Sectoral Effects of Aggregate Shocks

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Abstract: In this paper, I use sectoral data to identify aggregate common factors and then quantify the contribution of these factors to economic fluctuations. Using a combination of long-run and sign restrictions to identify aggregate monetary and productivity factors, I find that the monetary factor is responsible for long swings in nominal variables but has little effect on fluctuations in output, real wage, or labor input growth. The productivity factor in addition to increasing output growth and real wage growth in the short and long runs, also results in increases in labor input and decreases in prices, but the quantitative effect of the productivity factor on labor input is relatively small. These results are robust to the number of factors included in the model and to alternative priors about the short-run effects of the monetary factor, and to the inclusion of oil prices. Finally, the oil price factor has only a modest effect on economic fluctuations and, in fact, oil prices are largely driven by the other aggregate factors.

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1. Introduction

Much of the recent literature on accounting for the sources of economic fluctuations have focused on monetary and productivity shocks. Quantifying the effect of money shocks is important for evaluating theories of price stickiness and for determining the efficacy of monetary policy.[1] Productivity or technology shocks have featured prominently in stochastic general equilibrium models of business cycles although recent empirical work has cast doubt on the ability of technology shock driven models to explain business cycle fluctuations.[2]

Most of the literature use VARs to describe the data generating process and assume a recursive structure to identify economic shocks. These recursive schemes are not always well motivated and often rely on ad hoc timing restrictions. A few papers have applied non-recursive identification schemes. For example, Gali (1992) and others use long-run restrictions to identify monetary shocks while Gali (1999) and Francis and Ramey (2005) use long-run restrictions to identify productivity shocks. These long-run relationships are often thought to be more robust across models and policy regimes.[3] Sign restrictions rather than zero restrictions for impulse responses have also been used to identify monetary shocks (Faust (1998), Canova and De Nicolo (2002) and Uhlig (2005)) as well as productivity shocks (Peersman and Straub (2009)). Again, these sign restrictions might be viewed as less stringent and more robust to alternative economic structures than traditional recursive zero restrictions.

In this paper, I depart from the standard approach taken in most of the literature in several key respects. First, instead of using aggregate data, I use matched sectoral data on prices, output, wages, and labor input to identify monetary and aggregate productivity shocks. Using disaggregated data can bring additional information to bear in identification beyond that in aggregate variables alone. Not only are more series used, but economic theory often has implications for sectoral variables as well as for aggregate variables. For example, I use long-run monetary neutrality to identify a common monetary factor; monetary neutrality implies that relative prices and individual sector

[1] See Christiano, Evans, and Eichenbaum (1999) and (2005) for an extensive review of the VAR literature on quantifying the effect of monetary shocks on economic activity.
[2] See for example, Gali (1999), Francis and Ramey (2005), and Basu, Fernald, and Kimball (2006).

outputs, real wages, or labor input are unaffected by a change in stock of money. Using only an aggregate price index or an aggregate measure of output would miss this sectoral implication of monetary neutrality. Similarly, aggregate productivity shocks should have effects across many sectors, in particular, raising real wages and output across sectors in the long run; the timing and the extent of these effects, however, may vary across sectors. Here, I capture these sectoral effects of aggregate productivity shocks in the form of non-negativity constraints on the long-run response of sectoral real wages and output.[4]

Second, rather than estimate a VAR I use a common factor model to estimate monetary and aggregate productivity shocks. A common factor model is a natural way to model the effect of a few important shocks on a wide cross-section of observables. As the primary focus in the literature has been on a small number of aggregate shocks, focusing on a few common factors does not lessen the economic interest of the empirical analysis. In addition to aggregate monetary and productivity factors, I include a third factor that while not having a clear a priori interpretation will end up looking like an aggregate demand factor. Also, I consider a model that includes oil prices and an additional factor that is interpreted as an oil factor.

Third, I use Bayesian methods to estimate the common factor model. While Bayesian methods are not crucial for the implementation of long-run or sign restrictions, in this application they greatly simplify the empirical analysis. Furthermore, a Bayesian approach allows one to set priors over short-run responses and use those, in addition to long-run restrictions, in the identification of aggregate shocks.

I find that the estimated monetary factor is responsible for much of the long swings in sector price growth, M2 growth, and the nominal interest rate, suggesting that this factor is capturing underlying inflationary pressure in nominal variables. Taking the unweighted average across sectors to be a measure of aggregate activity, the monetary factor, on the other hand, explains little of the historical fluctuations in “aggregate” output growth, real wages, or labor growth. Impulse response analysis for the monetary

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[3]Using long-run restrictions to identify structural shocks is not uncontroversial, see for example the critique of Faust and Leeper (1997), Chari, Kehoe, and McGrattan (2008) and Dupor and Kiefer (2008).

[4] Besides helping to identify aggregate shocks, the response of disaggregated variables to aggregate shocks is interesting in its own right. Many recent theories of nominal rigidities suggest that relative price effects are central to the effect of money on real economic activity and the welfare consequences of inflation (Woodford (2003)).

factor is somewhat sensitive to the prior assumptions that one makes about the short-run responses of sectoral variables to a monetary shock; suggesting that the data are not too informative about these short-run effects.

Productivity shocks, on the other hand, are estimated to increase aggregate output, real wages, and labor input in both the short-run and long-run but the size of the increases varies substantially across sectors. These results are robust to alternative priors about the short-run effect of monetary shocks. That productivity shocks are associated with increases in labor input both at the aggregate and sectoral level are in contrast to the results of Gali (1999) and Francis and Ramey (2005). Nevertheless, while historical decompositions for output and real wages suggest that the aggregate productivity factor is an important source of fluctuations in these variables, the aggregate productivity factor has only a small impact on labor fluctuations over our sample.

