woodford (2003), Mankiw and Reis (2002) have argued that sticky information models yield more plausible aggregate price dynamics than the Calvo-type sticky price model. In the context of our analysis, we take as a representative sticky information model a model similar to that of Mankiw and Reis (2002).

In every period, firms are free to set their price equal to the “optimal” price given the information they have available. However, because of frictions in gathering and processing information, firms do not always have up-to-date information. Firms are assumed to update their information in any given time period with a (exogenous) probability, $1-\lambda$. Thus, the proportion of firms with up-to-date information is $1-\lambda$. These firms set their price equal to $p^{*}_{i,t}$ (again given by equation (6)). Firms that have an information set of vintage k set their price equal to $\underset{t-k}{E}\, p^{*}_{i,t}$.

Again, a monetary shock will affect the desired price of all firms who have updated their information in the same way. Relative price movements occur because only a fraction of firms have updated information. However, as all prices changes are occurring in the same direction, the relative price movements are not like those we observed in our empirical analysis.

8.3 Monetary shocks and the desired price

None of the three models described above can capture the kind of quantitative movements in relative prices we see in the data. The reason is that in all three models a monetary shock moves desired prices in the same direction. That close to half of the prices in our data rise in response to a contractionary monetary shock is a puzzle that none of these models can adequately account for.

One interpretation of these results suggests that the source of the relative price movements may in fact be deeper than the fact that some prices can move more frequently than can others—richer microeconomic structure is need. Perhaps, allowing for supply and demand complementarities between goods (in addition to substitutes in

Hercowitz model) might yield richer relative price movements. Input/output relationships between sectors and the distinction between final use as consumption or as investment may lead to richer relative price relationships. For example, in a multi-sector model characterized by input/output relationships, Balke and Nath (2003) show a positive technology shock in capital goods producing sector can look like a demand shifts in other sectors--price and output rise-- while shocks to intermediate goods sectors look more like supply shocks—price falls and output rises.

That a substantial number of the 8-digit PPI prices rise in the short-run in response to a contractionary monetary shock is likely related to the price puzzle that has been identified in the literature (Sims (1992)). Ramey and Barth (2001) have suggested that because of financial market frictions (for example limited participation models) a contractionary monetary shock acts like a cost shock. Firms, who must borrow working capital, see their costs rise as interest rates rise and these in turn result in an increase in prices. However, to get some prices to rise and others to fall, markets (or firms) must differ to the extent to which financial market friction bind. Perhaps, combining heterogeneity in financial market frictions with an input-output structure may yield relative price movements in response to a monetary shock closer to those documented above.

9. Conclusions.

In this paper we characterize the response of over 600 8-digit producer price indices to monetary shocks as identified in a standard VAR framework. We found that monetary shocks have substantial relative price effects. In fact, in the short-run, nearly equal proportions of goods prices show a significant increase as show a significant decrease in response to a contractionary shock. This type of relative price movement is very difficult for standard “macro” models of relative price movements to capture. Most existing models of short run monetary non neutralities that make detailed predictions about the movements of individual prices in response to nominal shocks have all prices moving in the same direction as the shock. Relative price movements are generated by having some prices move more than others. The results reported above suggest that these models are incapable of replicating a key feature of the data. Our findings complement the earlier findings of Bils, Klenow and Kryvtsov (2003) for components of the CPI and pose an important challenge for models of short run monetary nonneutrality.

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Table 1.

Panel A: Proportion of Prices Whose Mean Response is Significantly Negative															
Horizon:	Commodity Group														
Month after shock	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0.59	0.44	0.33	0.25	0.00	0.49	0.39	0.43	0.29	0.34	0.38	0.40	0.33	0.67	0.53
1	0.41	0.44	0.40	0.25	0.00	0.43	0.43	0.57	0.25	0.42	0.36	0.35	0.24	0.33	0.53
6	0.55	0.51	0.50	1.00	0.20	0.38	0.35	0.49	0.27	0.45	0.39	0.31	0.43	0.44	0.42
12	0.77	0.46	0.47	0.50	0.20	0.62	0.43	0.69	0.33	0.50	0.45	0.45	0.57	0.44	0.37
24	0.55	0.54	0.53	0.75	0.00	0.66	0.57	0.74	0.42	0.66	0.60	0.53	0.57	0.11	0.63
36	0.55	0.65	0.65	0.75	0.40	0.79	0.74	0.77	0.65	0.75	0.72	0.65	0.71	0.44	0.42
60	0.45	0.75	0.75	0.75	0.80	0.77	0.83	0.80	0.56	0.65	0.83	0.79	0.86	0.78	0.79

Panel B: Proportion of Prices Whose Mean Response is Significantly Positive															
Horizon:	Commodity Group														
Month after shock	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0.41	0.53	0.62	0.75	0.80	0.47	0.57	0.49	0.69	0.63	0.59	0.55	0.57	0.11	0.47
1	0.50	0.51	0.57	0.50	1.00	0.53	0.48	0.40	0.71	0.54	0.60	0.60	0.76	0.67	0.47
6	0.41	0.49	0.47	0.00	0.80	0.57	0.61	0.46	0.67	0.52	0.56	0.65	0.52	0.44	0.58
12	0.23	0.51	0.50	0.25	0.80	0.36	0.57	0.29	0.62	0.47	0.52	0.47	0.43	0.56	0.58
24	0.36	0.44	0.40	0.25	0.80	0.30	0.39	0.17	0.54	0.30	0.38	0.47	0.33	0.89	0.42
36	0.41	0.28	0.28	0.25	0.40	0.21	0.26	0.20	0.31	0.23	0.23	0.24	0.29	0.44	0.58
60	0.32	0.14	0.15	0.00	0.00	0.15	0.17	0.14	0.33	0.29	0.13	0.16	0.05	0.22	0.16

Notes: Panel A (Panel B) is proportion of prices that can reject one-sided null hypothesis that mean response is positive (negative) with a p-value of 10%.
Commodity groups (with number of prices in commodity group in our sample):
1. Farm Products (22).
2. Processed foods and feeds (57).
3. Textile products and apparel (40).
4. Hides, skins, leather, and related products (4).
5. Fuels and related products and power (5).
6. Chemicals and allied products (47).
7. Rubber and plastic products (23).
8. Lumber and wood products (35).
9. Pulp, paper, and allied products (48).
10. Metals and metal products (110).
11. Machinery and equipment (114).
12. Furniture and household durables (62).
13. Nonmetallic mineral products (21).
14. Transportation equipment (9).
15. Miscellaneous products (19).

