Sectoral Effects of Monetary Shocks

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1. Introduction

There has been substantial research at introducing monetary non-neutralities into Dynamic Stochastic General Equilibrium (DSGE) models. These have typically taken the form of either sticky prices (Yun (1994), Chari, Kehoe, McGratten (1999)), sticky wages (Erceg, Henderson, Levin (2001)), or financial market frictions as in limited participation models (Lucas (1990), Fuerst (1992), Christiano, Eichenbaum, and Evans (1997) and (2005)). Most of this literature has focused on trying to generate persistent output (and price) movements in response to a monetary shock similar to those identified in the macroeconomic vector autoregression (VAR) literature.

The relative price implications of monetary shocks and sectoral implications of monetary shocks more generally have received substantially less attention in the DSGE and VAR literature. Most of the empirical literature on relative price variability has focused on the relationship between price dispersion and aggregate inflation, with most studies finding a positive relationship between inflation and dispersion. Only a handful of papers have examined the relative price implications of monetary shocks. Hercowitz (1982) examined whether how the dispersion in cross-section distribution of prices changed in response to anticipated and unanticipated money changes. He finds that money changes do not have a statistically significant effect on the dispersion of the cross-section distribution. Barth and Ramey (2001) examined the response of manufacturing industry output and prices to monetary shocks, as identified from a standard macroeconomic vector autoregression, and found that the effect of a contractionary monetary shock looks like that of a supply shock—price rises and output falls. However, they do not focus on how the responses differ across sectors. Bils, Klenow, and Krystov

(2003) examined how the response of prices differs depending on whether the price is classified as being in a flexible price versus a sticky price. They find monetary shocks have persistent and “anomalous” effects on the relative price of sticky versus flexible price sectors; namely; prices in sectors that are classified as flexible price sectors display evidence of the "price puzzle".[1] Balke and Wynne (2007) find using 8 digit monthly PPI data that monetary shocks have substantial relative price effects as well. Like Barth and Ramey and Bils et al ., Balke and Wynne find that not only does the dispersion of the cross-section distribution of prices increase, but, in response to a contractionary monetary shock, a large percentage of goods prices rise while a slightly smaller percentage of goods prices fall—that is, prices are moving in opposite directions. Lastrapes (2004), using more aggregate price indices than Balke and Wynne but an identification scheme from a macroeconomic vector autoregression that imposes long-run monetary neutrality with respect to aggregate output, finds that monetary shocks have persistent effects on the cross-section distribution of prices but little evidence of a "price puzzle".

Understanding the apparently large relative price effects of a monetary shock has not been adequately addressed with the current generation of DSGE models. First, in most of the DSGE models, either there is a single (final) good or firms/consumers are identical in terms of their tastes and production technology—there are no relative prices for goods. The only relative prices in these models are between leisure and goods (the real wage) and economic activity across time (the interest rate). Second, in models that do have explicit relative price implications such as sticky price models (or sticky information models such as Woodford (2001) and Mankiw and Reis (2002)) where

[1] The price puzzle refers the fact that in many macro VARs the price level appears to rise, at least temporarily, in response to a contractionary monetary shock.

relative price changes occur because some firms change prices and other do not, the mapping between the theoretical model and actual price data is too coarse. Those models have predictions for cross-section distribution of the prices of otherwise identical firms. In the steady state, all firms will have the same price. The data, on the other hand, is typically prices at the industry or commodity level. The data clearly reflect heterogeneity in demand and supply that is not present in the simple models.

In this paper, we extend the literature on the sectoral consequences of monetary shocks in two important ways. First, on the empirical side, we extract an exogenous monetary factor from sector prices, wages, and output data by imposing long-run monetary neutrality for sectoral economic activity. That is, monetary shocks in our framework have no effect on relative prices, real wages, and output in the long-run. We use Bayesian Markov Chain Monte Carlo methods to estimate a common factor model that imposes long-run monetary neutrality for sectoral data.

Second, we build multi-sector DSGE models in which the mapping from the model to the data is exact. Specifically, our models will have predictions about the same prices, wages, and output that were used in our empirical analysis. By using a multi-sector model calibrated to sectoral data, we introduce plausible microeconomic heterogeneity across goods and industries. We do this by allowing goods (and labor supplies) to have different weights in household utility. This reflects that fact that some goods are used primarily for consumption goods while others are used primarily as intermediate inputs. We also allow production technology to differ across industries; that is, the composition of inputs can differ substantially across industries. To this multi-sector model we add the alternative mechanisms for generating monetary nonneutrality that has been the focus in much of the recent literature: sticky prices and limited participation.

2. Empirics: Response of sectoral prices, output, and wages to a monetary shock.

2.1 Identifying Monetary Shocks

In this paper, we use long-run monetary neutrality to identify monetary shocks. By long-run neutrality, we mean that real economic activity is not affected in the long-run as result of an exogenous increase in the stock of money and that all prices move proportionally to money stock in long-run. As we use sectoral data in our analysis, this means that the level of sectoral output is unaffected in the long-run by an exogenous money shock while log sectoral prices, wages and the money stock move one-for-one in the long-run in response to a monetary shock. Long-run monetary neutrality can also imply that nominal interest rates are unchanged in long-run so long as a monetary shock does not change the long-run inflation rate. While long-run monetary neutrality at the macro level has previously been used to identify monetary shocks (Gali 1992, Keating 1992, Lastrapes and Selgin (1995), ours is the first paper to impose those restrictions at a sectoral level.[2] Note, we do not rule out the possibility that other types of shocks, say technological change in financial markets, could affect both real economic activity and the stock of money; however, these type of shocks would not be classified as a "monetary shock".

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[2] Lastrapes (2004), in his analysis of the relative price effects of monetary shocks, uses the long-run identifying assumption that a monetary shock has no effect on aggregate real output in the long-run. However, he does not restrict a monetary shock to have zero relative price effects in the long-run. This

Why long-run neutrality? The short-run effects of monetary shocks are still of substantial debate within the profession; long-run neutrality is less controversial (Lucas 1996). Also, many of the New Keynesian models such as Gali and Gertler (199*) or Mankiw and Reis (2002) and nominal misperceptions model such as Lucas (1972) and Barro (1976) imply long-run monetary neutrality. More importantly, our long-run identification allows a greater coherence between what is called a monetary shock in the data and what is called a monetary shock in the Dynamic General Equilibrium models considered below in Sections 4 and 5. The linearized versions of these models imply long-run monetary neutrality (but not superneutrality), yet the short-run responses can be quite different across models. Our identification of monetary shock is also consistent with the kind of thought experiments typically conducted in the Dynamic General Equilibrium literature: a shock to a stationary exogenous money growth process.

The primary source of data for our analysis is an extended version of the KLEM data set that consists of annual observations on gross output, price and various inputs for 35 sectors of the US economy, originally compiled by Jorgenson, Gollop and Fraumeni (1987). This data set covers the period from 1947 to 1989 and these thirty-five sectors roughly match the 2-digit SIC of the U.S. industries. This data set forms the basis for the calibration of sectoral technology shocks used in our dynamic general equilibrium model below. In our application, we use log M2 as a measure of money stock and three month T-bill as our interest rate variable.

To achieve identification, we require that the money stock, sectoral prices, and sectoral wages to be integrated of at least order one (or I(1)). That is, there must be

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yields in something of a contradiction in that overall aggregate real economic activity in the long-run is unaffected by a monetary shock but sectoral activity could be.

permanent shocks to the money stock, prices and wages in order to use long-run monetary neutrality to identify a monetary factor. For our data, the assumption of nonstationary money stock, prices and wages is uncontroversial. While it is not necessary for our identification scheme that sectoral outputs to be integrated of order one, we model sectoral output and (implicitly) real wages as I(1) as well.[3] Nominal interest rates (here 3 month t-bill) are arguably I(0) and we model them as such. This means that interest rates will not play a role empirically in our identification of the monetary component.

2.2 Common factor model.

As we have price, output, and nominal wage in 35 sectors, it is not possible to estimate a VAR to these data. What we do instead is to estimate a common factor model. One of these common factors we will interpret as a "monetary" factor. This factor will exhibit long-run neutrality for sectoral prices and wages, and sectoral output. Other than the long-run effect of the monetary factor, we want the rest of the model to be relatively flexible. Most importantly, we place no constraints on the short-run response of prices, wages, and output to a money shock.[4] We do allow for other aggregate factors that can affect sectoral output, prices, and wages; these factors along with the monetary factor will

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[3] For all thirty-five sectors, standard augmented Dickey-Fuller tests (with constant and time trend) fail to reject unit root in log prices and log wages while for log output the unit root null is rejected in only ten sectors.

[4] Common factor models have been applied to disaggregated price movements before, for example Bryan and Cecchetti (1995) and Nath (2003). However, these papers only examine sectoral prices not sectoral output and wages. Furthermore, Nath does not explicitly tie a common factor to a monetary component while Bryan and Cecchetti (1995) estimate a common factor model with a common monetary factor but they impose strong restrictions on the short-run response of prices to the monetary component—they move one-for-one with the monetary factor. Similarly, Quah and Sargent (199*) apply common factor model to … Norrbin and Schlagenhauf (1988) extract common factors from regional and 1-digit SIC industry

capture all the co-movement in the data across sectors. We also allow for sector specific shocks that affect sectoral output, prices, and wages in that sector but not in other sectors. In our empirical work, we will place fairly strong priors on the initial response of the interest rate to a monetary shock so that the interest rate response to a positive monetary shock is negative. It turns out that this prior will not be quantitatively important for our estimates of the sectoral responses to a monetary shock.

Formally, our common factor model is described by:

(2.1a) $$\Delta y_{i,t} = A_{i,y,y}(L)\,\Delta y_{i,t-1} + A_{i,y,p}(L)\,\Delta p_{i,t-1} + A_{i,y,w}(L)\,\Delta w_{i,t-1} + H_{i,y,m}(L)\,\Delta s_{m,t} + \sum_{j=1}^{J} H_{i,y,j}(L)\,s_{j,t} + e_{i,y,t}, \quad i = 1,\ldots, I$$

(2.1b) $$\Delta p_{i,t} = A_{i,p,y}(L)\,\Delta y_{i,t} + A_{i,p,p}(L)\,\Delta p_{i,t-1} + A_{i,p,w}(L)\,\Delta w_{i,t-1} + H_{i,p,m}(L)\,\Delta s_{m,t} + \sum_{j=1}^{J} H_{i,p,j}(L)\,s_{j,t} + e_{i,p,t}, \quad i = 1,\ldots, I$$

(2.1c) $$\Delta w_{i,t} = A_{i,w,y}(L)\,\Delta y_{i,t} + A_{i,w,p}(L)\,\Delta p_{i,t} + A_{i,w,w}(L)\,\Delta w_{i,t-1} + H_{i,w,m}(L)\,\Delta s_{m,t} + \sum_{j=1}^{J} H_{i,w,j}(L)\,s_{j,t} + e_{i,w,t}, \quad i = 1,\ldots, I$$

(2.1d) $$\Delta m_{t} = A_{m,m}(L)\,\Delta m_{t-1} + A_{m,r}(L)\,r_{t-1} + H_{m,m}(L)\,\Delta s_{m,t} + \sum_{j=1}^{J} H_{m,j}(L)\,s_{j,t} + e_{m,t}$$

(2.1e) $$r_{t} = A_{r,m}(L)\,\Delta m_{t-1} + A_{r,r}(L)\,r_{t-1} + H_{r,m}(L)\,\Delta s_{m,t} + \sum_{j=1}^{J} H_{r,j}(L)\,s_{j,t} + e_{r,t}\ .$$

where $A_{i,\bullet,\bullet}(L) = \sum_{k=0}^{K} a_{k,i,\bullet,\bullet} L^k$ and $H_{i,\bullet,\bullet}(L) = \sum_{n=0}^{N} h_{n,i,\bullet,\bullet} L^n$ are lag polynomials for sector i. $\Delta s_{m,t}$ represents the growth rate (log first differences) of the common monetary factor

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employment and industrial production data but do not include sectoral prices and wages nor do they impose long-run monetary neutrality on a monetary factor.

while $s_{j,t}$ represents other the common factors. These common factors are assumed to be orthogonal and will capture all the co-movement of output, prices and wages across sectors. We assume that the idiosyncratic shocks ($e's$) to sectoral output, prices, and wages as well as to money growth and the nominal interest rate are orthogonal as well. We further assume that sectoral variables have no direct effect on the aggregate money stock or interest rate.

The assumption of long-run neutrality implies the following restrictions:

(2.2a) $A_{i,y,p}(1) + A_{i,y,w}(1) + H_{i,y,m}(1) = 0$

(2.2b) $A_{i,p,p}(1) + A_{i,p,w}(1) + H_{i,p,m}(1) = 1 \qquad i = 1,..., I$

(2.2c) $A_{i,w,p}(1) + A_{i,w,w}(1) + H_{i,w,m}(1) = 1$.

(2.2d) $A_{m,m}(1) + H_{m,m}(1) = 1$.

These restrictions ensure that in the long-run (log) price and wages in all sectors and the money stock move one-for-one with the monetary factor, $s_{m,t}$, while sectoral output is unchanged. Note that because the nominal interest rate is modeled as stationary, shocks to the monetary factor will not have a long-run effect on nominal interest rates.

Note that the specification of (2.1a)-(2.1e) does not rule out the possibility that other types of shocks (including shocks to the other common factors) can have permanent effects on sectoral output, prices, and wages; we only place restrictions on the long-run effects of money shocks. As we are primarily interested in identifying the effects of monetary shocks, we impose a triangular contemporaneous structure between sector i output, prices, and wages. While the sectoral shocks, e_i's, do not have clear economic interpretations, the simple triangular structure in (2.1a)-(2.1c) allows us to capture any sector specific co-movement in output, price, and wage not captured by the common (across sectors) factors.

We assume that the common factors themselves follow stationary univariate AR(2) processes with independent shocks. Thus, we can write the model in state space form:

(2.3) $Y_t = A(L)Y_t + HS_t + E_t$

(2.4) $S_t = FS_{t-1} + V_t$

where

$$Y_t = \left(\Delta y_{1,t}\ \Delta p_{1,t}\ \Delta w_{1,t} \quad \cdots \quad \Delta y_{35,t}\ \Delta p_{35,t}\ \Delta w_{35,t} \quad \Delta m_t \quad r_t\right)',$$

$$E_t = \left(e_{1,y,t}\ e_{1,p,t}\ e_{1,w,t} \quad \cdots \quad e_{35,y,t}\ e_{35,p,t}\ e_{35,w,t} \quad e_{m,t} \quad e_{r,t}\right)',$$

$$S_t = \left(\Delta s_{m,t}\ s_{1,t} \cdots s_{J,t} \quad \Delta s_{m,t-1}\ s_{1,t-1} \cdots s_{J,t-1} \quad \cdots \quad \Delta s_{m,t-N}\ s_{1,t-N} \cdots s_{J,t-N}\right)',$$

$V_t = \left(v_{m,t}\ v_{1,t} \cdots v_{J,t} \quad 0 \cdots 0 \quad \cdots \quad 0 \cdots 0\right)'$, and

$$F = \begin{pmatrix} \begin{matrix}\rho_{m,1} & & & \\ & \rho_{1,1} & & \\ & & \ddots & \\ & & & \rho_{J,1}\end{matrix} & \begin{matrix}\rho_{m,2} & & & \\ & \rho_{1,2} & & \\ & & \ddots & \\ & & & \rho_{J,2}\end{matrix} & 0_{J+1,(J+1)(N-2)} & 0_{J+1,(J+1)} \\ I_{J+1} & 0_{J+1,J+1} & 0_{J+1,(J+1)(N-2)} & 0_{J+1,(J+1)} \\ 0_{J+1,J+1} & I_{J+1} & 0_{J+1,(J+1)(N-2)} & 0_{J+1,(J+1)} \\ 0_{(J+1)(N-2),J+1} & 0_{(J+1)(N-2),J+1} & I_{(J+1)(N-2)} & 0_{(J+1)(N-2),(J+1)} \end{pmatrix}.$$

The factor loading matrix, H, reflects the restrictions given in equations (2.2a)-(2.2d). $E_t \sim N(0, R)$, where R is a diagonal matrix, and $v_{m,t} \sim N(0, \sigma^2_{s_m})$. To fix the scale of the additional common factors we assume $v_{j,t} \sim N(0,1)$ for j=1, …, J. Similarly, we set the initial factor loadings in the interest rate equation for the non-monetary common factors to be positive ($h_{0,r,j} > 0$ for $j = 1,...,J$).