When I include oil prices and an "oil factor" in the analysis, the findings for the monetary or productivity factors are not substantially changed. The "oil factor" contributes only modestly to fluctuations in aggregate output, inflation, labor, and real wages. Interestingly, the "oil factor" seems to affect aggregate and sectoral economic activity primarily through a demand channel rather than through supply-side channel. Finally, a large fraction of oil price fluctuations appears to be driven by the aggregate demand factor, suggesting that oil prices are responding endogenously to overall economic activity.

Several previous papers have applied factor models to disaggregated data in a macroeconomic context. Explicit dynamic common factor models have been employed to explain cyclical behavior of sectoral output (Quah and Sargent (1994) and Forni and Reichlin (1998)), world and regional growth rates (Kose, Otrok, and Whiteman (2003)), and disaggregated prices (Bryan and Cecchetti (1993) and Nath (2004)).[5] Stock and

[5] There is also an empirical literature that examines the relative price implications of monetary shocks. Hercowitz (1982) examined how the dispersion in cross-section distribution of prices changed in response to anticipated and unanticipated money changes. 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. Balke and Wynne (2007) find using 8 digit monthly PPI data that monetary shocks have substantial relative price effects. Lastrapes (2006), using more aggregated price indices than Balke and Wynne finds that monetary shocks have persistent effects on the cross-section distribution of prices.

Watson (2002), Bernanke, Boivin, and Eliasz (2005), among others, employed factor models where the factors are based on the principal components of disaggregate data.

Three papers that come closest to the analysis in the current paper are Boivin, Giannovi, and Mihov (2009), Ahmadi and Uhlig (2007), and Reis and Watson (2009). Boivin et al (2009) use a large number of disaggregated variables to estimate a monetary factor. In fact, in one of their specifications they impose a sort of long-run monetary neutrality restriction for relative prices. However, they do not consider implications of long-run neutrality for other real variables. Ahmadi and Uhlig (2007) examine a Bayesian FAVAR and employ sign restrictions to identify monetary shocks, but do use long-run monetary neutrality. Neither paper tries to identify aggregate productivity shocks. Reis and Watson (2009) look at large cross section of price indices and extract a common "pure inflation" factor in which all prices move one-to-one with this factor (i.e., no relative price effects) as well as other factors that have relative price effects. However, they do not examine disaggregate real variables nor do they examine the impact of productivity shocks.

The rest of this paper is organized as follows. In section 2, I discuss the sectoral data used in the paper and present some evidence about the degree to which this sectoral data can be described by a few common factors. In section 3, I discuss the specification and estimation of the structural dynamic common factor model. Section 4 contains the empirical results for the benchmark factor model. In section 5, I examine the effects of shocks to the aggregate factor on individual sectors. Section 6 examines the robustness of the benchmark model to alternative short-run priors and the number of factors. Section 7 adds oil prices to the analysis. Section 8 concludes.

2. Sectoral Co-movement

In this section, I examine the degree of co-movement in sector price growth, output growth, real wage growth, and labor input growth for the U.S economy using principal components. The primary source of data is an extended version of the Jorgenson KLEM data set originally compiled by Jorgenson, Gollop and Fraumeni (1987) that consists of annual observations on gross output, as well as the price and various inputs for 35 sectors of the US economy. These thirty-five sectors roughly correspond to 2-digit SIC level for U.S. industries. Table 1 lists the thirty five sectors by sector number and the fraction of their output used for consumption, investment, and materials input. Two data sets, one covering the period 1947 to 1989 and another covering the more recent period from 1960-2005, are spliced together. I divide sector price of labor input by sector output price to obtain sector real wage.

Table 2 displays fraction the total sectoral variance that can be explained by the five largest principle components of the cross-sector covariance matrix. In addition to examining variance/covariance matrices of sectoral price growth, output growth, real wage growth, and labor input growth separately, the joint covariance matrix of all four sectoral variables is also examined. From Table 2, one observes that the first five principal components can explain a large fraction of the cross-sector variances. For sectoral prices and output, a single principal component can explain over forty percent of the total variance. Even when one examines the covariance matrix for all four sectoral variables jointly, the first three principal components explain over 46 percent of the sum of sectoral variances.[6] In fact, the Bai and Ng (2002) IC_1 and IC_2 criteria for selecting the number of factors in a static factor model both suggest two factors.

If one looks at each sectoral variable individually, the average contribution across sectors of the first three principal components is close to thirty percent for all but sectoral real wages (see Table 3). If one takes unweighted averages of sector variables to construct aggregate variables, these same three principle components account for over eighty percent the aggregate variables' variances (Table 4). Interestingly, the first principal component accounts for the majority of the variance of sectoral and aggregate output and labor input while the second principal component accounts for most of the variance of sectoral and aggregate prices and real wages. This suggests that the aggregate factors that affect wages and prices may be different from those that affect output and labor input.

[6] There are a total of 140 sectoral variables yet only 57 observations for these variables. As a result, the variance/covariance matrix of all 140 variables is singular.

3. Common factor model with aggregate monetary and productivity shocks

While the principal components analysis is suggestive of strong co-movement across sectoral variables, I build a common factor model to delve more deeply into the nature of the co-movement and to provide an economic interpretation to these co-movements. In addition to the sectoral variables examined above, I include M2 growth and three month T-bill as observation variables in the system as these have typically played a role in studies of aggregate shocks and to some extent reflect monetary conditions in the economy.

The relationship between the sectoral variables and aggregate factors is given by:

$$Y_t = A(L)Y_{t-1} + H(L)S_t + E_t, \qquad (1)$$

where Y_t is the vector of sectoral data (plus M2 growth and the nominal interest rate), S_t is the vector of aggregate common factors, and E_t is a vector of sector specific or idiosyncratic shocks. H(L) is the factor loading matrix on current and lagged values of the common factors; in the empirical analysis I set the number of lags in H(L) to four. As S_t reflects the co-movement of variables across sectors, the A(L) matrix is restricted so that lags of variables in other sectors are zero. Similarly, the elements of E_t are uncorrelated across sectors but not necessarily with in a sector; that is, sector specific shocks affect variables in that sector but not in variables in other sectors. A low order VAR describes the intra-sector relationship of output, prices, real wages, and labor inputs. Individual sectoral variables are assumed have no direct effect on the aggregate money stock or interest rate.