Figure 1

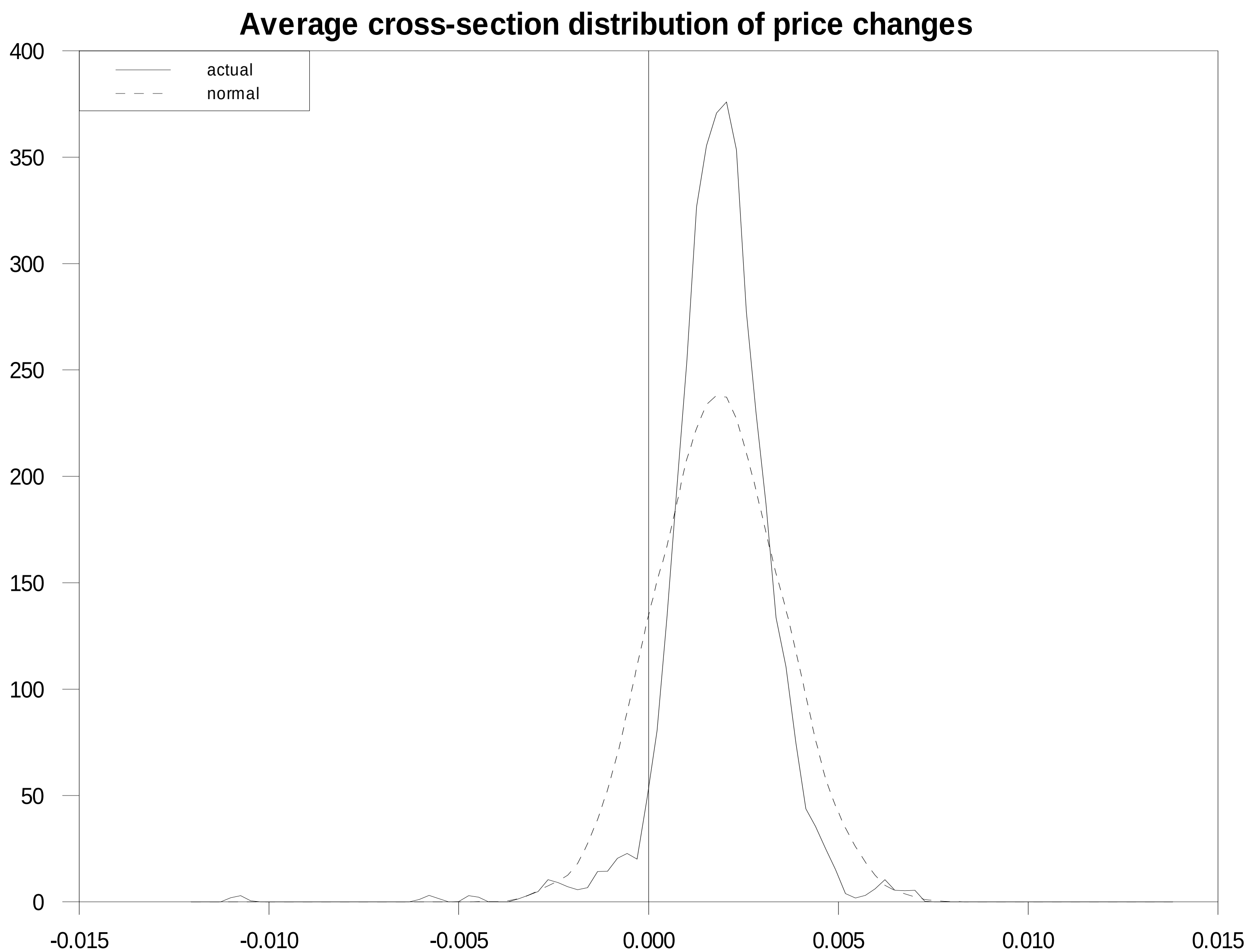

Average cross-section distribution of price changes
400
350
300
250
200
150
100
50
0
actual
normal
-0.015
-0.010
-0.005
0.000
0.005
0.010
0.015

Figure 2.
Time series of selected moments of the cross-section distribution of price changes

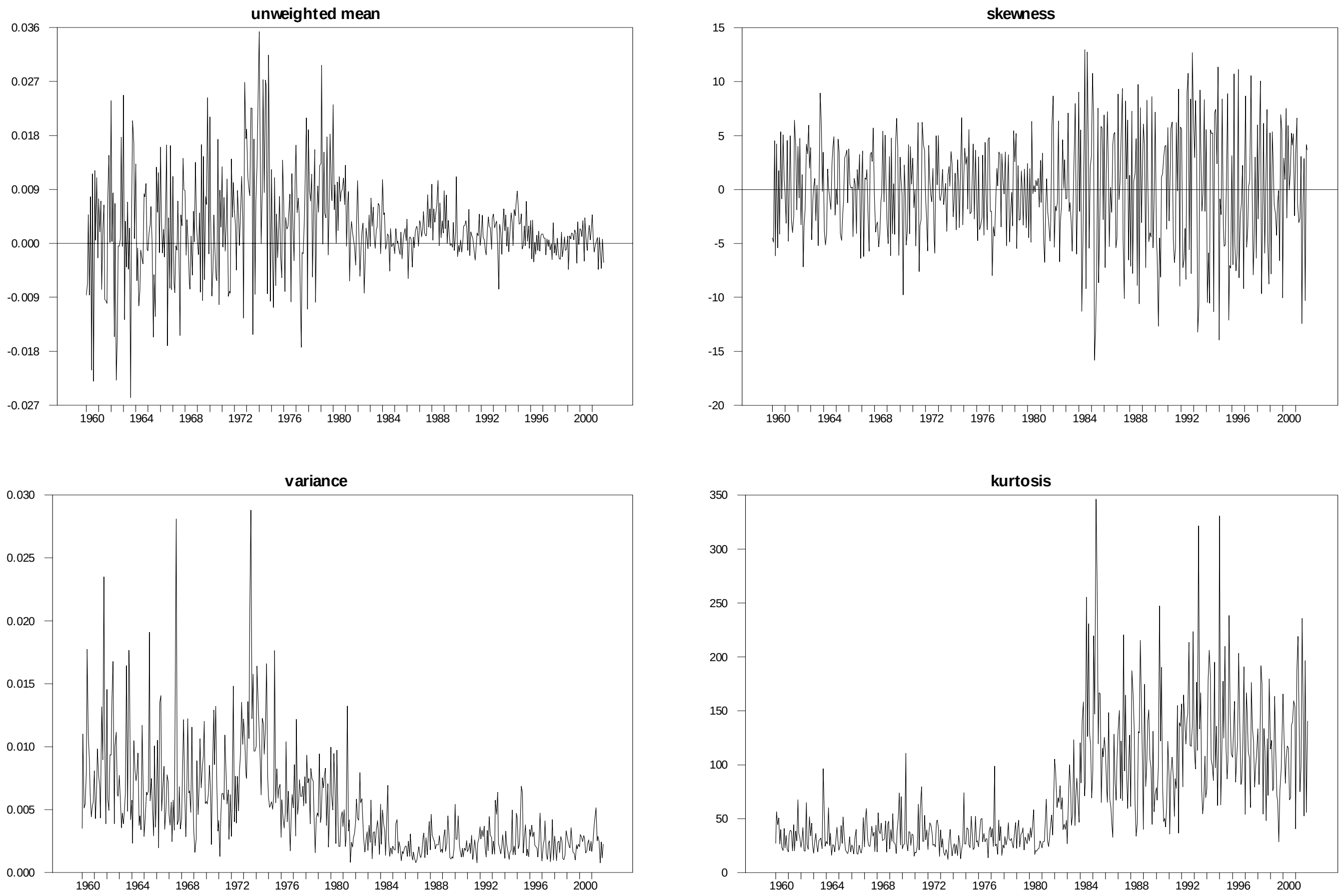


Figure 3.
Response of Output, Prices, Commodity Prices, M2 Money Supply, and Fed Fund Rate to a Contractionary Monetary Shock