Given there are 35 sectors in our data, the observation "equation" (2.3) consists of 107 equations. We set the number of common factors to be five: one monetary factor and four other common factors. With the exception of the M2 money growth equation, we set the number of lags in the $A(L)$ matrix to two and the number of lags of the common factors to four. In the M2 money growth equation, we set $A_{m,m}(L) = A_{m,r}(L) = 0$ and $H_{m,m}(L) = 1$. This implies that changes in the monetary factor affect M2 money growth one-for-one and with no delay. We allow the monetary factor to have a direct effect on interest rates but no indirect effect, i.e. $A_{r,m}(L) = 0$. All the data is demeaned prior to estimation.

2.3 Bayesian Estimation of Common Factor Model.

We take a Bayesian approach rather than the more standard maximum likelihood method to estimate the model. By using Markov Chain Monte Carlo methods, here the Gibbs sampler, we can break up a rather large problem into a number of smaller, but computationally tractable, problems by sequentially drawing a parameter from its conditional distribution given all the other parameters (and unobserved states). In fact, the linear structure of the model and standard conjugate priors make it very easy to write posterior conditional distributions. Even the restrictions implied by equations (2a-2d) can be handled fairly easily. If the common factors were known, it is straightforward to rewrite equations (1a-1e), imposing the restrictions given by (2a-2d), so that resulting equations are linear equations with no restrictions on parameters (see appendix A).

Because the model above is stationary, parameter draws that result in the roots of A(L) and F being outside the unit circle are rejected and are redrawn. Finally, by treating unobserved common factors like parameters, we can obtain the joint posterior distribution of the parameters and unobserved states. The empirical estimate of the posterior distribution is based on 5000 draws from the Gibbs sampler with a start-up period of 50,000 draws. See appendix A3 for a detailed discussion of the Gibbs sampler.

2.4 Prior distributions

For nearly all the parameters in the model we use relatively neutral and uninformed priors for parameters of the A(L), H, F, R, and Q matrices (see appendix A2). While our identification of monetary shocks imposes long-run neutrality, we may want to use some prior information on the short-run responses of monetary shocks as well. That is, we may want our prior distribution of output, price, and interest rate responses to a monetary shock in the short-run to correspond qualitatively to those typically seen in the VAR identifications. We can achieve this by setting the priors for the coefficients on the monetary factor in the interest rate, output, price and wage equations. Because the response of sectoral outputs, prices, and wages to a monetary shock and are complex nonlinear functions of the underlying parameters in the state space model, we plot the implied prior distribution for the impulse responses to a money shock in Figure 1. From Figure 1, we observe that the means of the prior distributions of sectoral output and price (and wage) responses to a monetary shock are positive while the mean of the prior distribution for the nominal interest rate response is negative. With the exception of the nominal interest rate, the variances of the prior distributions are set so that a wide range of sectoral responses are possible—it is quite possible for an individual sectoral price or output to fall in response to a monetary shock. The aggregate responses (or unweighted mean response across sectors) suggest the standard responses to a monetary shock—aggregate price, output, and real money supply rise and nominal interest rate falls. In appendix A2, we also discuss an alternative set of priors which correspond to short-run monetary neutrality.[5]

3. Empirical Results.

Figure 2, panel A displays the mean of the posterior distribution for monetary factor along with the 10th and 90th percentiles. For reference, in panel B, actual M2 growth is displayed as well as the simple average of the growth rates of prices for the thirty-five sectors in our sample. The monetary component we obtain from the common factor model appears to capture much of the same low frequency movements present in prices and M2 money growth (as it was designed to do). We observe a general drift up in growth on the monetary component in the sixties, seventies and early eighties and the drift back down in the eighties. We take the estimated monetary factor to be a plausible description of (long-run) inflation over the sample.

Figure 3 displays the impulse response of the unweighted mean (across sectors) of sectoral prices, output, and wages. M2 money growth, and the interest rate to a one standard deviation shock in the monetary factor. From the figure, we observe that the mean of the cross-section distribution of prices rises in response to an expansionary

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[5] As the responses in Figure 1 represent the response to a unit shock in the monetary factor $(v_{m,t} = 1)$, these responses do not reflect uncertainty about the size of a typical monetary shock, σ_m. The responses below and their percentiles do reflect this uncertainty about the value of σ_m.

monetary shock. Unlike some of the other non long-run identification schemes, we find no evidence of a price puzzle. Perhaps this is not too surprising given our identifying assumptions, but recall these assumptions did not preclude finding a price puzzle. Mean output across sectors rises as well and we do observe a slight "hump" shaped response for aggregate output typically seen in the literature. Aggregate nominal wages also rise as does the implied real wage. The aggregate inflation response (as opposed to the aggregate price response) is positive as expected and hump shaped, peaking two to three years after initial monetary shock. The nominal interest rate falls in the initial period but rises thereafter while the real money supply ($-(p_t - m_t)$) rises in response to an expansionary monetary shock.[6] The ex post real interest rate also falls and its decline is longer lasting the decline in the nominal interest rat. Thus, an expansionary monetary shock is accompanied in the short-run by an increase in the aggregate price level, output, wage, nominal and real money stock, and by a decline in nominal and real interest rates. In the long-run of course, given our identifying assumptions, a monetary shock increases prices, wages, and the money stock one-for-one and the output, real wage, and interest rate response is zero.

Turning to what happens at the sectoral level, Figure 4 displays histograms for the the posterior means of the sectoral price responses to a monetary shock. Figure 4 suggests that monetary shocks do indeed have relative price effects. These relative price effects despite being zero in the long-run are still quite persistent. Even after five years there has been a substantial change in the cross-section distribution of prices. After 10

[6] Unlike prices, output, and wages, our specification of the prior has an important affect on the posterior distribution of the interest rate response and the response of the real money supply. When we use the alternative prior of short-run monetary neutrality, the mean of the posterior distribution for the initial interest rate response is positive and real money supply response is negative.

years, though diminished, relative price effects are still present. The cross-section distribution of nominal wages is also affected by monetary shock though to a slightly lesser extent than prices (see Figure 5). Again, this effect persists for several years decreasing gradually so that by twenty years after the shock the distributional effects are substantially diminished.

From Figure 6, the effect of a monetary shock on the cross-section distribution of output is substantial as well. The initial effect is to shift the mean of the cross-section of output to the right as well as increase the dispersion. Gradually the distribution shifts back to the left so that it is centered around zero, but the dispersion persists longer. Thus, while the aggregate output response is “close” to zero after five years, sectoral output responses are still present. Similarly, the effect on the dispersion of sectoral real wages is substantial (see Figure 7), with a slight shift of the distribution to the right (increase in real wage). In sum, these results suggest that the effect of a monetary shock can vary substantially across sectors and that these distributional effects can be quite persistent.

The effect on the cross-section distribution can be summarized by examining the dispersion in the cross-section distribution. Figure 8 plots the variance of the cross-section distribution of price, output, nominal wage, and real wage responses to a monetary shock. The increase in dispersion for the sectoral prices, output, and wages are of similar magnitudes. For real wages the increase in dispersion is larger than the other variables. For all the variables, the effect on the dispersion peaks after four years and then gradually diminishes. Recall that by definition effect on dispersion in the long-run is zero.

What sectors are most affected? We classify industries according to whether they are used primarily as a consumption good, an investment good, or an intermediate good (see Figure 9). It turns out that prices for the intermediate and investment good sectors tend to respond slightly more than for the consumption good sector, although only the difference between intermediate and consumption good responses are statistically significant at the 10% level and only for the first few years. The output response of all three goods is positive with perhaps intermediate goods having the greatest response.

Table 1 presents the initial period price and output responses to a monetary shock for all thirty-five sectors. Perhaps not surprisingly, sectors with large price tend to have smaller output responses and sectors with large output responses tend to have smaller price responses; the correlation between price and output responses across sectors was, -0.17.

4. Multi-sector models with monetary nonneutralities.

Given that we find substantial relative price, output, and wage effects across sectors in response to a monetary shock, it would be interesting to examine the implications for sectoral economic activity of multi-sector versions of recent DGE models with monetary frictions. In this section, we examine a model that is essentially a multi-sector model of Christiano, Eichenbaum, and Evans (1997). We extend their model to include thirty-five sectors that differ in their output use, some are used primarily as consumption goods and others primarily as materials inputs, and in their usage of inputs. Like Christiano et al, we abstract from capital accumulation in this model in order to keep the number of state variables in the system small.

4.1 Households.

Household utility is given by

$$(4.1) \quad \sum_{i=0}^{\infty}\beta^{i}U(c_{t+i}, l_{t+i})$$

where $c_t = C(c_{1,t}, \ldots, c_{J,t})$ is a composite consumption good made of goods from various sectors, $c_{j,t}$, and $l_t = 1 - N(n^h_{1,t}, \ldots, n^h_{J,t})$ is a composite good that reflects household preference for leisure and which allows disutility of work to differ across sectors.

Here we use CES aggregators to describe the composite goods:

$$(4.2) \quad C(c_{1,t}, \ldots, c_{J,t}) = \left(\sum_{j=1}^{J}\theta_j c_{j,t}{}^{1/\rho}\right)^{\rho},$$

$$(4.3) \quad N(n_{1,t}, \ldots, n_{J,t}) = \left(\sum_{j=1}^{J}\theta^n_j n_{j,t}{}^{1/\rho_n}\right)^{\rho_n}.$$

In our analysis below, we will use the labor aggregator to reflect the fact that labor may not be completely flexible across sectors. If $\rho_n = 1$, then labor across sectors are perfect substitutes implying the same nominal wage across sectors.

The household's budget constraint is given by:

$$(4.3) \quad m_t + \sum_{j=1}^{J} w_{j,t} n^h_{j,t} + (R_t - 1)d_t + \sum_{j=1}^{J}\pi_{j,t} + \pi_{FI,t} - \sum_{j=1}^{J} p_{j,t} c_{j,t} - m_{t+1} = 0,$$

where m_t is the beginning of period money balances, $n^h_{j,t}$ is the labor supplied in sector j while $w_{j,t}$ is the nominal wage and $p_{j,t}$ is the price in sector j. R_t is the gross interest rate on deposits (d_t) in financial intermediaries and R_t-1 is the net interest rate. $\pi_{j,t}$ are lump-sum profit distributions from firms in sector j and $\pi_{FI,t}$ is lump-sum profit distribution from financial intermediaries.

Households face a cash-in-advance constraint for consumption where cash (money less deposits) is augmented by cash wage payments by firms in sectors j = 1,…,J.

$$m_t - d_t + \sum_{j=1}^{J} \phi_j w_{j,t} n_{j,t}^h - \sum_{j=1}^{J} p_{j,t} c_{j,t} \geq 0 \qquad (4.4)$$

$0 \leq \phi_j \leq 1$ is the degree to which firms in sector j are subject to a cash constraint on paying inputs.

4.2 Firms and Financial Intermediaries.

In each industry, there is monopolistically competitive market structure as in Dixit-Stiglitz (1977). Each firm z in industry i produces a differentiated good whose demand is given by

(4.5) $$y_{i,t}(z) = \left(p_{i,t}(z)/p_{i,t}\right)^{-\mu_i/(\mu_i-1)} y_{i,t}$$

where $y_{i,t}$ is industry demand and $p_{i,t}$ is an industry price index:

(4.6) $$p_{i,t} = \left(\int p_{i,t}(z)^{1/(1-\mu_i)} dz\right)^{(1-\mu_i)}$$

(4.7) $$y_{i,t} = \left(\int y_{i,t}(z)^{1/\mu_i} dz\right)^{\mu_i}.$$

Each firm in the industry has identical production technology given by constant returns to scale Cobb-Douglas production function with labor and materials inputs. If a firm is free to set its price, it chooses its price to be a constant markup over marginal cost:

(4.8) $$p_{i,t}(z) = \mu_i \lambda^c_{i,t}$$

where μ_i is the industry markup and $\lambda^c_{i,t}$ is marginal cost (identical across firms in the industry).

Given their optimal price, firms choose inputs to minimize cost. Costs for firm z are given by:

(4.9) $$(\phi_i R_t + (1-\phi_i))(w_{i,t} n^f_{i,t}(z) + \sum_{j=1}^{J} p_{j,t} x_{i,j,t}(z)),$$

where ϕ_i is the fraction of costs that must be paid in advance and $x_{i,j,t}(z)$ is the amount of intermediate input used by firm z in sector i originating from sector j. Firms raise the necessary cash to pay for these inputs by borrowing from financial intermediaries at the gross interest rate R_t. Defining industry i input demands $x_{i,j,t} = \int_0^1 x_{i,j,t}(z)dz$ and

$n^f_{i,t} = \int_0^1 n^f_{i,t}(z)dz$ and total industry output as $\bar{y}_{i,t} = \int_0^1 y_{i,t}(z)dz$, industry i demand for

labor and materials inputs will satisfy:

(4.10) $\Phi(R_t, \phi_i) w_{i,t} n^f_{i,t} = b_i \lambda^c_{i,t} \bar{y}_{i,t}$

(4.11) $\Phi(R_t, \phi_i) p_{j,t} x_{i,j,t} = a_{ij} \lambda^c_{i,t} \bar{y}_{i,t}$

(4.12) $\lambda^c_{i,t} = \lambda^c_i z_{i,t}{}^{-1} \Phi(R_t, \phi_i) w_{i,t}{}^{b_i} \prod_{j=1}^{J} p_{j,t}{}^{a_{ij}}$,

where $\Phi(R_t, \phi_i) = \phi_i R_t + (1 - \phi_i)$ reflects the additional cost to firms of having to borrow to pay for inputs, λ^c_i is a constant, b_i is the output elasticity of labor, a_{ij} is the output elasticity in industry i of materials inputs from industry j, and z_{it} is total factor productivity in industry i.

Perfectly competitive financial intermediaries take deposits from households as well as monetary injections and lend these out to firms who must pay input costs before selling product. Profits of financial intermediaries are just:

(4.13) $\pi_{FI,t} = R_t V_t$,

where V_t is a monetary injection.

4.3 Market clearing.

Aggregating across firms in each sector, we consider sectoral equilibria in which supply and demand in each sector are equated. The market clearing conditions are:

(4.14) $n^h_{i,t} = n^f_{i,t}$, for i = 1,…J. (labor market)

(4.15) $d_t + V_t = \sum_{i=1}^{J} \phi_i (w_{i,t} n^f_{i,t} + \sum_{j=1}^{J} p_{j,t} x_{i,j,t})$. (credit market)

In the goods market, the total industry demand is given by,

(4.16) $y_{i,t} = c_{i,t} + \sum_{j=1}^{J} x_{j,i,t}$, for i = 1,…J.