The evolution of the common factors is governed by

$$S_t = F(L)S_{t-1} + V_t, \qquad (2)$$

where V_t is a vector of shocks to the common factors. The common factors are orthogonal to one another so that F(L) consists of stationary univariate AR(2) processes for the common factors while the elements of V_t are uncorrelated with each other and with the elements of E_t. Based in part on the principal components analysis in the previous section, I will specify three common factors in the benchmark model: a monetary factor ($s_{m,t}$), an aggregate productivity factor ($s_{z,t}$), and a third factor ($s_{f,t}$)

that a priori does not have a specific economic interpretation.[7] I assume the monetary factor shock is distributed: $v_{m,t} \sim N(0, \sigma^2_{s_m})$, while to fix the scale of the aggregate productivity factor and the third common factor I assume $v_{z,t}$ and $v_{f,t} \sim N(0,1)$. Finally, the factor loading in the interest rate equation for $s_{f,t}$ is constrained to be positive.

3.1 Identifying Monetary and Aggregate Productivity Shocks

The monetary factor is assumed to satisfy long-run monetary neutrality; that is, an increase to the monetary factor is assumed to have no affect on real economic activity and that all prices move proportionally to the money stock in long-run. This means that the level of sectoral output, real wages, and labor input are unaffected in the long-run by an exogenous money shock while log sectoral prices, nominal wages, and the money stock move one-for-one in the long-run in response to a monetary shock.[8] While long-run monetary neutrality at the macro level has previously been used to identify monetary shocks (Gali 1992 and Lastrapes and Selgin (1995)), I impose those restrictions on sectoral prices and outputs.[9]

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 Christiano, Eichenbaum, and Evans (1999 and 2005), Gali and Gertler (1999), and Mankiw and Reis (2002) and nominal misperceptions models such as Lucas (1972) and Barro (1976) imply long-run monetary neutrality but do not necessarily have the same predicitions for the short-run.

In order to identify the aggregate productivity factor, I assume that an aggregate productivity shock will result in an increase in sector outputs and real wages in the long-

[7] While the Bai and Ng (2002) criteria suggested two static factors, I start with three common factors in the benchmark dynamic factor model. I do this for two reasons. First, the monetary and productivity factors impose substantial restrictions across sectors and adding another factor might be useful capturing the remaining co-movement across sectors. Second, it seems plausible from economic grounds that there could be important aggregate sources of sector co-movement other than monetary or aggregate productivity shocks.

[8] 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.

[9] Lastrapes and Loo (1998) examine the effect on money shocks on industry level output while Lastrapes (2006) examines the effect of money shock on relative prices. Both these papers use the long-run identifying assumption that a monetary shock has no effect on aggregate real output in the long-run but no such restriction is implied for individual sector outputs or relative prices.

run.[10] This increase need not be the same across sectors, and there is no restriction on the long-run effect of the productivity shock on sectoral prices, labor input, and the stock of money. Unlike monetary neutrality which implies a one-for-one change in prices and money and a zero response for outputs and real wages, the restriction on aggregate productivity takes the form of a sign restriction on the long-run response of sector output and real wages to an aggregate productivity shock. Note that it is not just the long-run restrictions that matter in the identification but also the common factor restrictions. These cross-section restrictions are particularly important here because the cross-section dimension is substantially larger than the time dimension (142 variables in the observation vector versus 57 observations).

For these identification schemes to be valid, the (logarithms) of money stock, sectoral prices, and sectoral wages must be integrated of at least order one (or I(1)). That is, there must be permanent shocks to the money stock, prices and wages in order to use long-run restrictions to identify a factor. In order to use long-run restrictions to identify the aggregate productivity factor, output and real wages must be I(1). For our data, the assumption of nonstationary money stock, prices and wages is uncontroversial. While it is not necessary for our identification scheme, we model sectoral labor input as I(1) as well.[11] The nominal interest rate (here 3 month T-Bill) is arguably I(0) and is modeled as such. This means that the interest rate does not have a direct effect on the identification of the monetary factor. We do use the nominal interest rate to normalize the third common factor.

To see the restrictions imposed by the proposed long run restrictions, write the common factor model implied by equation (1) for a single sector, i:

$$\begin{pmatrix} \Delta p_{i,t} \\ \Delta q_{i,t} \\ \Delta w_{i,t} \\ \Delta l_{i,t} \end{pmatrix} = A_i(L) \begin{pmatrix} \Delta p_{i,t-1} \\ \Delta q_{i,t-1} \\ \Delta w_{i,t-1} \\ \Delta l_{i,t-1} \end{pmatrix} + \begin{pmatrix} H_{i,m}(L) & H_{i,z}(L) & H_{i,f}(L) \end{pmatrix} \begin{pmatrix} s_{m,t} \\ s_{z,t} \\ s_{f,t} \end{pmatrix} + \begin{pmatrix} e_{i,p,t} \\ e_{i,q,y} \\ e_{i,w,t} \\ e_{i,l,t} \end{pmatrix}, \quad (3)$$

[10] While an aggregate labor supply shock could also conceivably move real wages across sectors in the same direction, sectoral output would move in the opposite direction from real wages.