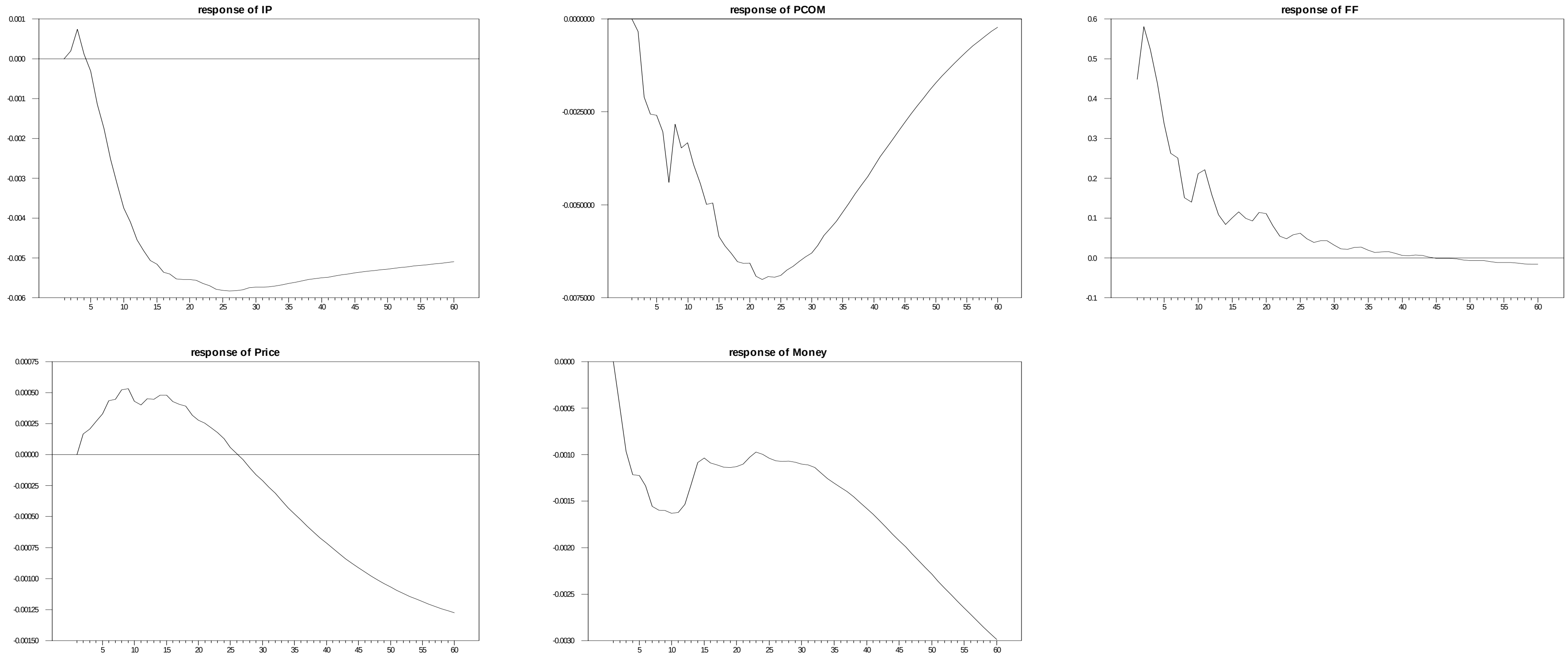


Figure 4
Response of Cross-section Distribution to a Monetary Shock

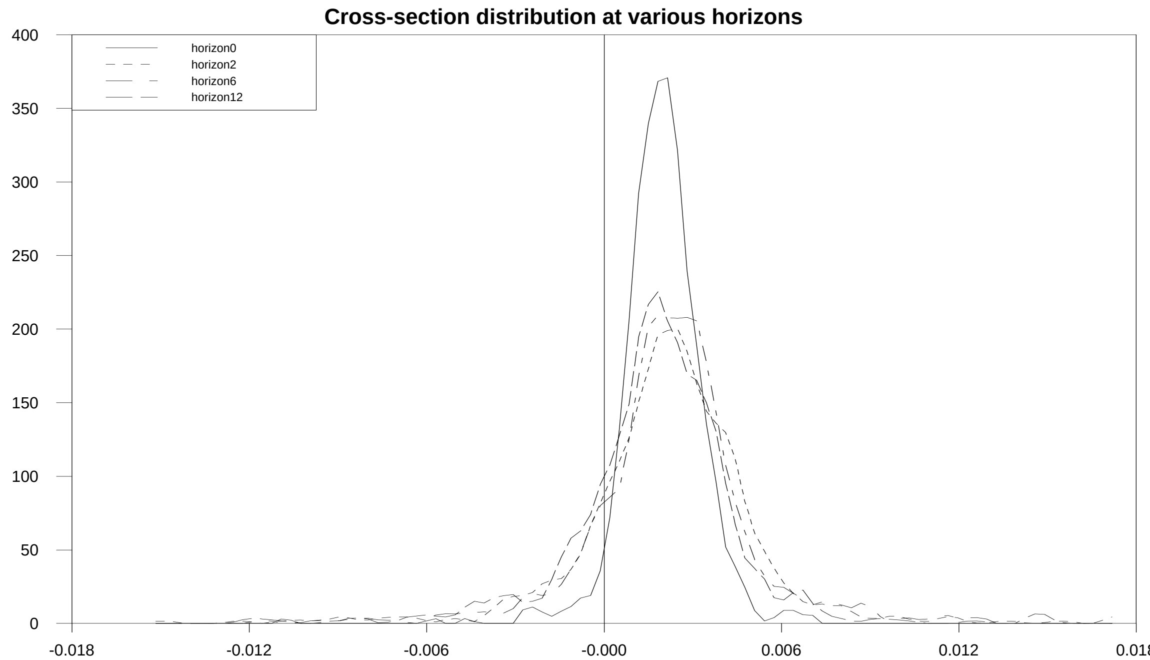


Figure 5
Response of Cross-section Cumulative Distribution to a Monetary Shock

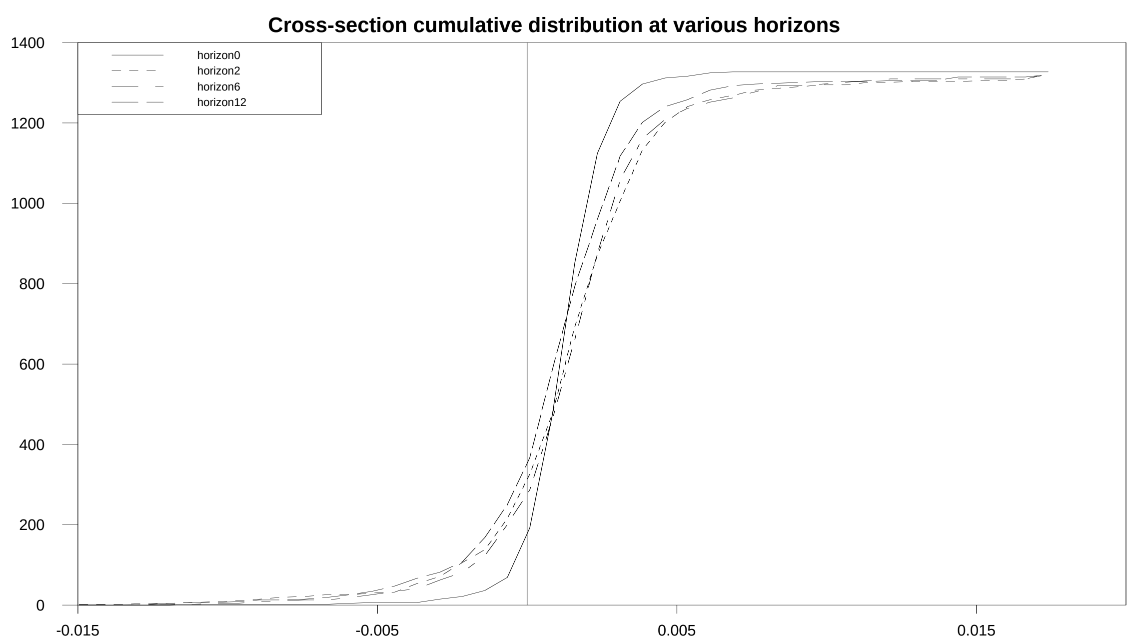


Figure 6.
Response of Selected Moments of Cross-section Distribution of Price Changes to a Monetary Shock
(with 10^{th} and 90^{th} simulated percentiles)