Total industry demand, $y_{i,t}$, is related to the definition of industry output, $\bar{y}_{i,t}$, by:

(4.17) $\bar{y}_{i,t} = \left(\frac{\bar{p}_{i,t}}{p_{i,t}} \right)^{\mu_i/(1-\mu_i)} y_{i,t}$

(4.18) $\bar{p}_{i,t} = \left[\int_0^1 p_{i,t}(z)^{\mu_i/(1-\mu_i)} dz \right]^{(1-\mu_i)/\mu_i}$

where $\bar{p}_{i,t}$ is an alternative price index for industry i. One can think of equation (4.17) as being similar to a market clearing condition for industry i even though formally industry i market structure is monopolistically competitive.

Finally, aggregate (per capita) stock of money, M_{t+1}, will in equilibrium equal household money balances, m_{t+1}, or $M_{t+1} = M_t + V_t = m_{t+1}$. In our numerical analysis below, we set growth rate of money (V_t/M_t) to follow the same autoregressive process estimated for the monetary factor in Section 3.

4.4 Limited participation and sticky prices

In the benchmark model with no frictions, households make asset allocation, consumption, and work decisions and firms make price and input demand decisions after observing sectoral technology shocks ($z_{i,t}$'s) and the monetary injection (V_t). For the limited participation model, we follow CEE by forcing households to choose deposits, d_t, before observing current period technology shocks or monetary injections.

Similarly, for the sticky price model, firms must set prices before they know current period shocks. As in CEE, the sticky price firm sets its price to maximize the value of expected profits, or

$$(4.19)\quad p_{i,t}(z) = \mu_i \frac{E_{t-1}(\lambda_t \lambda^c_{i,t})}{E_{t-1}(\lambda_t)},$$

where λ_t is the value in utility terms of an additional dollar in profits.

We allow for the possibility that some firms are able to set their price after observing the state. We let the fraction of firms in industry i whose price is set before observing the current state to be φ_i and $1-\varphi_i$ is the fraction of firms whose price is set after observing the current state. However, the price setting frictions last only one period, after the period all firms are free to set prices to whatever they wish. As a result, the industry price index is then given by:

$$(4.20)\quad p_{i,t} = \left(\varphi_i \left(\mu_i \frac{E_{t-1}(\lambda_t \lambda^c_{i,t})}{E_{t-1}(\lambda_t)} \right)^{1/1-\mu_i} + (1-\varphi_i)\left(\mu_i \lambda^c_{i,t}\right)^{1/1-\mu_i} \right)^{(1-\mu_i)}$$

and

$$(4.21)\quad \overline{p}_{i,t} = \left(\varphi_i \left(\mu_i \frac{E_{t-1}(\lambda_t \lambda^c_{i,t})}{E_{t-1}(\lambda_t)} \right)^{\mu_i/1-\mu_i} + (1-\varphi_i)\left(\mu \lambda^c_{i,t}\right)^{\mu_i/1-\mu_i} \right)^{(1-\mu_i)/\mu_i} .$$

4.5 Calibration and model solution

In this paper, we use the same 35 sectors and same input-output structure as in Balke and Wynne (2000). These sectors roughly correspond to 2-digit SIC level industries and reflect not only final goods but intermediate goods as well. We use input-output table to set the values of a_{ij} and set labor's share to be $b_i = 1 - \sum_{j=1}^{J} a_{ij}$. Actual data on the sectoral output and employment shares are used to calibrate consumption shares (θ_j's) and employment shares (θ_j^n's). We assume that log sectoral productivity shocks, $z_{i,t}$'s, are AR(1). We use actual sectoral Solow residuals to estimate the autoregressive parameters for the model's sectoral productivity growth process. As mentioned earlier, the money growth process is assumed to be that estimated for the monetary factor in section 3.

As there are not readily apparent data across industries for calibrating the degree to which firms must borrow to finance working capital or to the degree to which prices are sticky, we consider several alternative specifications for ϕ_i and ψ_i. For the basic case where we assume that industries have similar working capital constraints, we set the fraction of costs that firms must borrow to be $\phi_i = 0.5$. For sticky price models, we set the fraction of firms within an industry whose prices are set before the realization of shocks to be $\psi_i = 0.5$. We also consider alternative values for degree to which household are willing to substitute work across sectors and consumption across goods. Specifically, we consider cases in which labor is perfect substitutes across sectors ($\rho_n = 1.0$) and in which labor substitution is lower ($\rho_n = 2.0$). Similarly, for goods we consider the case of log preferences ($\rho = \infty$, or unitary elasticity of substitution across sectors) and the case where $\rho = 2.0$.

To solve the model, we linearize the optimality conditions for households and firms as well as the market clearing conditions around the deterministic steady state. We then solve the resulting linear rational expectations system of equations for the benchmark case, for limited participation model, for sticky price model, and for a model that combines both limited participation and sticky prices (see technical appendix). The only difference between the models is that some variables (d_t in the limited participation model and $p_{i,t}$ in the sticky price model) are chosen based on information at the beginning of the period (or t-1 information set).

5. Comparison of Models

Figures 10-18 displays the histogram of price, output, and wage responses to a monetary shock for various parameterizations of the benchmark model (BM-model), the limited participation model (LP-model), the sticky price model (SP-model) and a model in which both the limited participation and sticky price frictions are present (combined model). These are in black. For comparison, we overlay the histogram of the posterior means of the estimated responses from our empirical analysis. These are in grey.

For the parameterization with log utility for consumption, ($\rho = \infty$), but with labor supply across sectors perfect substitutes, $\rho_N = 1$, all of the models display a relative price response to a monetary shock (see Figure 10). Even in the benchmark model a monetary shock has relative price implications due to the cash-in-advance constraint that is present only for consumption goods. However, all of the models' relative prices responses are substantially smaller that the estimated responses. All four models imply that the cross-section distribution of prices has shifted to the right—aggregate price level is rising. For the benchmark model, the distribution shifts too far to the right relative to the estimated distribution while for the limited participation model and the combined model the distribution does not shift to the right enough. The lack of a shift in the cross-section distribution occurs because with the limited participation constraint, a money growth shock lowers the nominal interest rate. A decline in the interest rate in turn lowers the cost to firms of purchasing inputs. For the sticky price model, the mean of the cross-section distribution of price responses is much closer to the mean of the estimated price responses than the other models, even though the relative price changes are the smallest of all the models. Note that after the initial period all four models yield the same predictions. The reason is that both the limited participation and sticky price frictions only last the current period and, because there is no additional mechanism to propagate shocks (i.e., no physical capital) the effects of these frictions last only one period.

Turning to the models' predictions for output (see Figure 11), in all four models a monetary shock results in substantial dispersion in the cross-section distribution of output responses—more than for prices. The limited participation model results in the greatest dispersion while the sticky price model results in the least. Like the actual output responses, cross-section distribution is shifted to the right—aggregate output is rising—for the limited participation, sticky price, and combined models. For the benchmark model, the cross-section distribution of output responses shifts to left—aggregate output fall. This occurs because a money shock results in a persistent (but ultimately temporary) increase in money growth. As a result inflation rises and the resulting inflation tax on existing cash balances causes a decline in consumption (and increase in leisure). This effect is typical of cash-in-advance models that do not include the other types of nominal frictions (see Cooley and Hansen (1989)). This also explains why output falls in the subsequent periods when the other frictions are no longer present.

The wage response to monetary shock is not particularly interesting for the model when labor across sectors are perfect substitutes from the households' point of view (see Figure 12). Here the nominal wage is equalized across sectors.

Figures 13-15 display results for the four models when we lower the degree to which households are willing to move labor across sectors in the current period. Comparing Figure13 with Figure 10, we find that for all four models price dispersion is greater when households are less willing to substitute labor across sectors (although for this parameter setting the dispersion is still less than that implied by the estimated empirical price responses). The source of increased price dispersion is the increased dispersion in the cross-section distribution of nominal wages (see Figure 15). Monetary shocks, even without the limited participation and sticky price frictions (the benchmark model), have relative price effects. Because sectors differ in their usage of labor, wage dispersion across sectors increases in response to a monetary shock. The increased dispersion of wages across sectors, in turn, amplifies the dispersion in the cross-section distribution of prices. Again the limited participation model generates the greatest dispersion and sticky price model the least and the cross-section distribution of price responses shifts to the right—for the benchmark case too much, for the limited participation and combined model too little. Comparing Figure 11 with Figure 14, we note that making households less willing to move labor across sectors, does not (at least for these parameter settings) result in substantially greater output response dispersion.

How do the sectoral responses change if households become more willing to substitute across consumptions goods? When we set the value of $\rho = 2$ (down from infinity), we find that the dispersion of price and wage responses is generally greater than in the previous cases (see Figures 16-18). The exception is for the sticky price model. Here the fact that prices are somewhat sticky prevents large changes in relative prices (of goods). Of course, if one made consumption goods across sectors close to perfect substitutes, then the dispersion of price responses would be substantially lower—all goods prices would be very similar.

The bottom line is, perhaps not surprisingly, microeconomic details such as the degree to which households are willing to substitute goods across sectors or labor across sectors help determine the degree to which monetary shocks affect the cross-section distribution of sectoral prices, wages, and output; even though, all sectors are similarly affected by the limited participation or sticky price frictions. If we allow for heterogeneity across sectors with respect to the limited participation and sticky price frictions, one could expect even more relative price, relative wage, and relative output movements in response to a monetary shock.

5. Conclusion

Monetary shocks have implications not only for the general level of economy activity but also for economic activity across sectors. In this paper, we examined empirically the sectoral responses of prices, wage, and outputs to a monetary shock where monetary shocks were characterized by long-run money neutrality. We find that monetary shocks do indeed have substantial effects across sectors on prices, output, and wages. We also examined within the context of simple general equilibrium models the extent to which frictions such as sticky prices or limited participation constraints are capable generating the type of sectoral movements in economic activity we see in the data. We find that a model with a limited participation constraint implies the largest relative price movements in response to a monetary shock. Sticky prices, on the other hand, tend to lessen the relative price effect of monetary shocks that would otherwise be present in the absence of frictions (i.e. the benchmark model).

There are several extension of our analysis that we hope to examine in the future. Adding capital accumulation which could result in longer lasting dynamic relative price effects and which could provide another element of heterogeneity across sectors as some industries are more capital intensive than others. Increasing the length of time the frictions are present, particularly in the stick price model, could also help provide for longer relative price effects. Allowing sectors to differ in the degree to which they are affected by the limited participation constraint and price stickiness could also magnify the sectoral effects of monetary shocks.

Appendix

A1. Imposing Long-run Neutrality Restrictions.

We can impose the restrictions given by equations (2a-2d) by rewriting (1a)-(1d) equations so that the restrictions automatically hold. The resulting equations are given by:

(A1a) $$\Delta y_{i,t} = A_{i,y,y}(L)\,\Delta y_{i,t-1} + \sum_{k=1}^{K} a_{k,i,y,p}(\Delta p_{i,t-k} - \Delta s_{m,t}) + \sum_{k=1}^{K} a_{k,i,y,w}(\Delta w_{i,t-k} - \Delta s_{m,t}) + \sum_{n=0}^{N-1} \tilde{h}_{n,i,y,m}(\Delta s_{m,t-n} - \Delta s_{m,t-n-1}) + \sum_{j=1}^{J} H_{i,y,j}(L)\, s_{j,t} + e_{i,y,t}$$

(A1b) $$\Delta p_{i,t} - \Delta s_{m,t} = A_{i,p,y}(L)\,\Delta y_{i,t} + \sum_{k=1}^{K} a_{k,i,p,p}(\Delta p_{i,t-k} - \Delta s_{m,t}) + \sum_{k=1}^{K} a_{k,i,p,w}(\Delta w_{i,t-k} - \Delta s_{m,t}) + \sum_{n=0}^{N-1} \tilde{h}_{n,i,p,m}(\Delta s_{m,t-n} - \Delta s_{m,t-n-1}) + \sum_{j=1}^{J} H_{i,y,j}(L)\, s_{j,t} + e_{i,p,t}$$

(A1c) $$\Delta w_{i,t} - \Delta s_{m,t} = A_{i,w,y}(L)\,\Delta y_{i,t} + \sum_{k=0}^{K} a_{k,i,w,p}(\Delta p_{i,t-k} - \Delta s_{m,t}) + \sum_{k=1}^{K} a_{k,i,w,w}(\Delta w_{i,t-k} - \Delta s_{m,t}) + \sum_{n=0}^{N-1} \tilde{h}_{n,i,w,m}(\Delta s_{m,t-n} - \Delta s_{m,t-n-1}) + \sum_{j=1}^{J} H_{i,y,j}(L)\, s_{j,t} + e_{i,w,t}$$

(A1d) $$\Delta m_{t} - \Delta s_{m,t} = \sum_{k=1}^{K} a_{k,m.m}(\Delta m_{t-k} - \Delta s_{m,t}) + A_{m,r}(L)\, r_{t} + \sum_{n=0}^{N-1} \tilde{h}_{n,m,m}(\Delta s_{m,t-n} - \Delta s_{m,t-n-1}) + \sum_{j=1}^{J} H_{i,y,j}(L)\, s_{j,t} + e_{m,t}$$

The parameters in (A1a)-(A1d) are unrestricted and can be estimated by OLS if the values of $\Delta s_{m,t}$ and $s_{j,t}$ are known. The restrictions implied by equations (2a-2d) hold when (A1a)-(A1d) are converted back to the original system (1a-1d).

A2. Prior distributions of parameters.

For the autogressive parameters in the F matrix, we set prior distribution to be N(0,1). For lagged parameters in the A(L) polynomials we also assume that the prior distribution of the parameters are independently distributed N(0,1)). For the coefficients on the contemporaneous values of $\Delta y_{i,t}$ in equations (A1b) and (A1c), the coefficient on $\Delta p_{i,t}$ in the equation (A1c) ($a_{0,i,w,p}$) were also to have a prior distribution of N(0,1). The factor loading on the nonmonetary common factors, $H_{i,y,j}(L), H_{i,p,j}(L), H_{i,w,j}(L)$, were all assumed to be normally distributed N(0,5). For the each of variances in the R and Q matrices we assume an inverse gamma distribution, $IG(1/2, .01/2)$ (recall that the R and Q matrices are diagonal). This corresponds to very uninformative priors about the variances.