[11] 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 real wages while for log output the unit root null is rejected in only five sectors and for log labor input in six sectors. Note that aggregate output and labor input (summing up gross output and labor input across sectors) also appear to contain a unit roots.

where $(\Delta p_{i,t}\ \Delta q_{i,t}\ \Delta w_{i,t}\ \Delta l_{i,t})'$ is the vector of observable variables in sector i, $(s_{m,t}\ s_{z,t}\ s_{f,t})'$ is the vector of unobserved common factors, $A_i(L)$ is a 4x4 lag polynomial matrix, $H_{i,m}(L)$, $H_{i,z}(L)$, and $H_{i,f}(L)$ are 4x1 vectors that reflect the effect of the current value and four lags of the common factors on the sectoral variables, and $(e_{i,p,t}\ e_{i,q,t}\ e_{i,w,t}\ e_{i,l,t})'$ is the vector of sector specific shocks. I allow these sector specific shocks to be correlated within sectors but not across sectors. For M2 growth and interest rate, the equations have the form:

$$\Delta m2_t = A_{m2}(L)\Delta m2_{t-1} + \begin{pmatrix} H_{m2,m}(L) & H_{m2,z}(L) & H_{m2,f}(L) \end{pmatrix} \begin{pmatrix} s_{m,t} \\ s_{z,t} \\ s_{f,t} \end{pmatrix} + e_{m2,t}\,, \quad (4)$$

and

$$r_t = A_r(L) r_{t-1} + \begin{pmatrix} H_{r,m}(L) & H_{r,z}(L) & H_{r,f}(L) \end{pmatrix} \begin{pmatrix} s_{m,t} \\ s_{z,t} \\ s_{f,t} \end{pmatrix} + e_{r,t}\,. \quad (5)$$

The errors $e_{m2,t}$ and $e_{r,t}$ are uncorrelated with each other and with sector specific shocks.

Long-run neutrality for the monetary factor implies the following restriction:

$$\begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \end{pmatrix} = (I - A_i(1))^{-1} H_{i,m}(1)\,, \quad (6)$$

for every sector. That is, the long-run multiplier of the monetary factor is one for all sectoral prices and zero for sectoral output, real wages, and labor input. For M2, the long-run multiplier for monetary factor must satisfy:

$$1 = (1 - A_{m2}(1))^{-1} H_{m2,m}(1)\,. \quad (7)$$

Thus, the money stock and all prices and nominal wages move one-for-one in the long run with the monetary factor. Because interest rates are stationary, long-run neutrality has no implications for interest rates.

For aggregate productivity the long-run multiplier for sector i variables is:

$$\begin{pmatrix} \eta_{i,p} \\ \eta_{i,q} \\ \eta_{i,w} \\ \eta_{i,l} \end{pmatrix} = (I - A_i(1))^{-1} H_{i,z}(1), \tag{8}$$

where $\eta_{i,p}$, $\eta_{i,q}$, $\eta_{i,w}$, and $\eta_{i,l}$ are the long-run multipliers for sector i price, output, real wage, and labor input, respectively. I impose the sign restrictions, $\eta_{i,q} > 0$ and $\eta_{i,w} > 0$, to ensure that the aggregate productivity factor results in increases in sector output and real wages in the long run. However, these effects can differ across sectors. The long-run responses of sector i price, $\eta_{i,p}$, and labor input, $\eta_{i,l}$, are unrestricted. Similarly, the long-run response of M2 (not shown) is unrestricted.

Other than the long-run effect of the monetary factor and the long-run sign restrictions for the aggregate productivity factor, there are other few restrictions. Most importantly, no "hard" constraints are placed on the short-run responses of prices, output, real wages, and labor input to a money shock nor are constraints placed on the short-run response of sectoral variables to an aggregate productivity shock. Note that the specification does not rule out the possibility that shocks to the other aggregate factors ($s_{f,t}$) can have permanent effects on sectoral variables. As one is primarily interested in identifying the effects of aggregate shocks, the sectoral shocks, e_i's, do not have clear economic interpretations. They do, however, allow the model to capture any sector specific co-movement in output, price, real wage, and labor input not captured by the common (across sectors) factors.

3.2 Bayesian Estimation of Common Factor Model.

I take a Bayesian approach rather than the more standard maximum likelihood approach to estimate the common factor 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). Furthermore, by treating unobserved common factors like parameters, we can obtain the joint posterior distribution of the 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 (6) and (7) can be handled fairly easily. If the common factors were known, it is straightforward to rewrite equations (3) and (4), imposing the restrictions given by (6) and (7), so that the resulting equations are linear equations with no restrictions on parameters (see appendix A2). The inequality restrictions for the long-run response of real wages and output to productivity shock are also easy to implement in this context as parameter draws that do not satisfy the sign restrictions are rejected. The empirical estimate of the posterior distribution is constructed by taking every fifth draw from the Gibbs sample, 10,000 times, after running the sampler for a burn-in period of 100,000 draws. See appendix A4 for a detailed discussion of the Gibbs sampler.

3.3 Prior distributions

For most of the parameters of the model, relatively economically neutral and diffuse priors are employed (see appendix A3 for details). Setting priors over the parameters does have implications for the short-run response of variables to monetary shocks. In our benchmark model, the prior distribution is centered around short-run money neutrality with a relatively large spread of outcomes for the prior distribution. The mean and interior 80% of the implied prior distribution for the impulse responses to a money shock are plotted in Figure 1a.[12] While the prior distributions of the short-run responses are centered around monetary neutrality, one can see that the prior distributions support a wide range of non-neutral outcomes. This is particularly true for individual sectoral responses. For aggregated responses, here just the unweighted average of sectoral responses, the prior distribution is tighter around monetary neutrality but still suggests reasonable likelihood of non-neutral behavior in the short run. In section 6, we discuss an alternative set of priors for which the prior distribution of impulse responses to a monetary shock implies short-run money non-neutrality and coincides with responses typically found in the traditional VAR literature.

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[12] As the responses in Figure 1a 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.

Figure 1b displays the implied prior distribution for the response of sector and aggregate variables to an aggregate productivity shock. The mean of the prior distribution is positive for the response of output and real wages, although the individual sector prior is much more diffuse than that for the aggregate prior. For the response of prices, labor input, M2 growth, and interest rates to a productivity shock, the prior distributions are centered around zero but with substantial dispersion. With the exception of the nominal interest in the current period, the prior distributions for the response of individual sector and aggregate variables to a third aggregate factor shock (not shown) are all centered about zero. This reflects the lack of an a priori interpretation for the third aggregate factor.