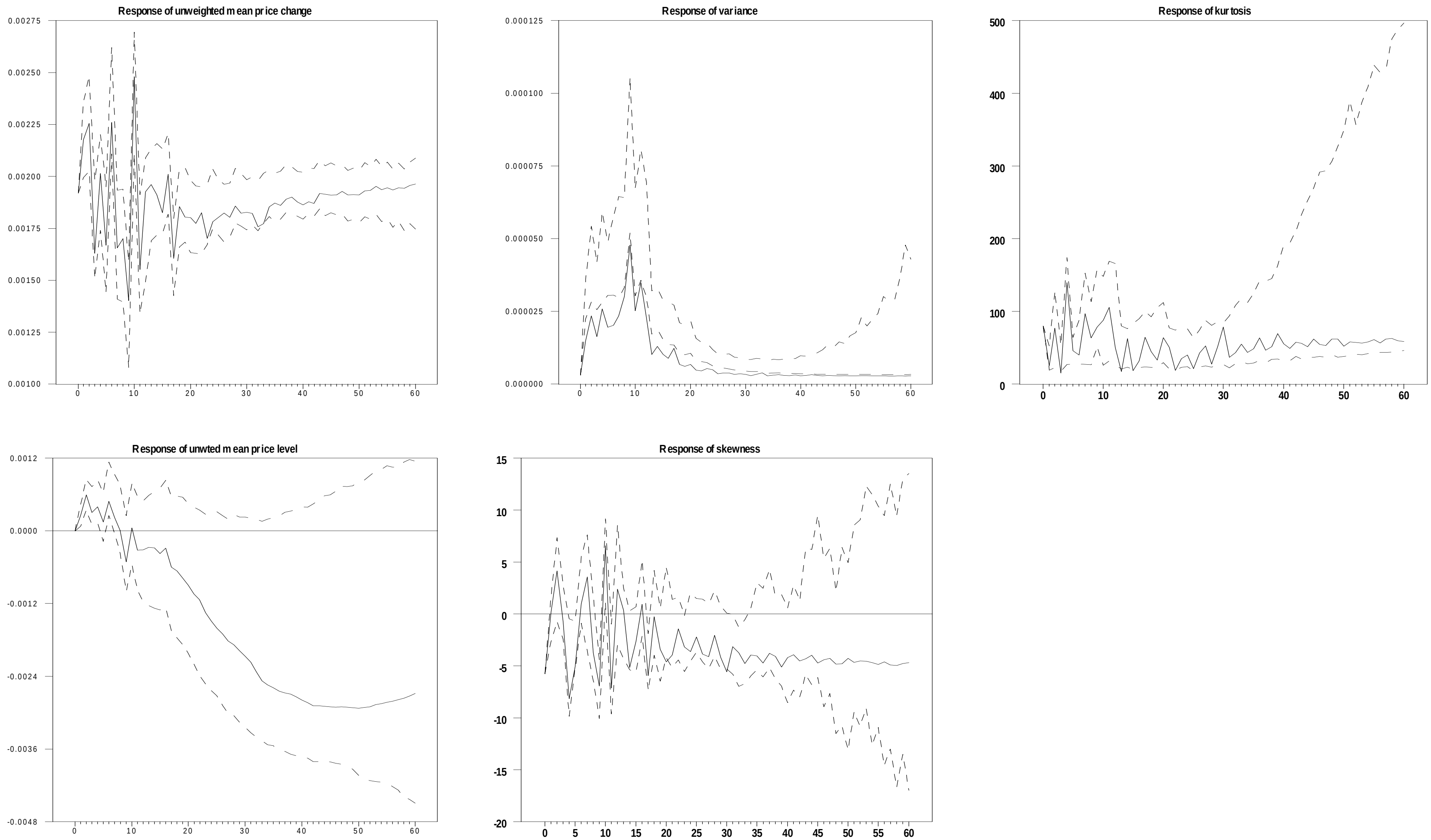


Figure 7
Histograms of accumulated price changes at various horizons

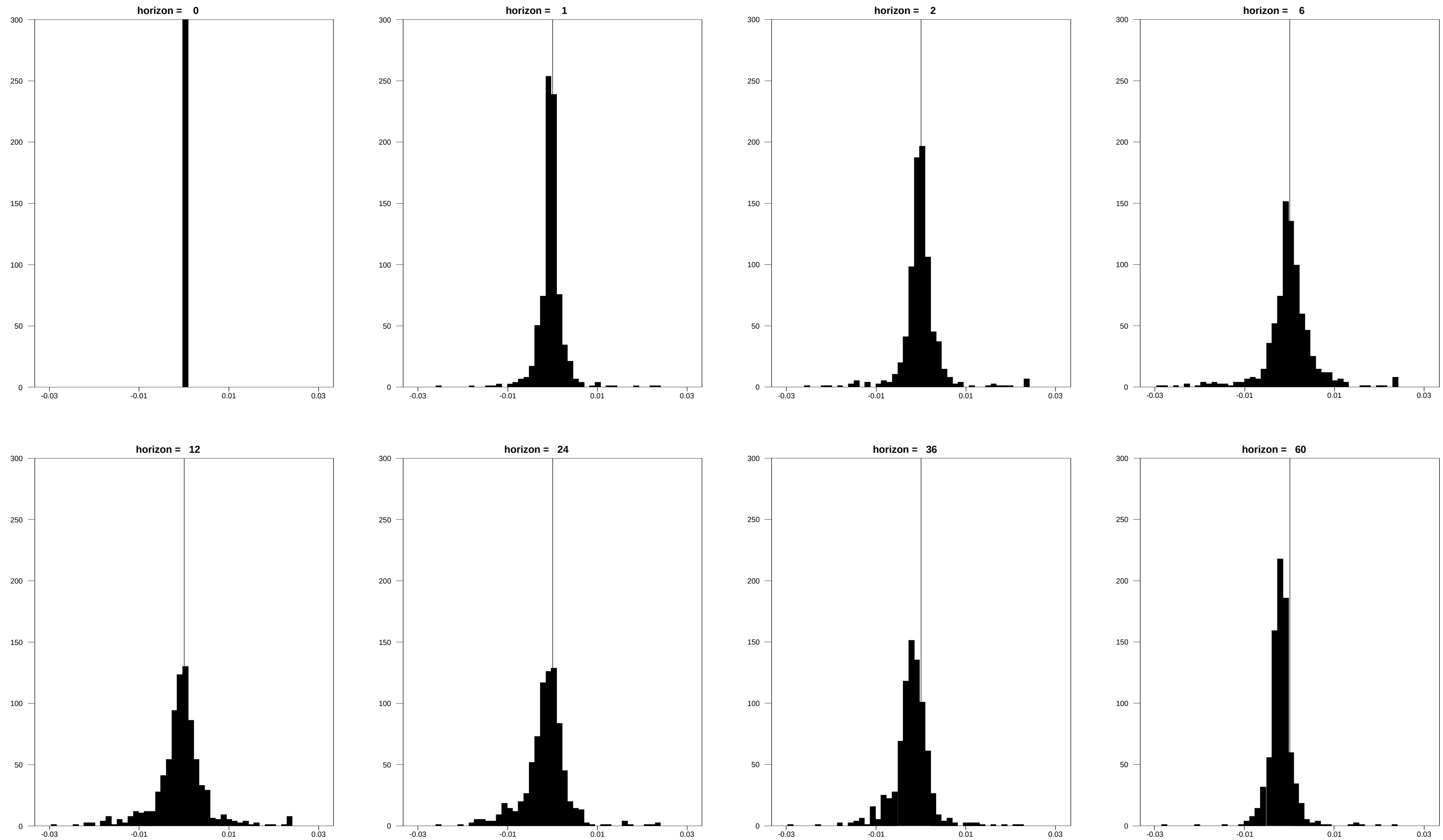