The parameters on the lagged polynomials $\tilde{H}_{i,y,m}(L), \tilde{H}_{i,p,m}(L), \tilde{H}_{i,w,m}(L)$ in equations (A1a)-(A1c) reflect the short-responses of sectoral variables to the monetary factor. In the paper, we present the case where the short-run response of prices (wages) and output correspond to that typically assumed in the literature. That is, prices and output rises in response to an expansionary monetary shock. To set this quanlitatively, we can think of nominal money demand (in logs) as:

$$m_t = p_t + y_t - \varepsilon r_t \quad (\varepsilon = \text{semi-elasticity of money demand}),$$

or money, m_t, equals nominal income, $p_t + y_t$, less velocity, εr_t. We assume that an exogenous increase in money supply can be broken into a nominal income change and a change in velocity (change in nominal interest rate). Nominal income changes can in turn be broken into a price change and an output change. Thus, we the mean response in current period is: $\Delta p_t = \kappa\eta\Delta m_t$, $\Delta y_t = \kappa(1-\eta)\Delta m_t$, $\Delta r_t = -(1/\varepsilon)(1-\kappa)\Delta m_t$ where κ equals the fraction of money supply increase that nominal incomes rises by, $1-\kappa$ equals the fraction of money supply increase that velocity decreases by, η equals the fraction of nominal income increase due to prices, while $1-\eta$ equals the fraction of nominal income increase due to output. We choose κ = 0.5, η = 0.5, and ε = 0.3. Thus, the prior distribution for $\tilde{h}_{0,i,p,m}, \tilde{h}_{0,i,w,m} \sim N(-0.75,1)$, $\tilde{h}_{0,i,y,m} \sim N(0.25,1)$, and $h_{0,r,m} \sim N(-1.67,.25^2)$. Unlike for prices, wages, and output, we place a fairly tight prior on the current period interest rate response to a monetary shock. We set the priors for the coefficients on the lagged monetary factor in equations (A1a-A1c) and the coefficients on lagged monetary factor in the interest rate equation (1d) to be distributed N(0,1).

A3. The Monte Carlo Markov Chain Bayesian approach

What we want is to find the posterior distribution of both the parameters, Θ, and the unobserved state vector, $\mathbf{S}$, given the data, $\mathbf{Y}$, or $P(\Theta, \mathbf{S} \mid \mathbf{Y})$. This distribution can be completely characterized by conditional distributions $P(\Theta \mid \mathbf{S}, \mathbf{Y})$ and $P(\mathbf{S} \mid \Theta, \mathbf{Y})$. For our problem, the posterior distributions $P(\Theta \mid \mathbf{S}, \mathbf{Y})$ and $P(\mathbf{S} \mid \Theta, \mathbf{Y})$ are fairly straightforward to derive, see for example Kim and Nelson (1999), and, hence, we use a Gibbs Sampler. By sequentially sampling $\mathbf{S}^{(i)}$ from $P(\mathbf{S} \mid \Theta^{(i-1)}, \mathbf{Y})$ and $\Theta^{(i)}$ from $P(\Theta \mid \mathbf{S}^{(i)}, \mathbf{Y})$ the resulting sample distribution of $(\mathbf{S}^{(i)}, \Theta^{(i)})$ converges to $P(\Theta, \mathbf{S} \mid \mathbf{Y})$.

The steps taken in the Gibbs Sampler are as follows:

1. Taking the parameters of the state space model as given, draw a realization of the state vector, S_t, from its conditional distribution. We use the multimove approach of Carter and Kohn (1994) (see also Kim and Nelson, 1999). The conditional distribution of the S_t given the data, parameters, and S_{t+1} is $N(S_{t|t,S_{t+1}}, P_{t|t,S_{t+1}})$ where

(A2a) $$S_{t|t,S_{t+1}} = S_{t|t} + P_{t|t}F'(FP_{t|t}F' + Q)^{-1}(S_{t+1} - FS_{t|t})$$

(A2b) $$P_{t|t,S_{t+1}} = P_{t|t} - P_{t|t}F'(FP_{t|t}F' + Q)^{-1}FP_{t|t}\,.$$

$S_{t|t}$ and $P_{t|t}$ are the standard updating matrices from the Kalman filter. For t = T, the conditional distribution of S_T is given by $N(S_{T|T}, P_{T|T})$. Starting at t = T, the sampling proceeds backwards, drawing S_t from its conditional distribution using the previous period's draw, S_{t+1}, in equation A2a.

2. Given state vector, S_t, $t = 1,...,T$, and Q matrix, draw parameters of the state equation, i.e. the parameters in the F matrix. Let $\tilde{\rho}_m = (\rho_{m,1} \quad \rho_{m,2})'$ and $\tilde{\rho}_j = (\rho_{j,1} \quad \rho_{j,2})'$ for $j = 1,...,J$. Given the prior distributions for $\tilde{\rho}_m$ and $\tilde{\rho}_j$ are N(0,I), their posterior distributions are given by: $\tilde{\rho}_m \sim N(A_m, B_m)$ and $\tilde{\rho}_j \sim N(A_j, B_j)$ for $j = 1,...,J$ where

$$B_m = (I + \sigma_m^{-2}(X_m{}' X_m))^{-1},\ A_m = (I + \sigma_m^{-2}(X_m{}' X_m))^{-1}(\sigma_m^{-2} X_m{}' Y_m)$$

$$B_j = (I + (X_j{}' X_j))^{-1},\ A_j = (I + (X_j{}' X_j))^{-1}(X_j{}' Y_j) \text{ for } j = 1,\ldots,J$$

$$X_m = \begin{pmatrix} \Delta s_{m,0} & \Delta s_{m,-1} \\ \vdots & \vdots \\ \Delta s_{m,T-1} & \Delta s_{m,T-2} \end{pmatrix},\ Y_m = \begin{pmatrix} \Delta s_{m,1} \\ \vdots \\ \Delta s_{m,T} \end{pmatrix},\ X_j = \begin{pmatrix} s_{j,0} & s_{j,-1} \\ \vdots & \vdots \\ s_{j,T-1} & s_{j,T-2} \end{pmatrix},\ Y_j = \begin{pmatrix} s_{j,1} \\ \vdots \\ s_{j,T} \end{pmatrix}.$$

Draws of $\tilde{\rho}_m$ and $\tilde{\rho}_j$ which roots outside the stationary region were discarded and another draw was made.

3. Given state vector, and parameters of F matrix, draw variances in Q matrix. Here only σ_m^2 is drawn as the other common factors' variances are set to one. Posterior distribution of σ_m^2 given the other parameters and the states variables is $IG(\frac{\nu_m}{2}, \frac{\delta_m}{2})$, where $\nu_m = T + 1$ and $\delta_m = (Y_m - X_m \tilde{\rho}_m)'(Y_m - X_m \tilde{\rho}_m) + 0.01$.

4. Given the state vector and the variance in R matrix, draw parameters in equations (A1a-A1c) for the thirty-five sectors. We assume that the initial conditions of the system are known allowing us to use the Gibbs-Sampler to estimate the posterior distribution. We exploit the triangular structure in (A1a-A1c) and the diagonal R matrix to draw parameters one equation at a time rather than as a system. Posterior distributions have similar forms as those in step 2 and 3 with the linear regressions given by equations (A1a-A1c). Parameter draws which resulted in a nonstationary system for (A1a-A1c) were discarded and another set of parameters drawn.

5. Given the state vector and the variances in R matrix, draw parameters in equations (A1d) and (1e). Again, we do so one equation at a time as in step 4.

6. Repeat steps 1-5. This is done 55,000 times with the last 5,000 draws representing draws from the posterior distribution.

References

Balke, Nathan S. and Mark A. Wynne (2007), The relative price effects of monetary shocks, forthcoming, *Journal of Macroeconomics*.

Balke, Nathan S. and Mark A. Wynne (2000) An equilibrium analysis of relative price changes and inflation. *Journal of Monetary Economics*, 45, 269-292.

Ball, Laurence and N. Gregory Mankiw (1995) Relative price changes as aggregate supply shocks. *Quarterly Journal of Economics*, 110, 161-193

Barth, Marvin J. III, and Valerie A. Ramey, (2001) The Cost Channel of Monetary Transmission, *NBER Macroeconomics Annual*,

Bils, Mark, Peter J. Klenow, Olesky Kryvtsov (2003) Sticky Prices and Monetary Policy Shocks, Quarterly Review Federal Reserve Bank of Minneapolis, Winter, 2-8.

Calvo, Guillermo A. (1983) Staggered prices in a utility-maximizing framework. *Journal of Monetary Economics*, 12, 383-398.

Christiano, Lawrence J., Martin Eichenbaum and Charles L. Evans (1997) Sticky price and limited participation models: A comparison. *European Economic Review*, 41, 1201-1249.

-----, -----, and ----- (1999) Monetary policy shocks: what have we learned and to what end? In John B. Taylor and Michael Woodford (eds.) *Handbook of Macroeconomics Volume 1A*. Amsterdam: Elsevier Science.

Hercowitz, Zvi (1982) Money and Price Dispersion in the United States. *Journal of Monetary Economics*, 10, 25-37.

Lucas, Robert E., Jr. (1972) Expectations and the neutrality of money. *Journal of Economic Theory*.

----- (1973) Some international evidence on output-inflation tradeoffs. *American Economic Review*, 63, 326-334.

----- (1990) Liquidity and interest rates. *Journal of Economic Theory*, 50, 237-264.

Mankiw, N. Gregory and Ricardo Reis (2002) Sticky Information Versus Sticky Prices: A Proposal to Replace the New Keynesian Phillips Curve. Mimeo, Harvard University.

Woodford, Michael (2001) Imperfect Common Knowledge and the Effects of Monetary Policy. Mimeo, Princeton University.

Table 1. Response of Sectoral Price and Output to a Monetary Shock
Horizon 0

Price Response			Output Response		
rank	sector		rank	sector	
1	textile	1.054	1	chemicals	1.375
2	coal mining	1.025	2	stone	0.959
3	food	0.995	3	motor veh	0.942
4	fabricated metal	0.93	4	transport	0.863
5	rubber	0.847	5	lumber	0.666
6	primary metals	0.675	6	primary metals	0.619
7	apparel	0.62	7	petroleum	0.612
8	construction	0.606	8	rubber	0.537
9	machinery	0.599	9	furniture	0.536
10	furniture	0.594	10	paper	0.517
11	metal mining	0.582	11	FIRE	0.475
12	lumber	0.524	12	construction	0.466
13	w. r. trade	0.507	13	misc_man	0.466
14	leather	0.486	14	nonmetallic	0.459
15	trans equip	0.467	15	food	0.418
16	elect mach	0.456	16	communications	0.355
17	petroleum	0.437	17	gas utilities	0.346
18	agriculture	0.408	18	textile	0.282
19	elec utilities	0.332	19	agriculture	0.281
20	stone	0.321	20	serv. water	0.272
21	motor veh	0.296	21	instruments	0.259
22	paper	0.296	22	tobacco	0.254
23	printing	0.257	23	gvt enter	0.237
24	communications	0.215	24	metal mining	0.211
25	misc_man	0.193	25	machinery	0.172
26	nonmetallic	0.185	26	printing	0.145
27	chemicals	0.178	27	coal mining	0.142
28	instruments	0.167	28	fabricated metal	0.023
29	FIRE	0.123	29	w. r. trade	-0.038
30	tobacco	0.05	30	leather	-0.118
31	serv. water	0.044	31	apparel	-0.203
32	oilgas	-0.017	32	elec utilities	-0.256
33	gvt enter	-0.067	33	oilgas	-0.299
34	transport	-0.13	34	trans equip.	-0.363
35	gas utilities	-0.269	35	elect mach	-0.775

Figure 1.

Implied prior distribution of response to a unit shock to the monetary factor

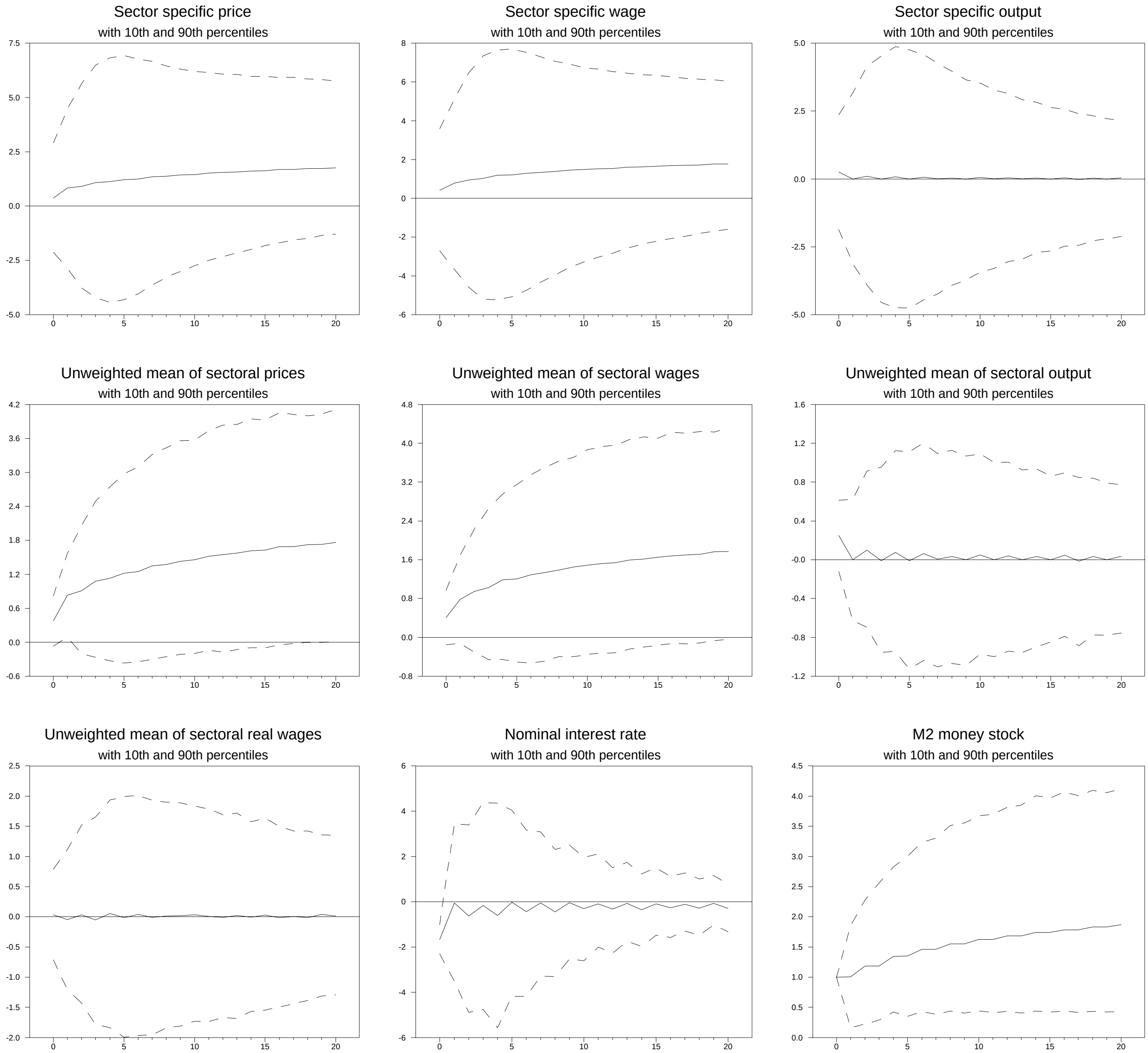
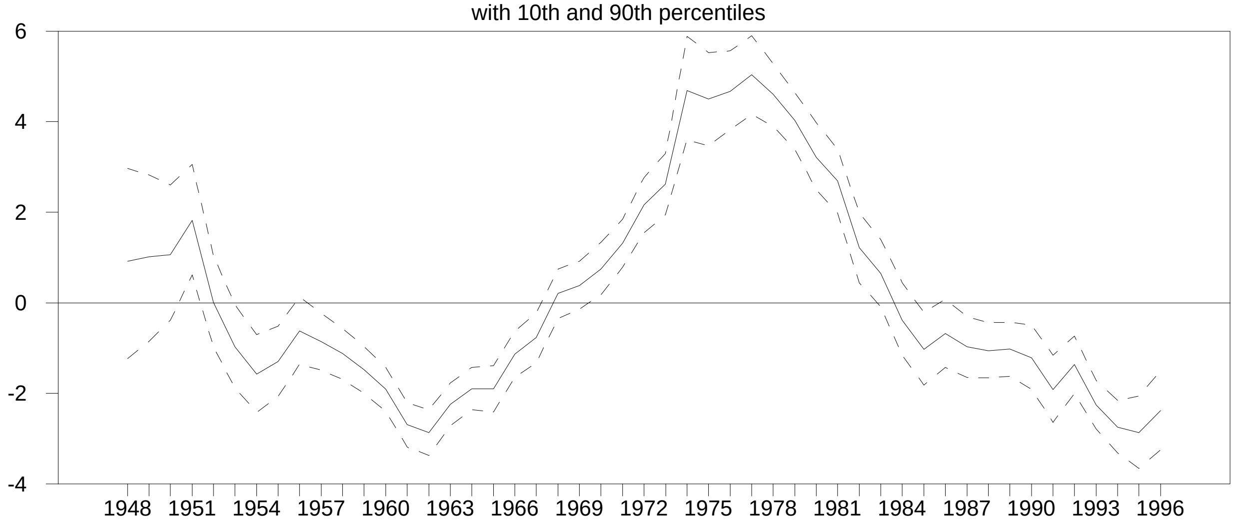


Figure 2.