4. Empirical Results: Implications for Aggregate Variables

Figure 2 displays the mean of the posterior distribution along with the 10th and 90th percentiles for the monetary factor, the aggregate productivity factor, and the third aggregate factor which I will argue below looks like an aggregate demand factor. From the figure, the monetary factor displays substantially more persistence than either the productivity or the third factor. The monetary factor shows a long swing upward in the mid 1970s and early 1980s and a decline in the late 1980s and through 1990s. These movements mirror the general movements in inflation over the sample. The aggregate productivity and demand factors feature movements that often, but not always, coincide with aggregate business cycles. For example, the productivity factor displays declines in the mid 1970s and early 1980s that coincide with recessions while third aggregate factor displays declines in the early 1990s and 2000s.

Before turning to the sectoral details, it will be instructive to examine the aggregate implications of the estimated model. Doing so will help evaluate whether the estimated aggregate factors make sense in light of more aggregated data. With that in mind, I examine impulse responses and historical decompositions for unweighted averages (across sectors) of sector price, output, real wage, and labor.

4.1 Aggregate impulse response analysis

Figure 3 displays the mean, 10th, and 90th percentiles of posterior distribution for the impulse responses of "aggregate" variables to a shock in the monetary factor. The mean of the cross-section distribution of price growth (inflation) rises in response to an expansionary monetary shock, hence, there is no "price puzzle". Perhaps this is not too surprising given the identifying assumptions, but recall these assumptions did not preclude finding a price puzzle in the short-run. On the other hand, mean output, real wage, and labor growth across sectors do not appear to respond significantly even in the short-run. Again, even though the short-run prior implied monetary neutrality, it was diffuse enough to allow non-neutral responses. Both M2 growth and the nominal interest rate increase in response to a monetary factor shock but do so with some delay.

Figure 4 displays the response of "aggregate" variables to an aggregate productivity shock. Output, real wage, and labor input growth all increase in response to a productivity shock. Furthermore, their responses display strong "humped" shapes. Interest rates also tend to rise after a productivity shock. Inflation, on the other hand, falls in response to a productivity shock. This decline while not as quantitatively large as the output response is long lasting. The strong, procyclical response of labor to a productivity shock I find here contrasts with the results of Gali (1999) and Francis and Ramey (2005) who found a negative response of labor to an identified technology shock My result are, however, consistent with results of Peersman and Straub (2009) whose sign restriction identification yielded a positive response of labor to a technology shock.

Figure 5 displays the "aggregate" responses to the third common factor. Here the mean price, output, and labor input growth rates across sectors increase as does the nominal interest rate. On the other, hand real wage growth falls. These aggregate responses, at least in the short-run, would be consistent with an increase in commodity demand. In fact, the response of inflation, output, labor, and real wages are reminiscent of a shift in the "IS" curve in a traditional IS/LM/AS model with sticky nominal wages. The slightly negative response of M2 growth and positive response of interest rates might also reflect a "lean against the wind" stance for monetary policy in response to positive aggregate demand shocks.

4.2 Historical decompositions of aggregated sectoral variables

Figures 6-9 present posterior distribution for the historical decompositions of the unweighted average (across sectors) of sector price, output, real wage, labor input growth as well as M2 growth and three-month T-Bill rate. In addition to the mean contribution, the figures display the 10^{th} and 90^{th} percentiles of the posterior distribution. Figure 6 displays the contribution of the monetary factor to movements in these "aggregate" variables. From Figure 6, one can observe that the monetary factor contributes very little to movement in aggregate output, real wage, and employment growth, but it does contribute substantially to the long swings in sectoral price growth, M2 growth, and the nominal interest rate. Clearly, the monetary factor reflects lower frequency movements in nominal variables—prices, money stock, interest rates (and implicitly nominal wages as well)—over the sample. In this respect, the monetary factor is quite similar to the "pure inflation" factor in Reis and Watson (2009). However, unlike Reis and Watson, the monetary factor does not imply a one-to-one movement in prices in every period, only in the long run. Recall that the common factor model did not impose the restrictions implied by long-run money neutrality on nominal interest rates, yet, nonetheless the monetary factor explains the run up in nominal interest rates in the 1970s and early 1980s and the run down of nominal rates in the late 1980s and 1990s.

Figure 7 displays the contributions of the aggregate productivity factor to fluctuation in the aggregated sectoral variables. Here, the productivity factor explains a substantial fraction of the movements in the average output growth across sectors. In fact, declines in the aggregate productivity factor contribute to declines in output growth in nearly every single recession, particularly in 1974 and 1980. The productivity factor also contributes substantially to fluctuations in real wage growth, although perhaps not to the extent of its contribution to output growth. The effect of aggregate productivity on labor input growth, on the other hand, is much more modest than its contribution to output growth with perhaps only the decline in labor growth in 1974-75 largely the result of aggregate productivity. Here the results are more in line with those of Gali (1999) in which technology shocks do not contribute much to employment fluctuations. While the productivity factor is not nearly so important in fluctuations of the nominal variables (prices, M2 growth, and interest rate), it does help contribute to the jump up in "aggregate" price growth in 1974-75 and 1980-81.

Figure 8 displays the contribution of the third aggregate factor, which I will interpret as representing an aggregate demand factor. This demand factor contributes to a substantial amount of the fluctuations in output growth and most of the fluctuations in labor input. In fact, with the exception of 1974-75 and 1980-1982 periods, this factor plays a key role in contributing to declines in output and labor input during recessions. On the other hand, the demand factor's contributions to real wage growth and short-run fluctuations in inflation are more modest than the contributions of the aggregate productivity factor. While the demand factor contributes little to the fluctuations in M2 growth, it does contribute to short-run swings in the nominal interest rate.