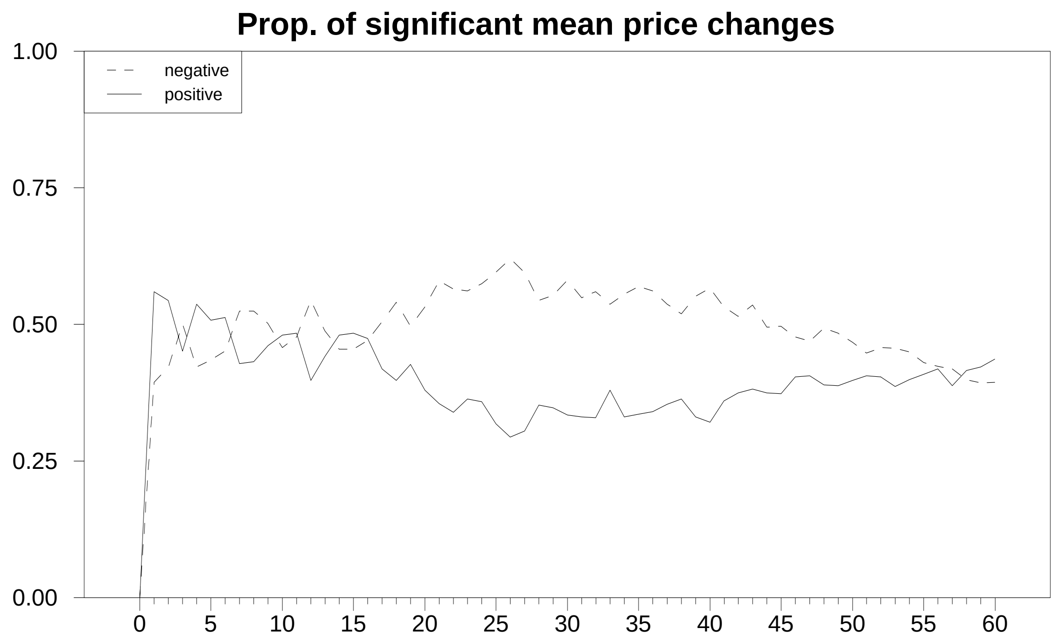


Figure 8.
Proportion of goods whose mean response is significantly positive or negative