Posterior Distribution of Monetary Factor

Mean of monetary factor

with 10th and 90th percentiles



Monetary factor, M2 growth, and unweighted mean of sectoral inflation

sample means removed

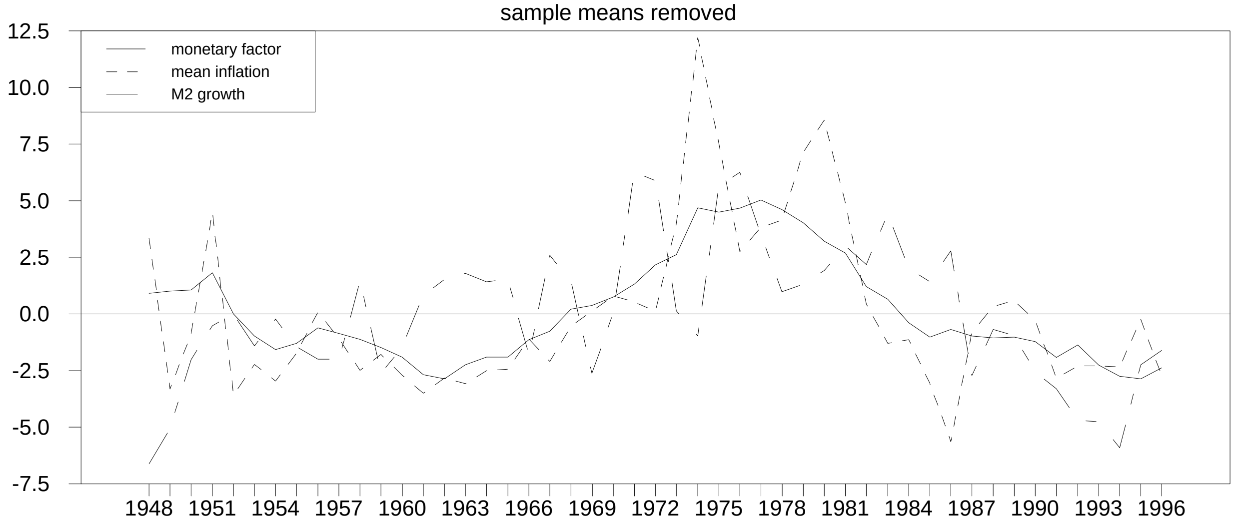


Figure 3.

Response to a one st. dev. shock to the monetary factor

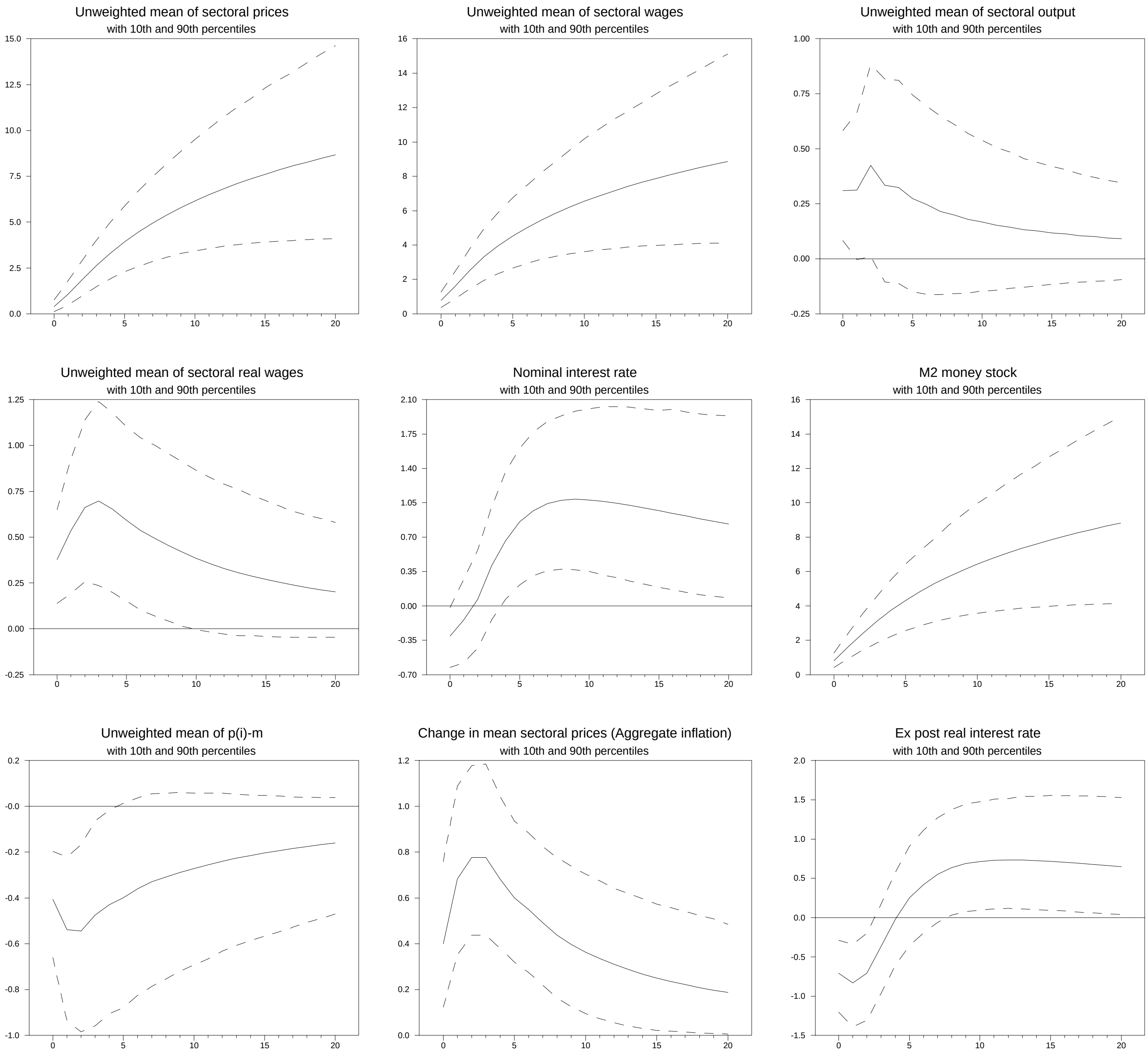


Figure 4.

Histograms of Sectoral Price Responses (posterior means)

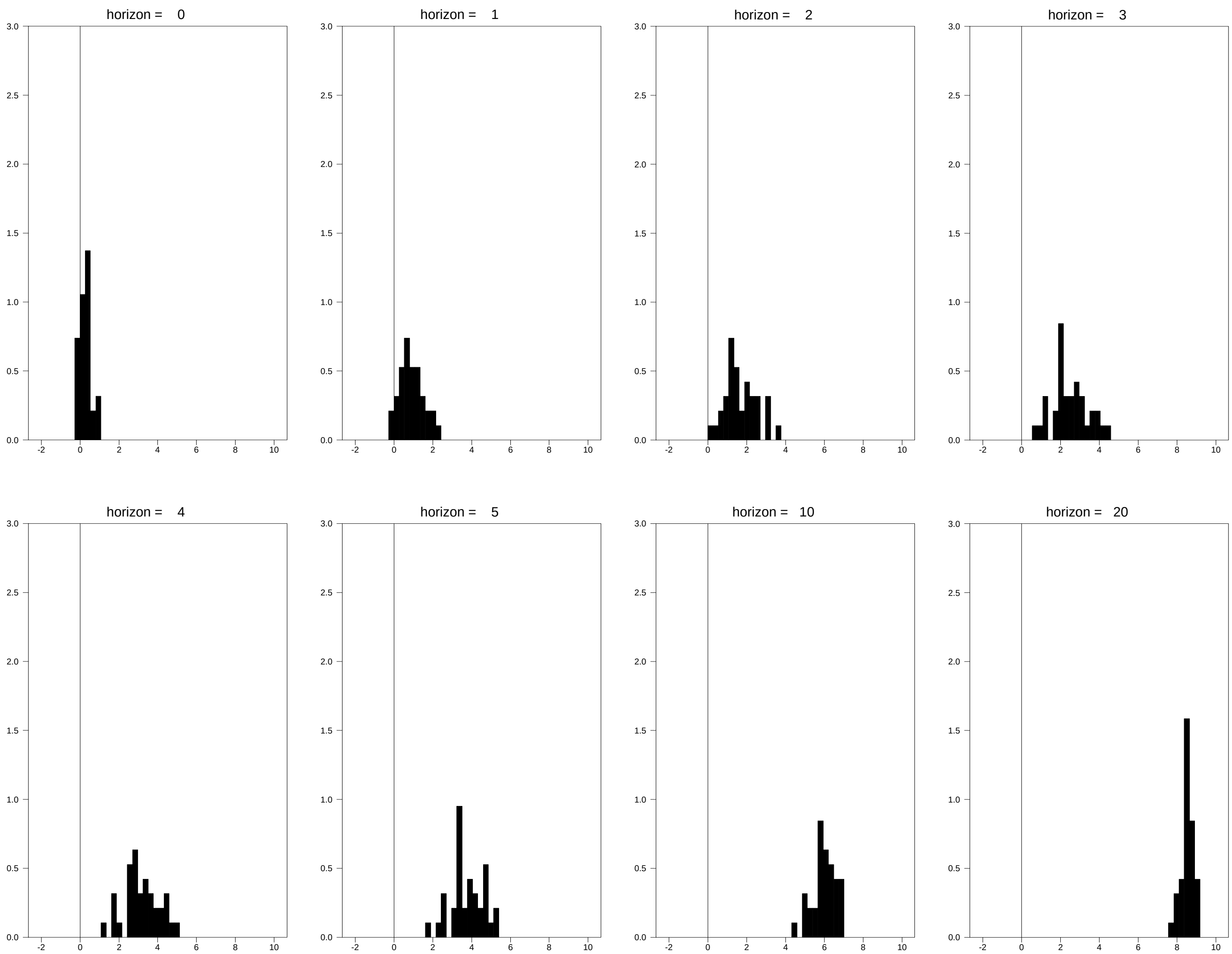


Figure 5.

Histograms of Sectoral Wage Responses (posterior means)

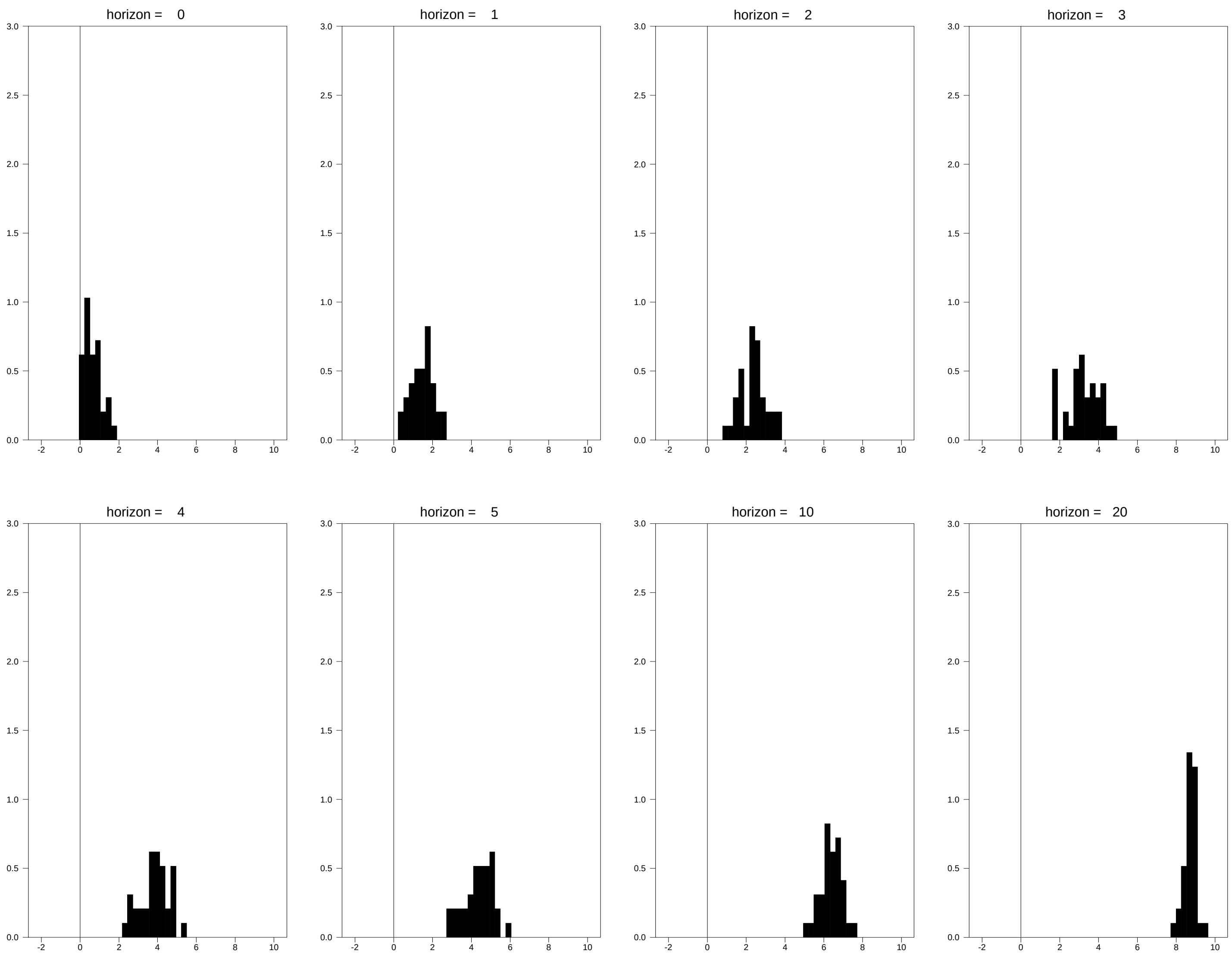


Figure 6.