Figure 9 shows the posterior distribution of the total contribution of the aggregate factors. The resulting unexplained fluctuations are the result of idiosyncratic factors for the sectors. Together the three aggregate factors contribute to a large portion of the fluctuations in the unweighted average of sector price, output, real wage, and labor input growth. Of course, taking the average of the sectoral variables tends to average away the contribution of the sectoral idiosyncratic factors for prices, output, real wages, and labor input tend leaving the bulk of "aggregate" fluctuations to be explained by the common factors. This does, however, suggest that the three common factors are sufficient to capture nearly all of the cross-sectoral co-movement. For M2 growth and interest rates, the idiosyncratic factors are more evident leaving a substantial amount of their fluctuations unexplained by the three aggregate factors.

4.3 Interpretation of aggregate factors.

The estimated monetary factor appears to capture the long swings in nominal variables over the sample. As such, shocks to this monetary factor probably do not reflect so-called monetary policy shocks as typically discussed in the VAR literature. These "monetary policy shocks" typically identified in the VAR literature can thought of surprises or mistakes in the monetary authority's reaction function. In this paper, shocks to the monetary factor might be better thought of as shocks to the long-run inflation target in something like a Taylor rule. Shocks in this long-run target will over time change inflation, interest rates, and, with stable velocity, the money growth rate by similar proportions. In the short-run, however, these variables may respond differently to change in the long-run inflation target.

The aggregate productivity factor was identified by assuming that a positive shock to this factor increased all sector real wages and outputs in the long run. Could this aggregate factor just be picking up business cycles driven by other phenomenon rather than aggregate productivity shocks? To get a sense whether the productivity factor is truly capturing productivity, we examine the actual unweighted average across sectors of the logarithm of output per labor input, $\log(Q_{i,t} / L_{i,t})$. Economic theory suggests that shocks to productivity should move sector (log) real wages and sector (log) average products of labor by similar amounts. In fact, if technology is Cobb-Douglas, the response of log real wages and log average products should be equal.[13] While nominal frictions and adjustment costs may prevent real wages and average products from moving together in the short run, there is strong a priori reasons to believe they are likely to move together in the long-run in response to shocks in productivity.

The top panel of Figure 10 displays the average growth rate across sectors of real wages and output per labor. While over the sample there are periods in which the two series move together, there is also a substantial portion of the sample in which to two series do not move in the same direction. The bottom panel of Figure 10 plots the long-run contribution of the aggregate productivity factor to real wage growth, $\sum_{i=1}^{N} \eta_{i,w} s_{z,t} / N$, and output per labor growth, $\sum_{i=1}^{N} (\eta_{i,q} - \eta_{i,l}) s_{z,t} / N$, where $\eta_{i,w}$, $\eta_{i,q}$, and $\eta_{i,l}$ are the long-run multipliers for sector i of a productivity shock for real wage, output, and labor given in equation (8). Unlike actual real wages and average products, the long-run contribution of the productivity factor to real wages and average products move together quite closely.[14] Furthermore, the correlation of the productivity factor and the unweighted average of sector KLEM Solow residual growth is 0.63. Taken together, it

[13] Recall, I am deflating nominal wages by its product price and not price of households' consumption goods.

appears that the estimated productivity factor generates movements in real wages and average products consistent with aggregate productivity shocks.

5. Empirical results: sectoral variables.

5.1 Sectoral impulse responses

Turning to what happens at the sectoral level, Figure 11 displays the mean of the posterior distribution of the response to a monetary shock for every sector at various horizons. The horizontal axis displays the sector numbers referenced in Table 1. Unlike previous impulse response diagrams, these figures display the (log) level of sector variables so that one can better discern the effect of shocks on relative sectoral behavior. Looking at log level of sector prices first, one observes that a monetary shock affects sector prices broadly—all sector prices rise; there is no evidence of a price puzzle at the sectoral level. All prices, however, do not move one-for-one, suggesting that monetary shocks have relative price effects, at least in the short run. These relative price effects are small initially, rise as the horizon lengths, and then fall again as the horizon gets large (horizon = 20). Among the sectors with the largest price increases are: coal mining, crude oil and natural gas, gas utility services, and petroleum refining. Among the sectors with the smallest price increases are: communications, personal and business services, and printing.

Monetary factor shocks have different real effects across sectors in the short-run as well, as some sectors increase while others decrease. Again the sectoral differences are modest at first, rise as the horizon lengthens, and then fall again as the horizon gets large. The sectors with the largest positive output response include: primary metals in the initial period, gas utility service, instruments, and communication in later periods. The sectors with the largest negative responses are apparel and footware initially and electrical machinery, transportation equipment, and metallic ore mining at longer horizons. Interestingly the sectors with the largest real wage declines are typically those with the largest labor input increases (crude oil and natural gas, coal mining, gas utilities).

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[14] Note that while $\eta_{i,w}$ and $\eta_{i,q}$ were restricted to be positive, there was no restrictions on $\eta_{i,l}$ nor on the relative sizes of these long-run multipliers in the estimation.

Figure 12 displays the sectoral responses to an aggregate productivity shock. By construction, aggregate productivity shocks have a positive effect on all sectors' outputs and real wages in the long-run. Nonetheless, there are substantial differences across sectors. Sectors like transportation equipment, fabricated metal, machinery, electrical machinery, rubber show large increases in their outputs while agriculture, FIRE, and food show only small increases. Prices in most sectors decline with agriculture, lumber and wood products, and FIRE being notable exceptions. Labor input generally increases across sectors but falls in five sectors, the largest declines occurring in personal and business services, agriculture, crude oil and natural gas, and printing sectors.