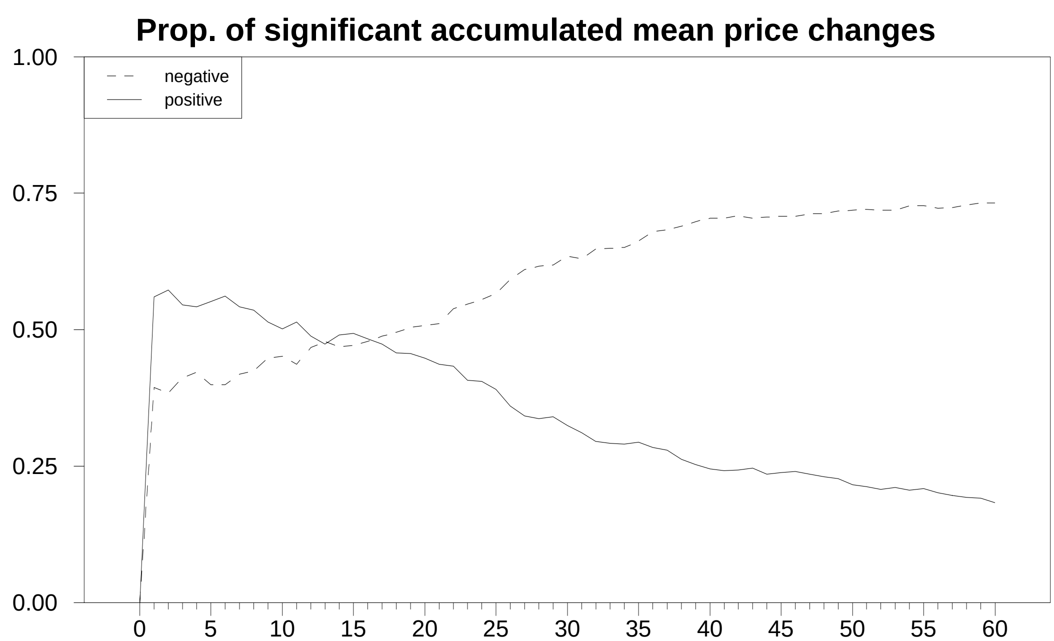
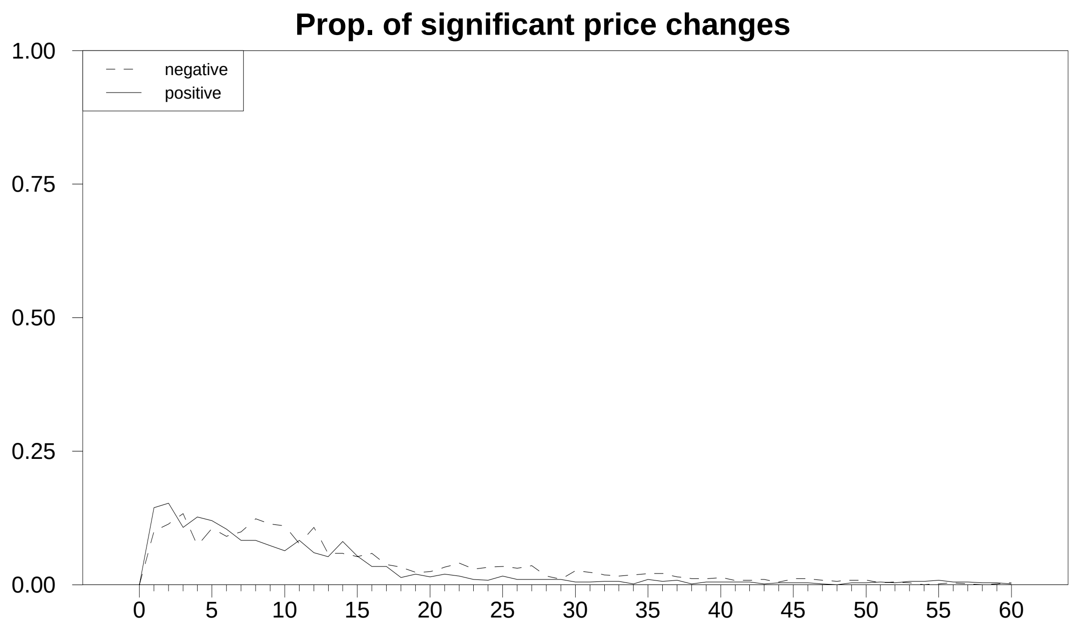


Figure 9
Proportion of goods in which over 90% of simulated responses were positive or negative



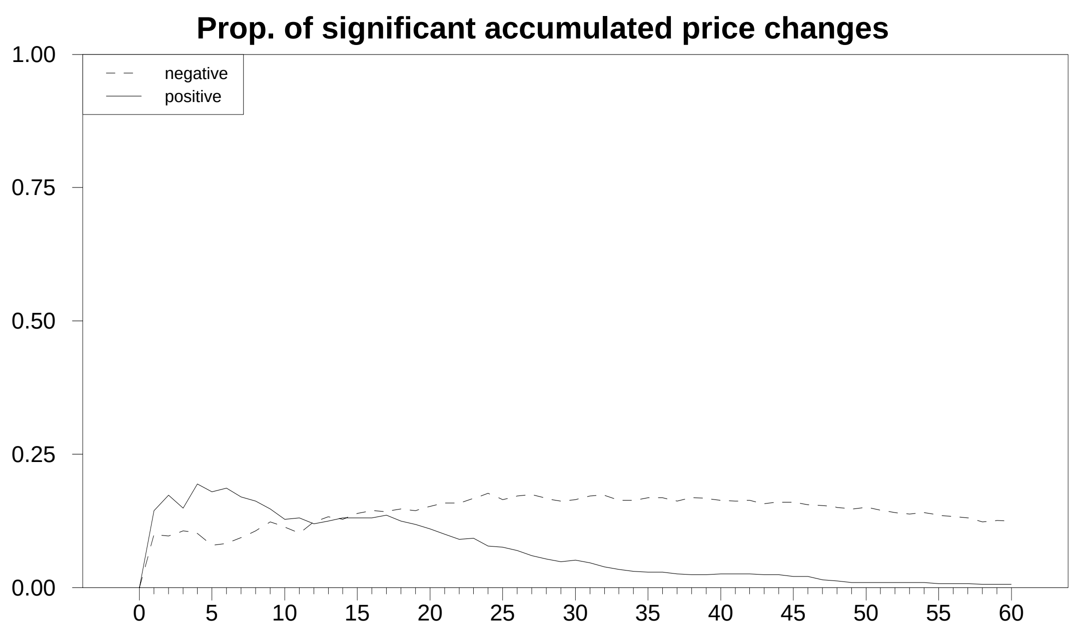
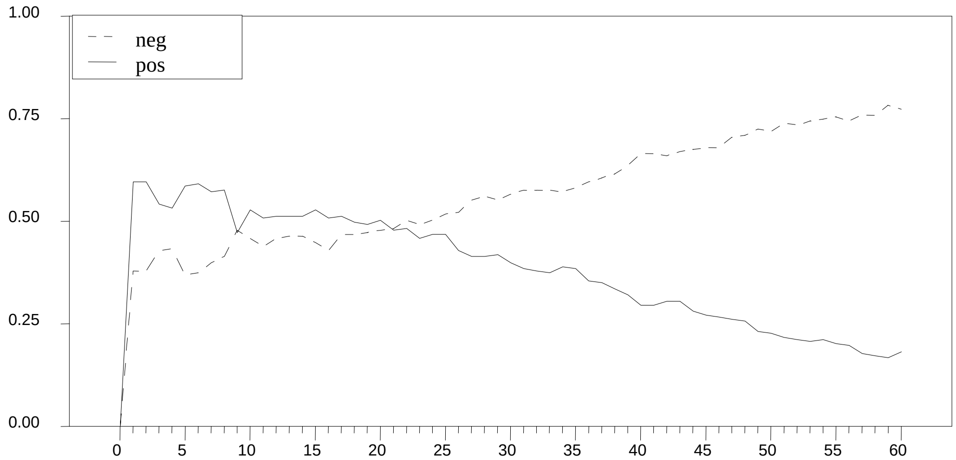
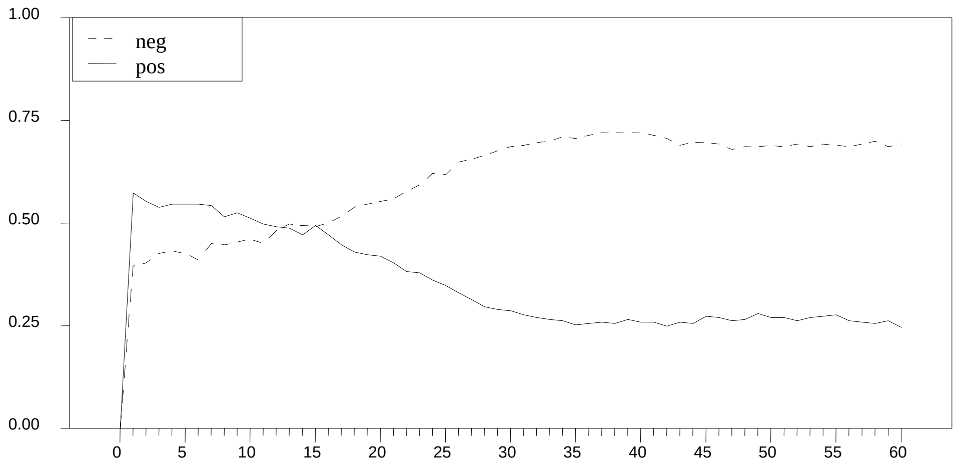