Histograms of Sectoral Output Responses (posterior means)

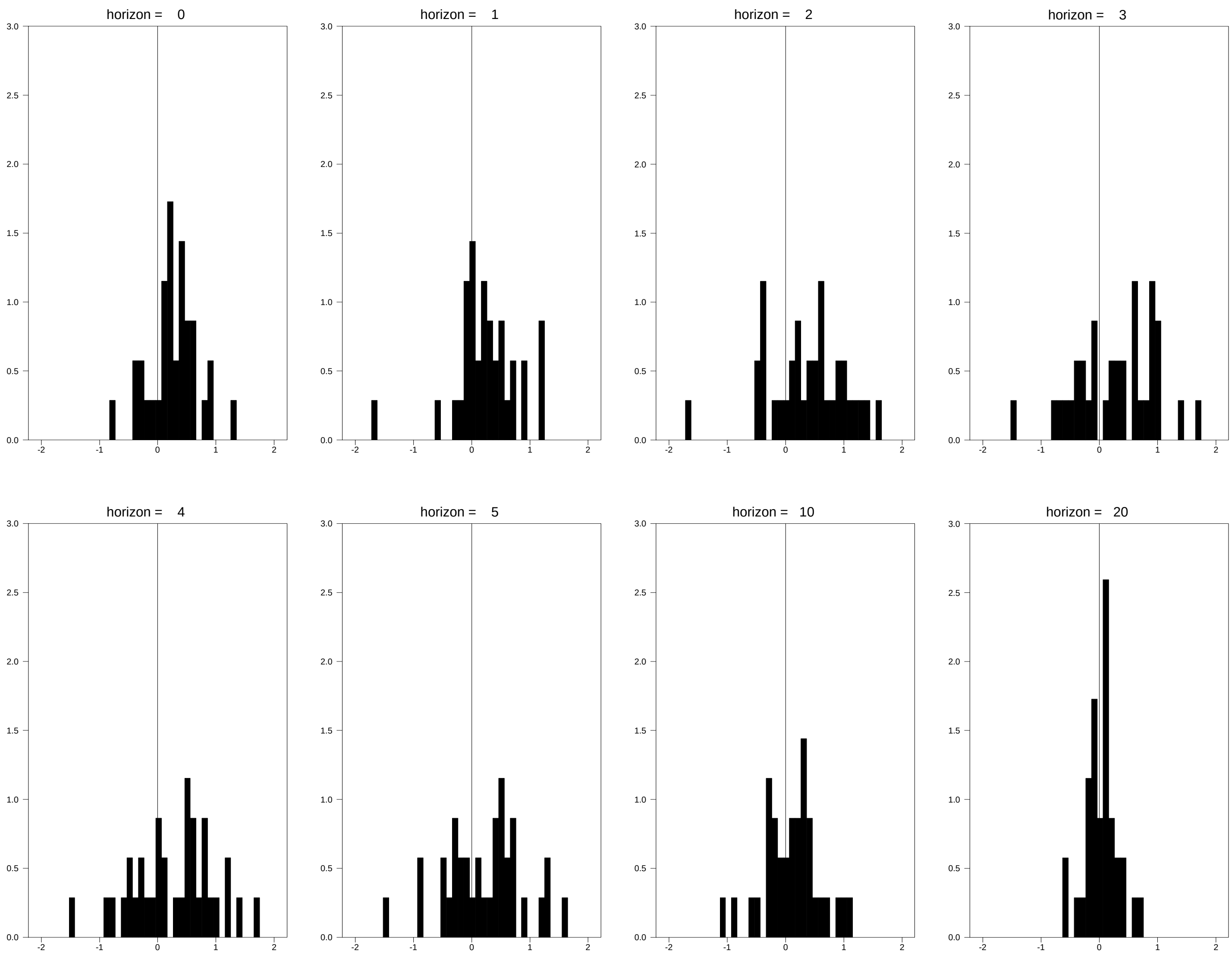


Figure 7.

Histograms of Sectoral Real Wage Responses (posterior means)

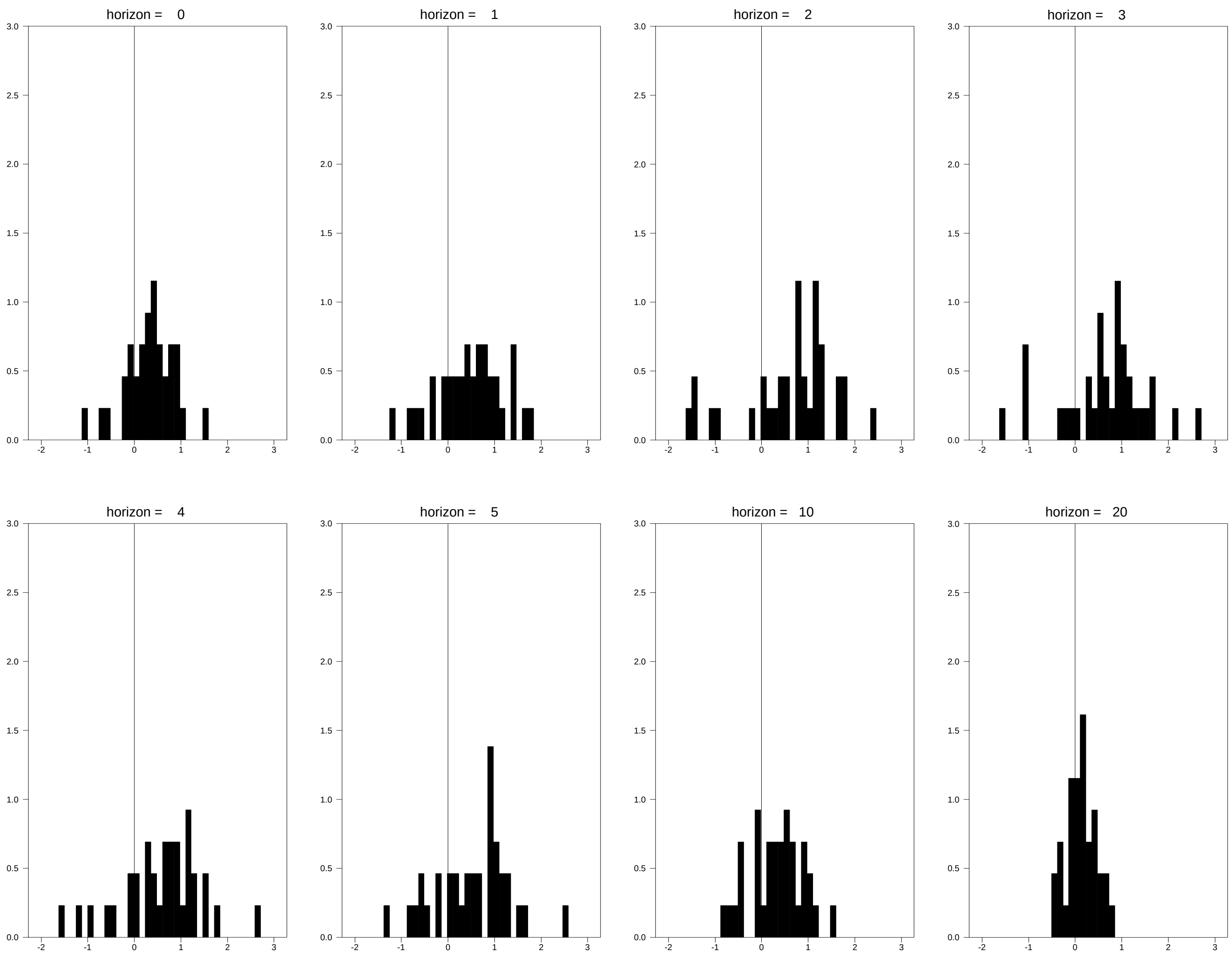


Figure 8.

Variance of Cross-section Distribution of Responses to Shock in Monetary Factor

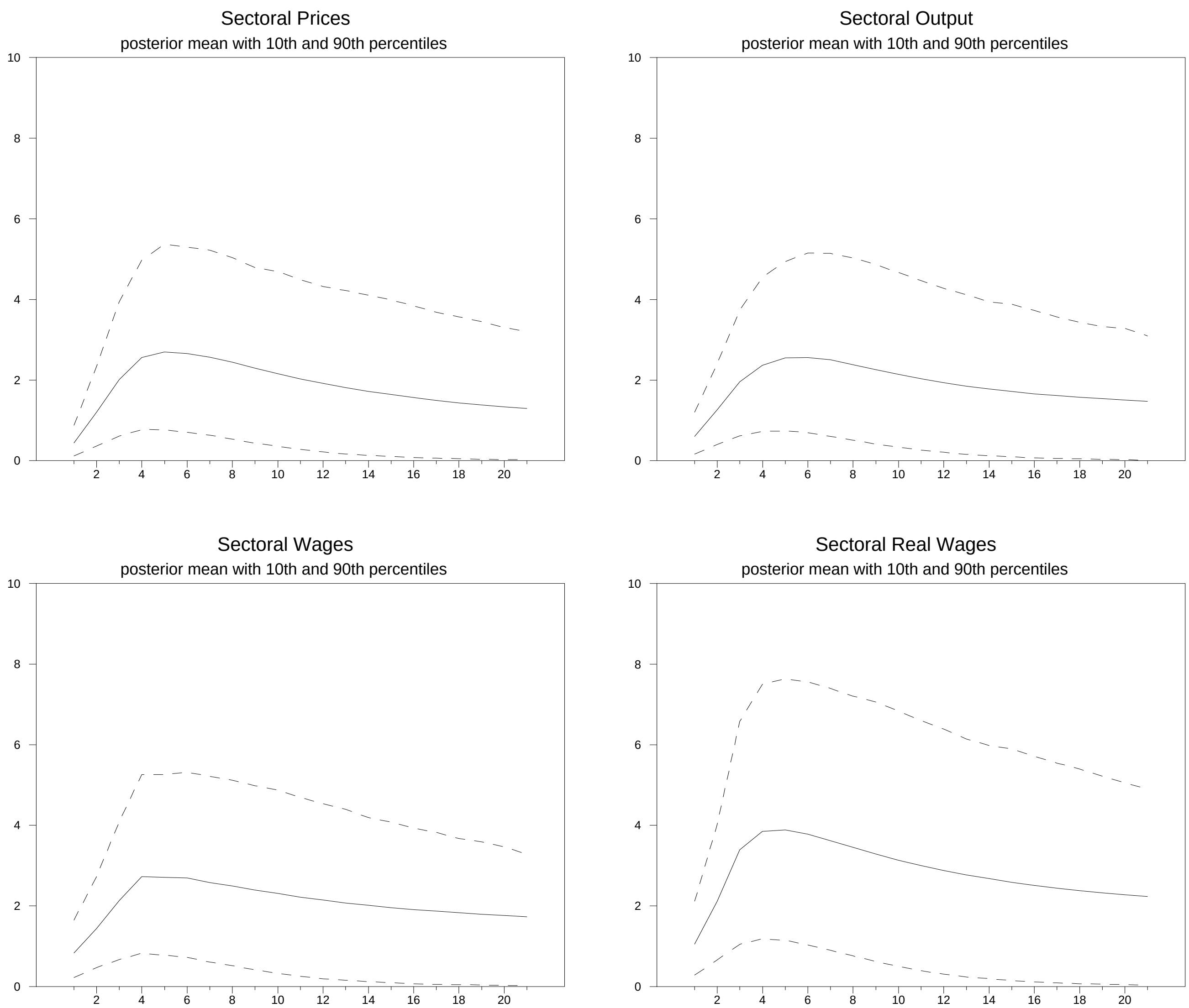


Figure 9.

Response to a one st. dev. shock to the monetary factor

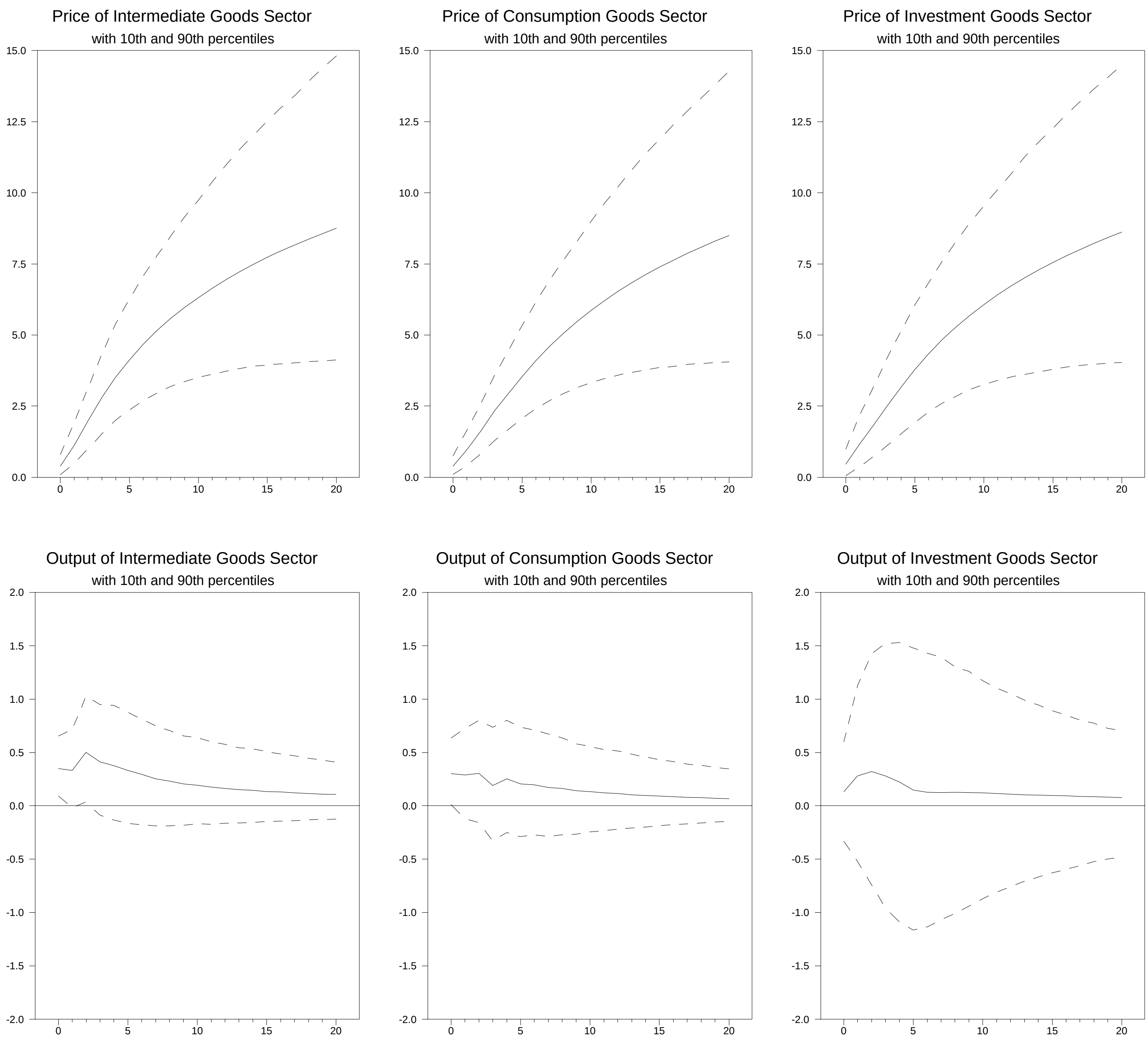


Figure 10.