Figure 13 displays the sectoral responses to a shock in the third aggregate factor. Recall this factor's aggregate impulse responses were reminiscent of an increase in commodity demand in an IS/LM model. Again the effect of a shock to this "aggregate demand" factor varies substantially across sectors. Among the sectors with the largest price responses are: primary metals and petroleum refining at short horizons and petroleum refining, chemicals, and nonmetallic minerals at longer horizons. The sectors with the largest output response include: machinery, electrical machinery, fabricated metals and primary metals while agriculture, FIRE, lumber and wood products, and construction display the smallest responses. The sectors with the largest labor responses include many of the sectors with large output responses plus the apparel and printing sectors.

To get a sense of whether sector responses vary according to how the sectors' goods are used, I classified sectors according to whether they are used primarily as a consumption good, an investment good, or an intermediate good (see Table 1). Figures 14-16 display the average sectoral responses (across good type) to the three types of aggregate shocks. From Figure 14, it appears that the response to monetary shocks does not differ substantially across of type of good. Of the three types of goods, the investment good sector's output and labor input respond the most to a shock in the productivity (see Figure 15). This is consistent with standard theoretical response of various types of goods to a productivity shock. While the responses of output, real wages, and labor input do not vary much across good type for a demand shock (see

Figure 16), prices of intermediate goods appear to respond more than do the prices of consumption or investment goods.

6. Robustness

6.1 Alternative short-run priors.

While the identification of monetary shocks imposes long-run neutrality, one may want to examine the sensitivity of the results to alternative priors about the short-run responses of monetary shocks. In particular, I consider a prior distribution in which the responses of output, price, labor input, and interest rates to a monetary shock correspond, at least in the short-run, to those typically employed in the VAR literature. In this literature, output responds positively and interest rates negatively to an expansionary monetary shock. There is much less consensus about the initial response of prices to a monetary shock, witness the discussion in the literature of the "price puzzle". Here, I set the mean of the prior distribution for prices so that they do not respond in the initial period to a monetary shock as suggested by the VAR analysis of Christiano, Eichenbaum, and Evans (1999). Unlike the benchmark model in which the prior responses are fairly diffuse, I assume that the prior distribution around the so-called traditional VAR prior is relatively tight. For the response of real wages to a monetary shock, I continue to assume the prior distribution is centered around zero and is fairly diffuse.

Figure 17 presents the means and 10^{th} and 90^{th} percentiles for the "traditional VAR" prior distribution. From Figure 17, the mean of the prior distribution for the initial response of sectoral and aggregate output and labor input are positive while the mean of the prior distribution for the nominal interest rate response is negative. For individual sectors, prior distribution is set so that a wide range of sectoral responses is still possible—for example, it is quite possible for an individual sectoral output to fall in response to an expansionary monetary shock. The aggregate (or unweighted mean response across sectors) responses, however, suggest the "traditional VAR" responses to a monetary shock—initially aggregate output (and labor input) rise and nominal interest rate falls while price remain unchanged. Note that the prior distribution implies a "zig-zag" shape for the output and labor responses. The reason for this shape is that long-run neutrality implies that positive output and labor responses initially must be offset by subsequent negative responses.

Figure 18 displays the posterior distribution of the impulse responses of aggregate variables to a monetary factor shock. Unlike the benchmark model, setting fairly tight priors results in both output and labor input growth rising in response to a monetary factor shock. This positive response is short-lived as long-run neutrality requires this initial positive response in growth to be followed by negative responses. Given that the results for the short-run monetary priors are quite different, this suggests that the data alone are not too informative about the short-run response of output to a long-run neutral monetary shock. On the other hand, despite the relatively tight prior that the inflation response is zero, the posterior distribution implies a strong positive response of inflation to a monetary factor shock. Clearly, the data suggest a strong initial price response to a shock in the monetary factor. Similarly, despite a relatively tight prior around a negative interest rate response, the posterior distribution for nominal interest rate response is close to zero for the initial response and positive shortly thereafter. Finally, for the initial response of real wage growth, the mean of the posterior distribution is negative, although the interior 80 percentiles of the posterior distribution includes zero. The general tendency for real wages to fall is in line with what traditional models of wage stickiness would predict for a monetary shock.

Perhaps not surprisingly, the alternative prior distribution does not substantially change the impulse responses to a productivity shock (not shown). Similarly, the "traditional VAR" prior has only a small effect on the means of the posterior distribution for the responses to a shock to the third aggregate factor (demand). However, under the "traditional VAR" prior, the posterior distributions of responses to the "demand" factor are more diffuse.

Figure 19 displays the contribution of the monetary factor to the historical decomposition of the aggregated sectoral variables when the "traditional VAR" prior is used. Comparison of these decompositions with those of the monetary neutral prior (Figure 6 above) suggests that assuming non-neutral short run priors does not change the interpretation of the main sources of fluctuations over our sample. Regardless of whether short-run priors imply monetary non-neutrality or neutrality, most of the long swings in prices, money stock, and interest rates are due to the monetary factor. On the other hand, the monetary factor does not contribute much to fluctuations in real output, real wage, or labor growth over the sample regardless of the short-run monetary prior. Likewise, assuming non-neutral priors does not appreciably change the contributions of the other factors. This suggests that it is the long-run identifying assumptions and the data rather than the short-run priors that are primarily responsible for the historical decomposition results.

Figure 20 displays the mean of the posterior distribution for all the individual sector variables' responses to a monetary factor shock when non-neutral priors are assumed. As in the benchmark model, there are substantial quantitative differences in the sectoral responses to a monetary shock when the alternative, non-neutral monetary priors are used. Unlike the benchmark model, the alternative priors result in widespread increases in output and labor input across sectors during the initial period after a monetary factor shock. Much like the benchmark model, the sectors with greatest output growth increases were primary metal manufacturing and transportation initially and gas utility service and chemicals later. While prior distributions for the initial sectoral price responses are centered around zero, the posterior mean for nearly all the sectors is positive. Thus, the data (and not the priors) suggests that the inflationary effect of the monetary factor is widespread across sectors. The sectoral effects of productivity factor shocks and the demand factor shocks for the alternative short-run monetary prior is similar to the benchmark model.