Figure 10.
Proportion of goods by stage of processing whose mean response is significantly positive or negative

Prop. of significant accumulated final goods prices changes



Prop. of significant accumulated inter. goods prices changes



Prop. of significant accumulated crude goods prices

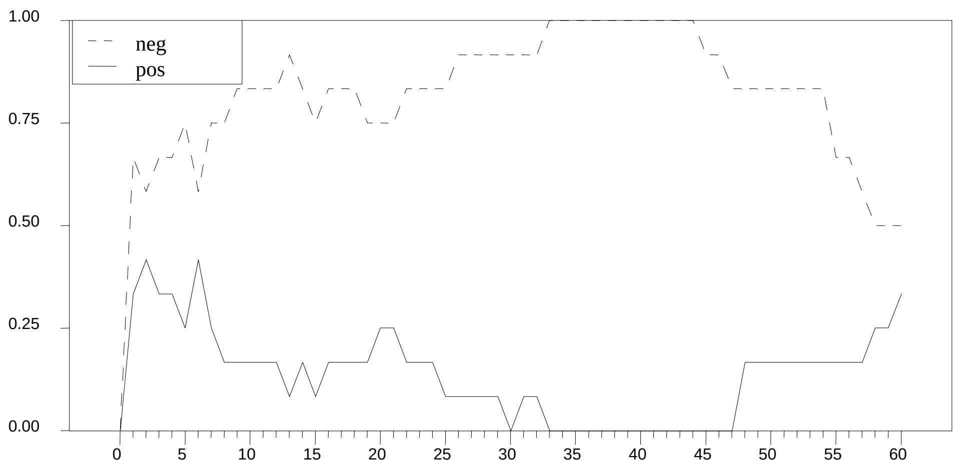


Figure 11.
Proportion of goods prices by stage of processing in which at least 90% of simulated responses are positive or negative

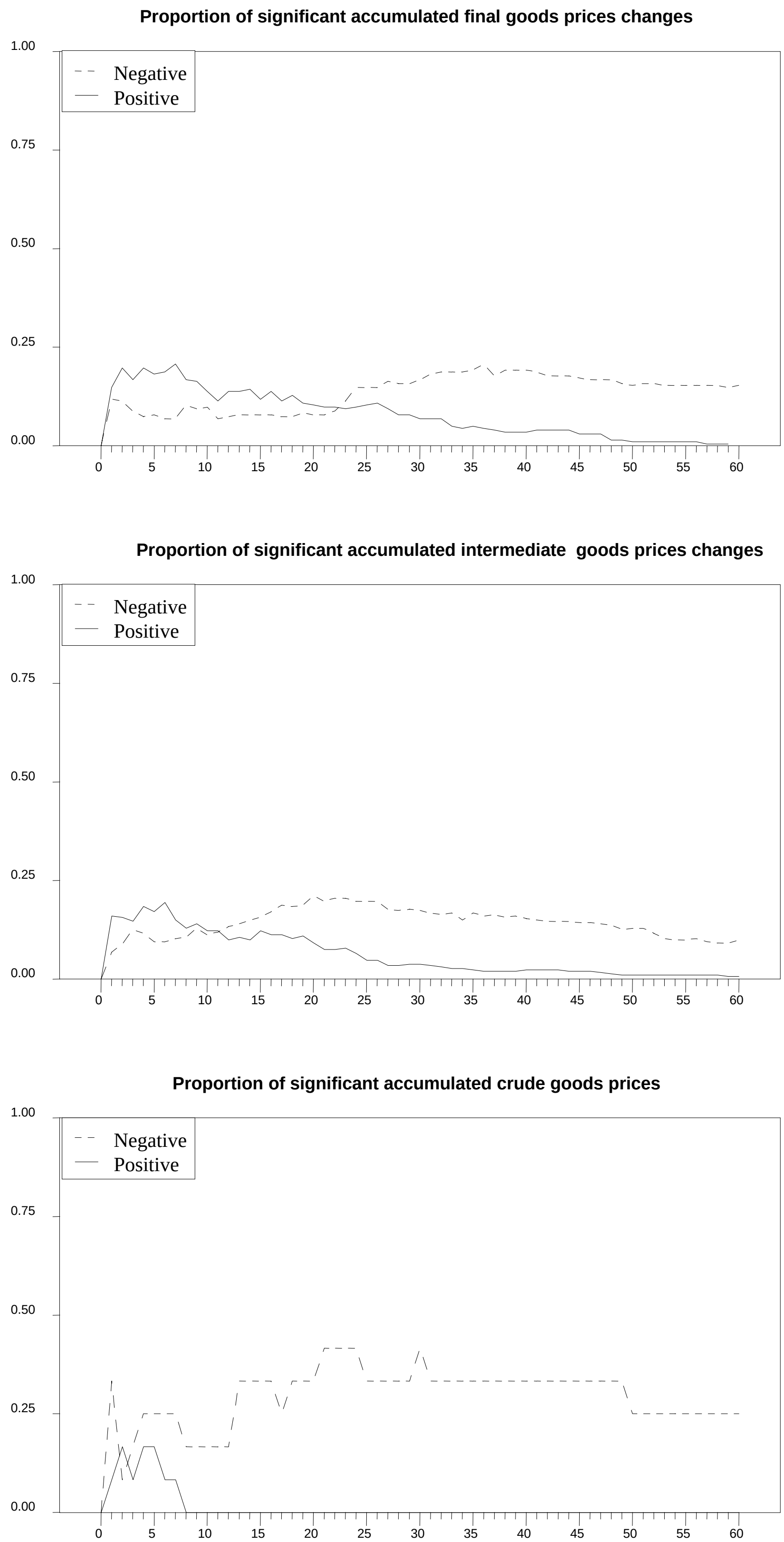
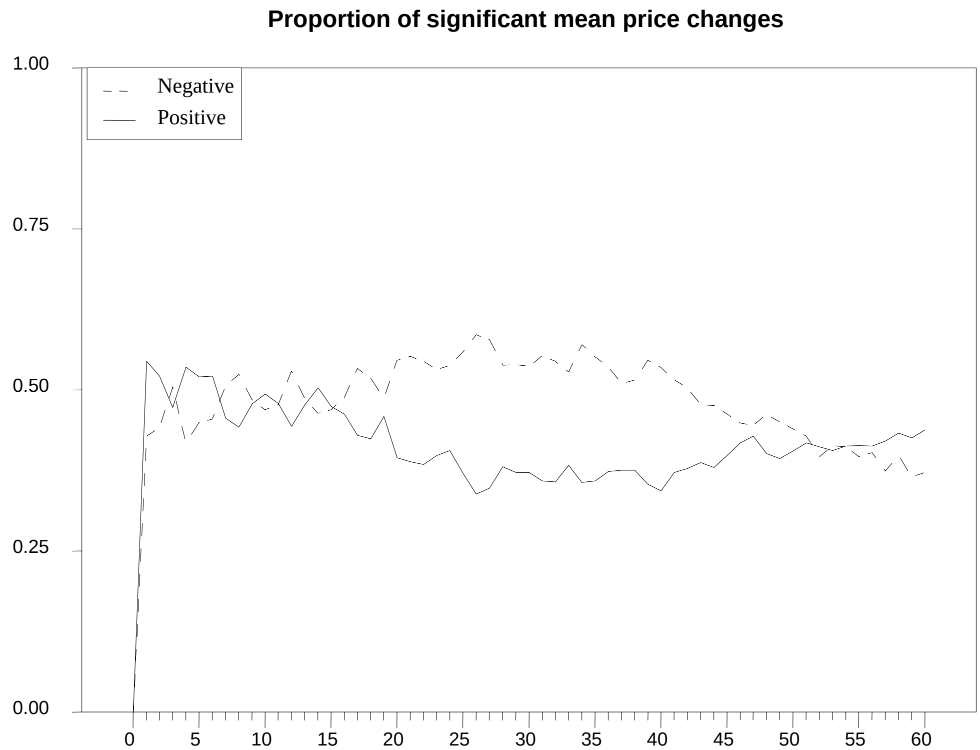