Histogram for Price Responses, high labor substitution

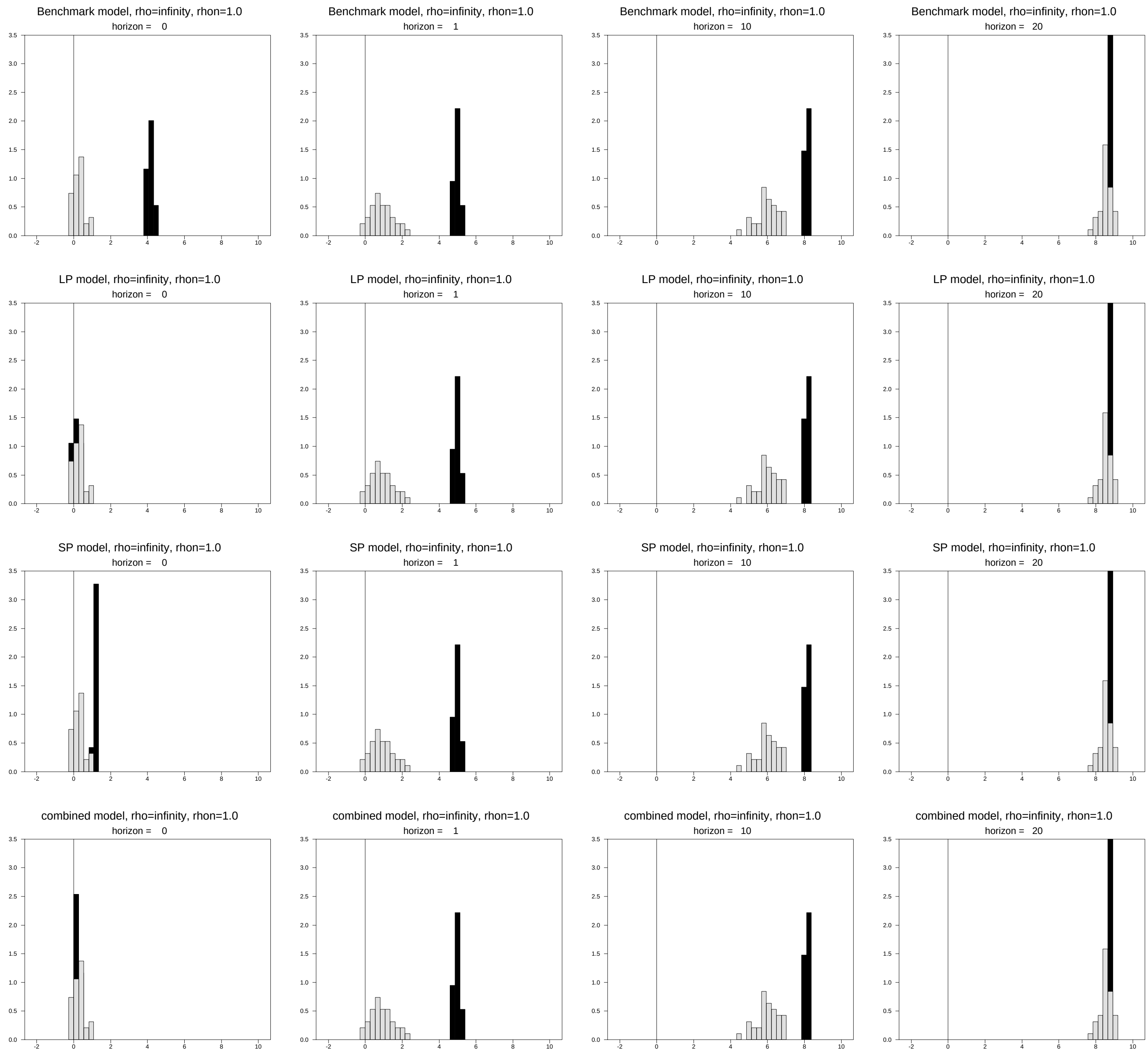


Figure 15.

Histogram for Wage Response, low labor substitution

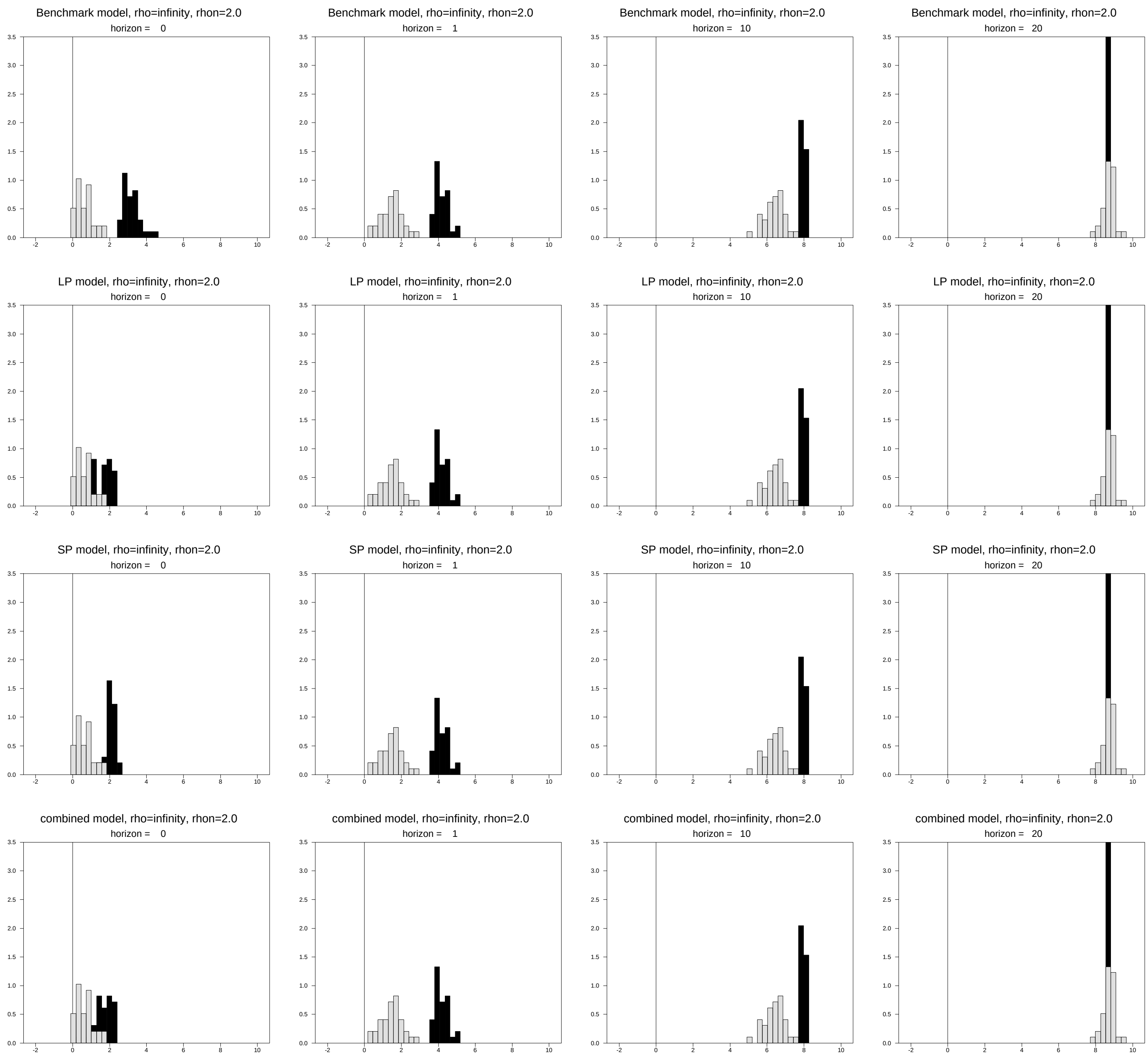


Figure 12.

Histogram for Wage Response, high labor substitution

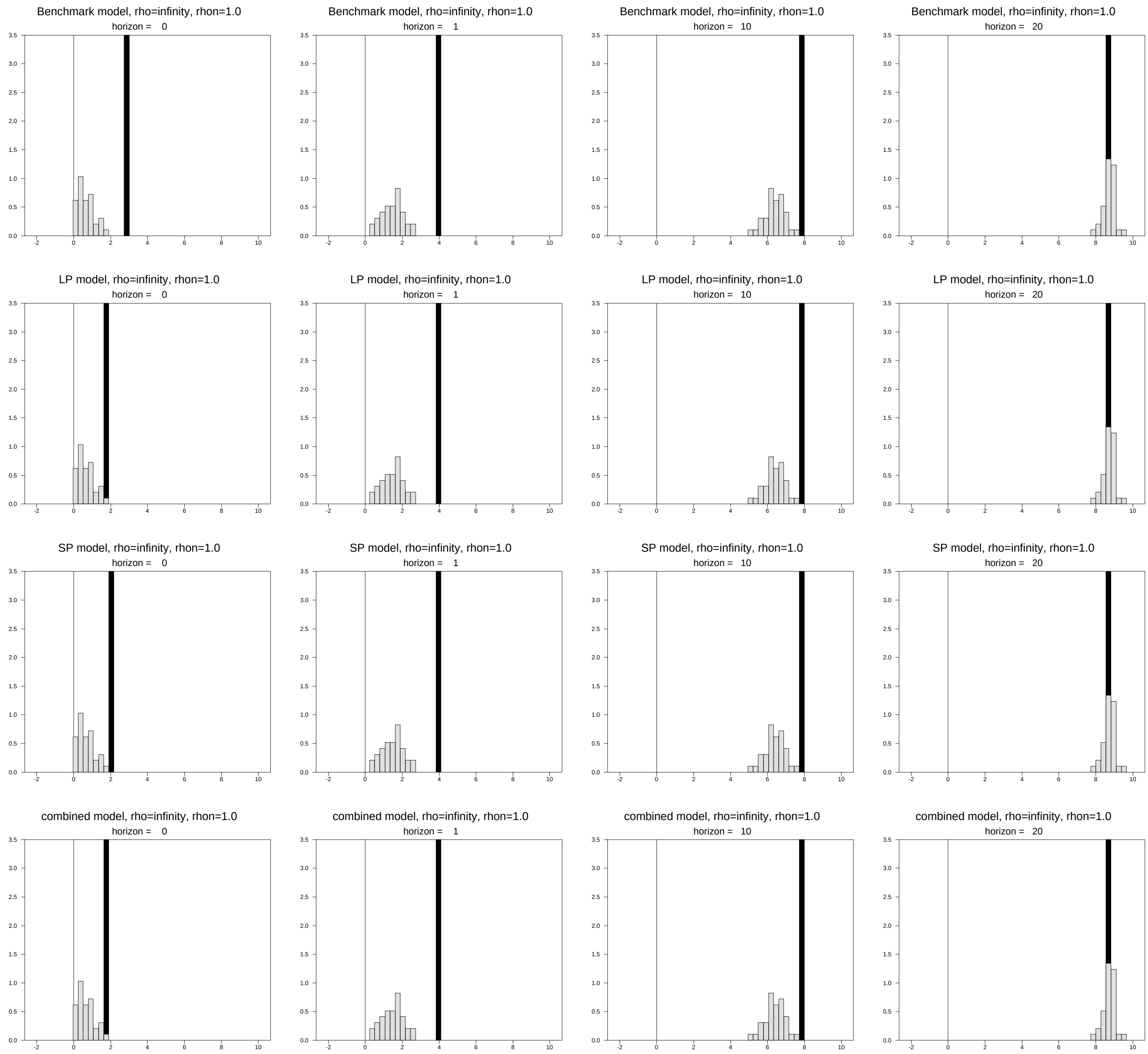


Figure 13.

Histogram for Price Responses, low labor substitution

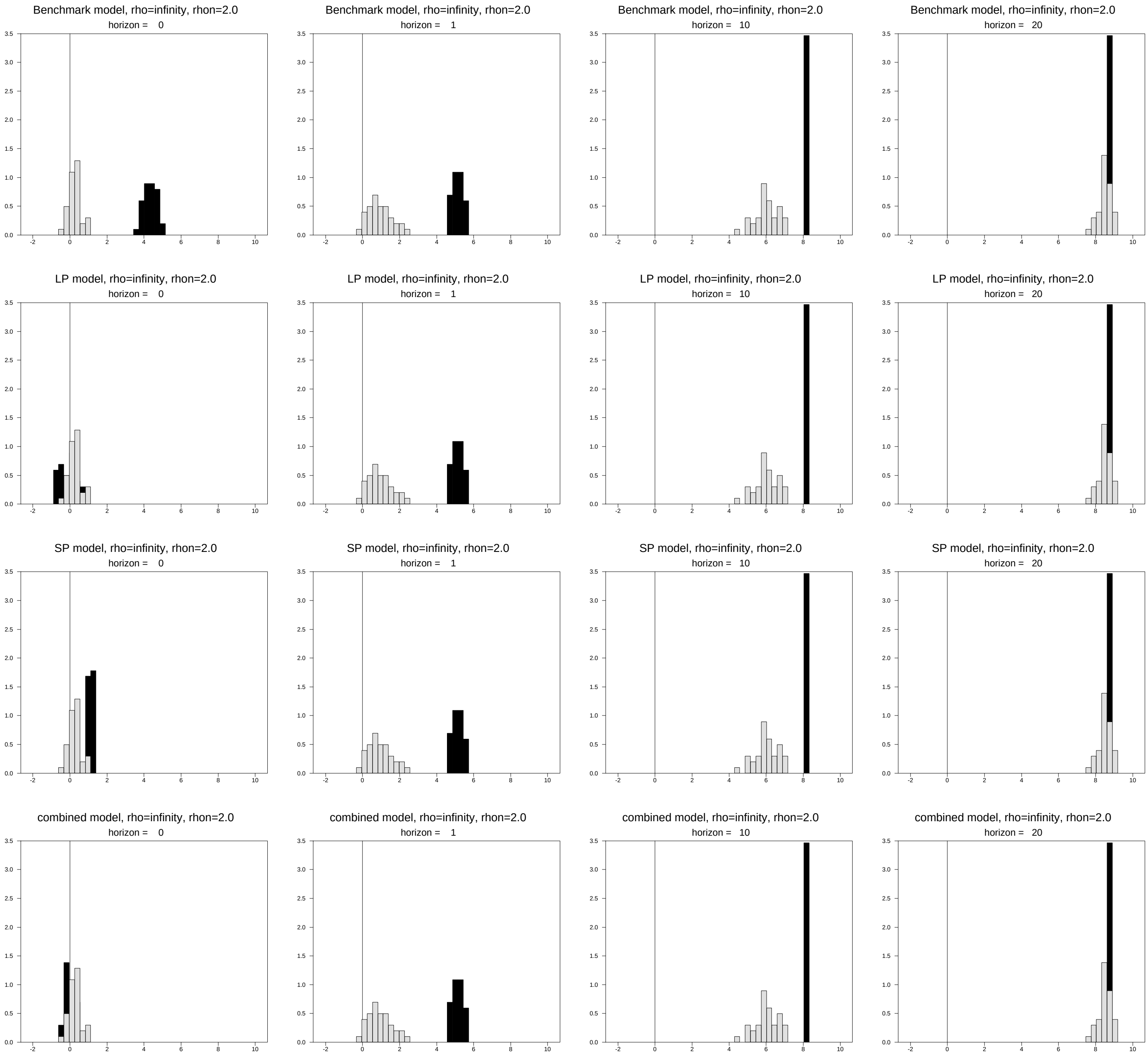


Figure 14.