Figure 12
Proportion of goods whose mean response is significantly positive or negative for the model that includes oil price variable in system



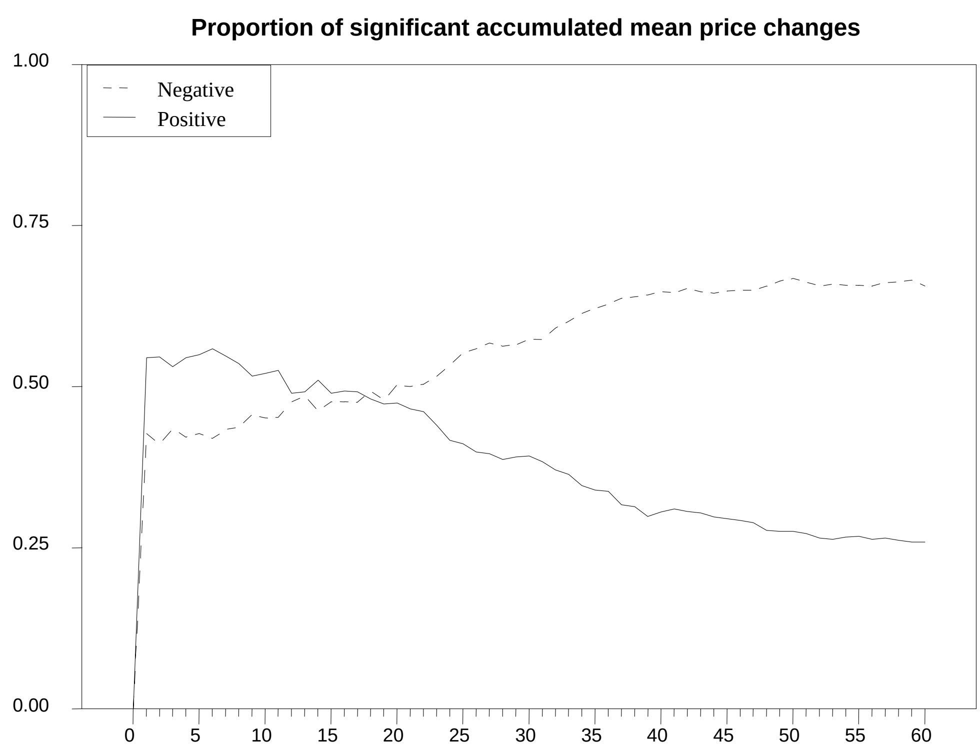
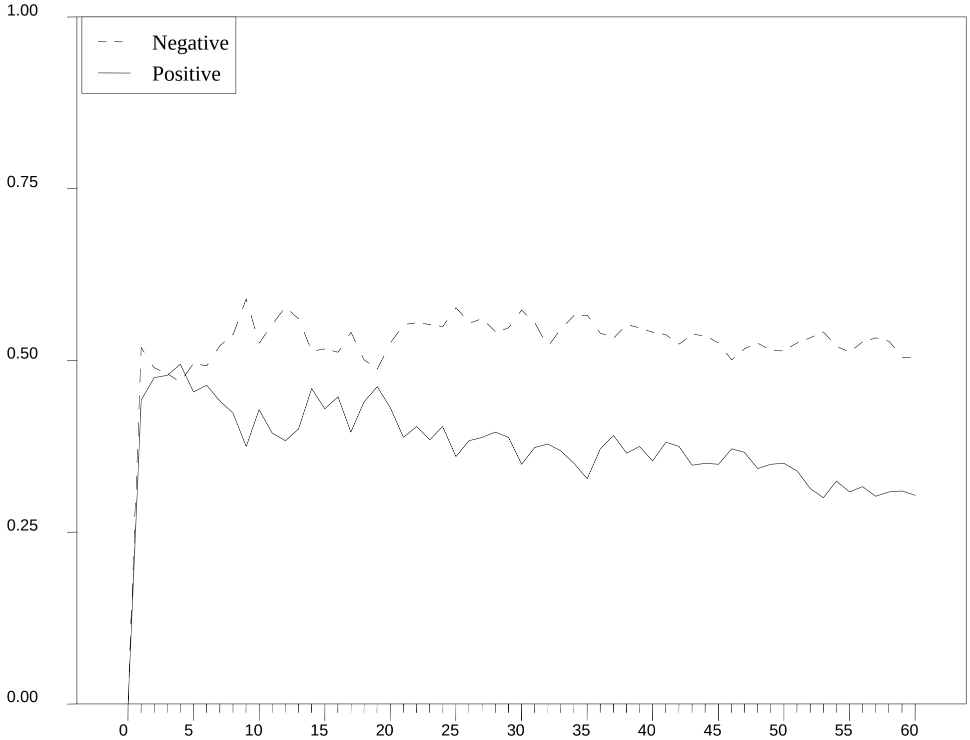


Figure 13
Proportion of goods whose mean response is significant for model in which monetary intervention is captured by Romer dates

Proportion of significant mean price changes



Proportion of significant accumulated mean price changes