Histogram for Output Responses, low labor substitution

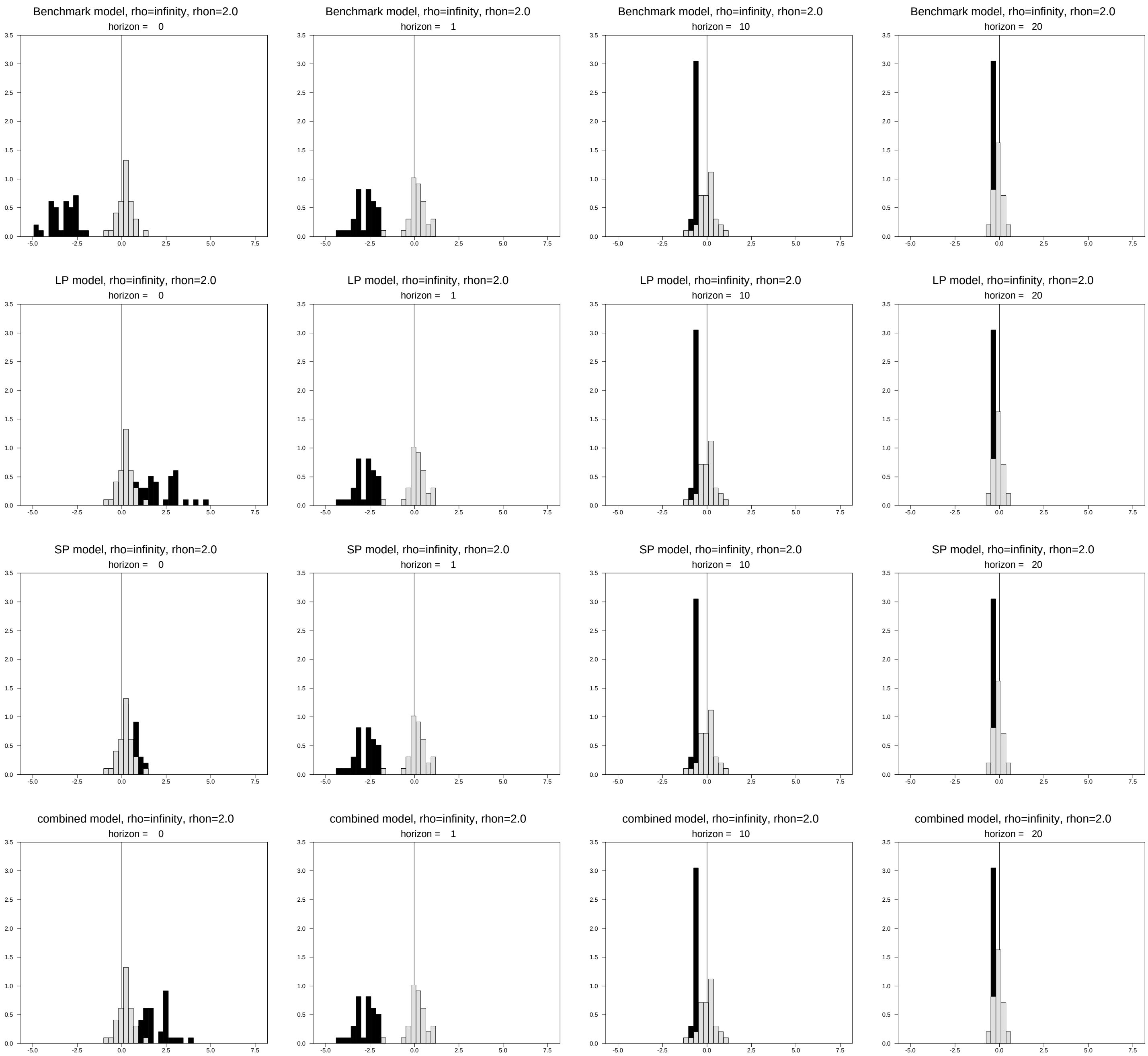


Figure 15.

Histogram for Wage Response, low labor substitution

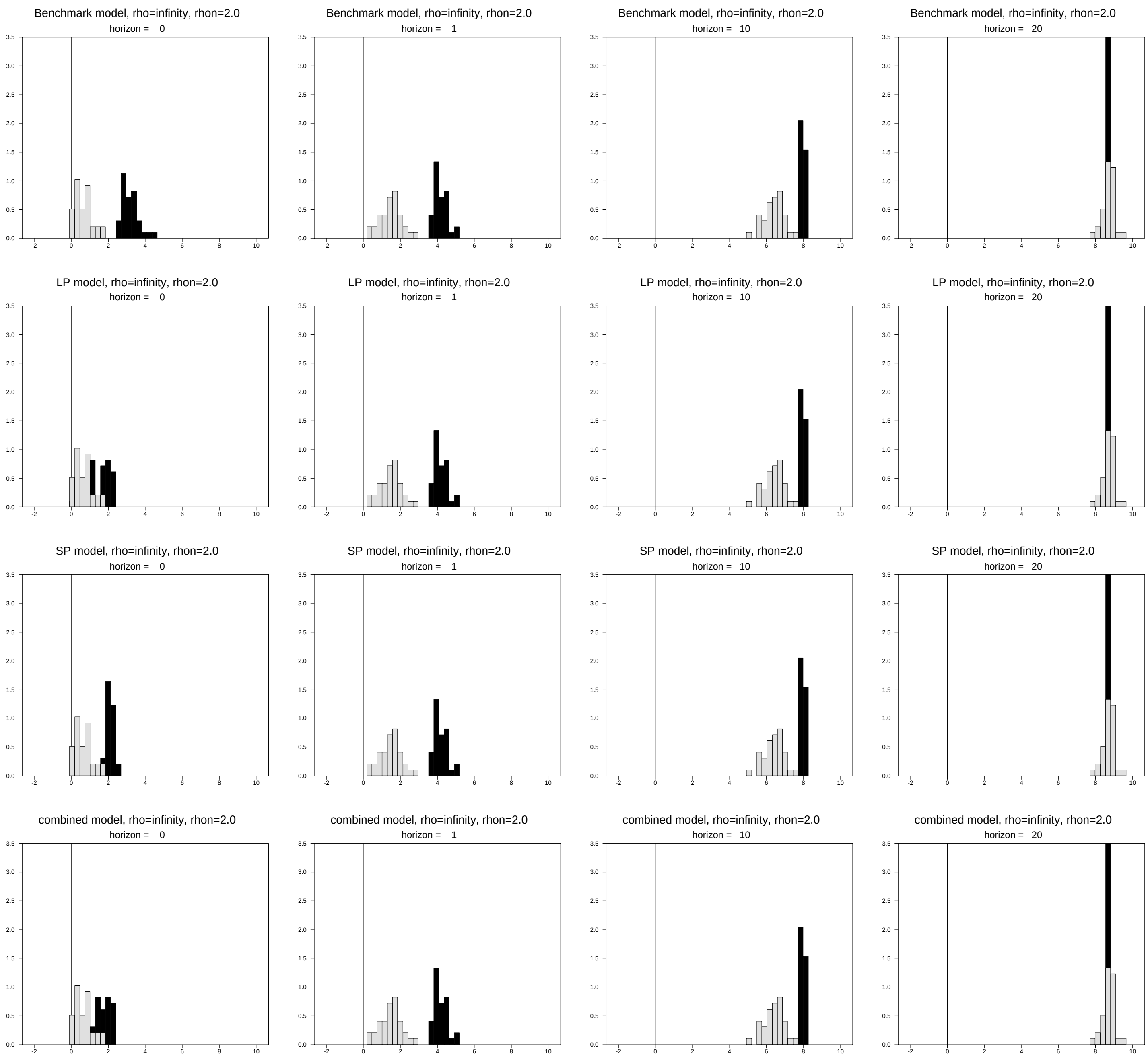


Figure 16.

Histogram for Price Responses, higher goods substitutability

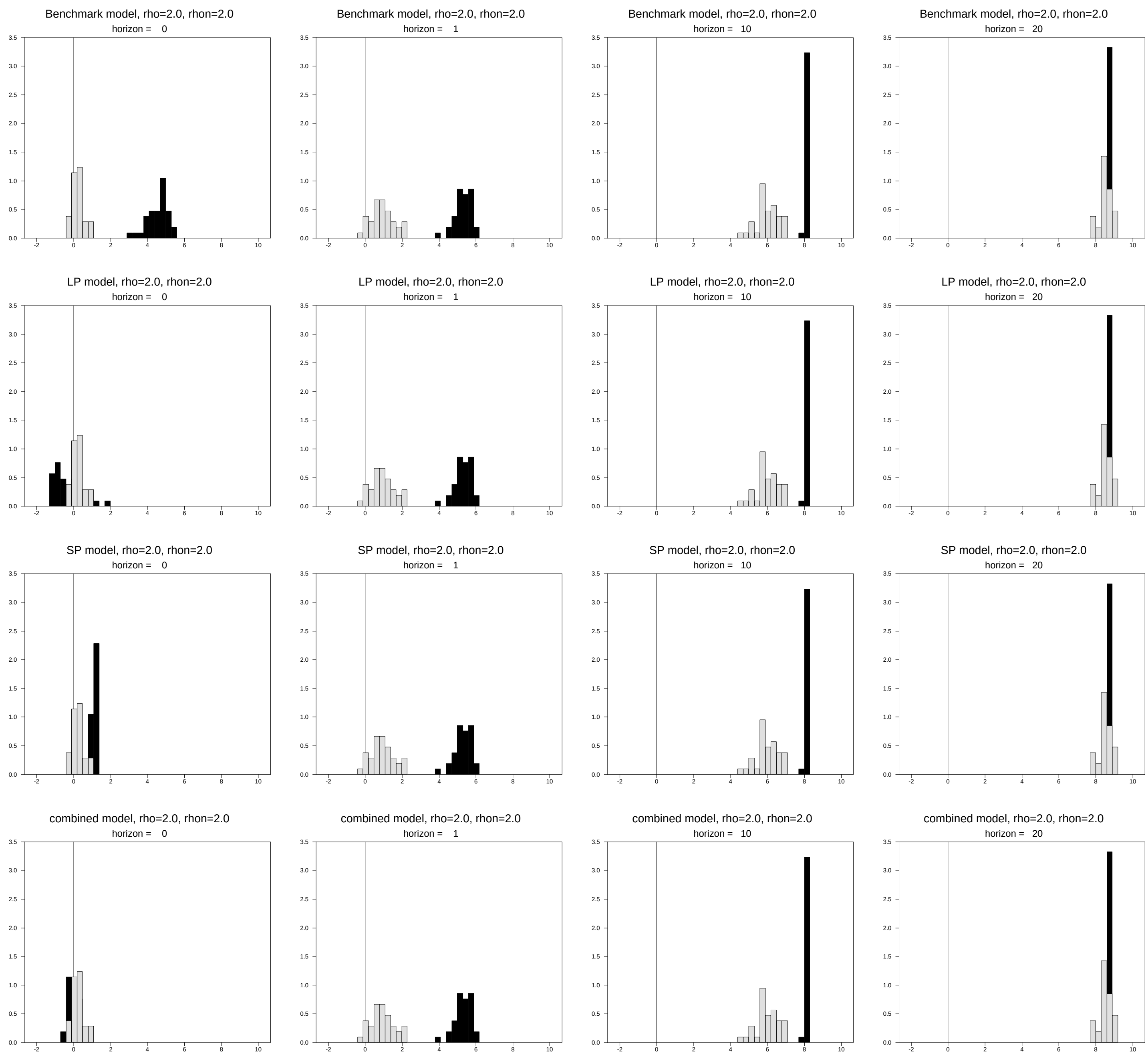


Figure 17.

Histogram for Output Responses, higher goods substitutability

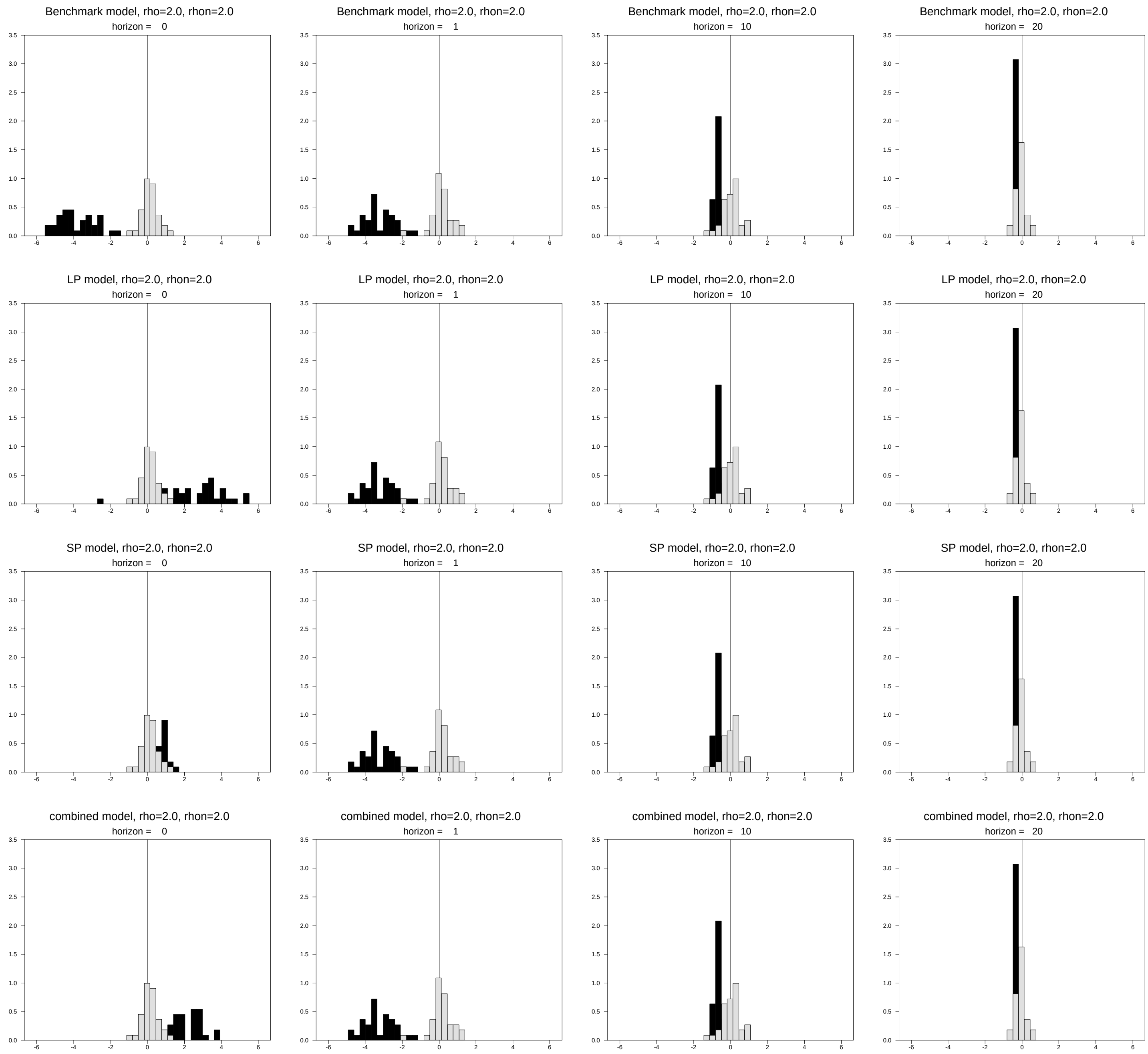


Figure 18.

Histogram for Wage Responses, higher goods substitutatibility