6.2 Adding additional aggregate factors.

To test the sensitivity of the initial assumption of three aggregate factors, I added an additional aggregate factor to the common factor model. This factor was normalized so that it resulted in an increase in M2 growth in the initial period, but was otherwise unrestricted. Like the demand factor in the three factor model, the priors of the other parameters were centered around zero and relatively diffuse. It turns out adding this factor does not alter the previous results for the monetary and productivity factors. It does seem to reduce the effect of what was termed the demand factor in the previous model. Figure 21 displays the contribution of this fourth factor to fluctuations in the aggregated sectoral variables over the sample. As one can see from the figure, this factor adds only a little to explaining fluctuations in the aggregated sectoral variables.

7. Oil prices, sectoral and aggregate fluctuations.

The previous results suggested that the aggregate productivity factor had important contributions to both sectoral and aggregate output fluctuations. In particular, the decline in output during the recessions of 1974-75 and 1980 show up largely as due to fluctuations in the aggregate productivity factor. It is possible that this result might actually reflect the effect of oil price changes that also occurred during these time periods. Indeed, oil prices have been considered to be an important source of fluctuations in their own right.[15] To determine whether the estimated aggregate productivity factor was in fact picking up the effect of oil prices on sectoral economic activity, I add oil prices to the observation vector and add an additional factor to the benchmark model.

To be consistent with the other sectoral data, I include the growth rate in nominal oil prices to the vector of observables. Identification of the monetary and productivity factors is the same as the benchmark model above. Like the other nominal variables, I assume that the monetary factor affects the (log) level of nominal oil prices one-for-one in the long run so that the real oil price is unaffected in the long-run by the monetary factor. Also like the other nominal prices, I place no restrictions on the long-run effect of the aggregate productivity factor on nominal oil prices. In addition to monetary and productivity factors, I include two additional common factors. One factor is normalized so that it has a positive effect on the interest rate in the current period; this will turn out to be similar to the so-called demand factor in the benchmark model. The other is normalized so that it has a positive effect on nominal oil prices in the current period; I will interpret this factor as an oil factor. As in the benchmark model, there are no additional restrictions on the factor loadings aside from these normalizations. I present the results from model with "traditional VAR" priors about the impact effects of the

[15] Many studies including Hamilton (1983), Mork (1989), and Hamilton (2009) have emphasized the important of for aggregate fluctuations. Other papers have questioned the importance of oil price shocks on economic activity. These include Hooker (1996), Bernanke, Gertler, and Watson (1997), and Barsky and Killian (2002) among others. Most of these papers examined the effect of oil prices on aggregate economic activity. Davis and Haltiwanger (2001) examine the effect of oil prices on sectoral level data.

monetary factor; these results are largely unaffected if short-run money neutrality priors were used instead.

First, how are the results for monetary and productivity factors affected by including oil prices and another factor into the benchmark model? Figures 22 and 23 display the contribution of the monetary and productivity factors to the historical decompositions of "aggregate" inflation, output, real wage, and labor growth for the model with oil prices. Adding oil prices and an "oil factor" to the model, does not appreciably change the relative contributions of the monetary and productivity factors. Monetary factor still contributes to the long swings in nominal variables over the sample and the productivity factor is an important contributor to output and real wage fluctuations. Even the in 1974 and 1980 recessions, the aggregate productivity factor is still an important source output declines. Thus, adding oil prices and an oil factor do not appreciably affect the previous results for the monetary and productivity factors.[16] Figure 24 displays the contribution of the oil factor to historical fluctuations in the aggregated sectoral variables. From Figure 24 one observes that the oil factor has only a moderate contribution to output and labor fluctuations and an even smaller contribution to inflation and real wage growth.

Does the oil factor shock look like an "oil shock"? Typically, oil shocks are envisioned to have a negative affect on output and employment and a positive effect on inflation. Figure 25 displays the response of the aggregated sectoral variables to a shock in the oil factor. As is typical in the oil shock literature, a shock to the oil factor does result in a decrease in output and labor growth (remember, by assumption, an oil factor shock has a positive affect on current oil prices). However, unlike the literature, inflation responds negatively to an oil price shock. This suggest a shock to the oil factor acts more like an aggregate demand shock rather than an aggregate supply shock.

Figure 26 displays the individual sector responses to a shock in the oil factor. The sector responses also suggest that an oil factor shock acts more like a demand shock than a typical supply shock. Prices, output, and labor across a wide group of sectors fall in response to a shock in the oil factor. Only prices in the crude oil, petroleum, and gas

[16] Adding oil prices and an oil factor also do not substantively change the impulse response functions for monetary, productivity, and demand factor shocks.

utility sectors rise in response to an oil factor shock while output and labor in the crude oil, FIRE, and, interestingly, construction sectors rise.[17] These results are consistent with the demand channel for transmission of oil price increases emphasized recently by Edelstein and Kilian (2009). My sectoral results do not suggest a widespread supply channel for oil prices. The sectors hardest hit, in terms of output and labor declines, by an oil factor shock include primary metals manufacturing, machinery, and autos at short to medium horizons and textiles and apparel at longer horizons.

Given that the oil factor is only a modest contributor to fluctuations in "aggregate" variables, to what extent are oil prices themselves are driven by fluctuations in other factors? Figure 27 displays the response of oil price changes to shocks in the other aggregate factors. Here there is a strong response of oil price changes to monetary and particularly "demand" factor shocks, but little effect of productivity factor shocks on oil prices. Interestingly, the response of oil prices to an oil factor shock and to a demand factor shock look very similar (but the responses of the other variables look very different). Figure 28 displays the historical decomposition of (nominal) oil price changes over the sample. While the monetary and productivity factors explain very little of the oil price fluctuations over the sample, the demand factor explains a large portion of the oil price fluctuations. In particular, the oil price increases at the end of our sample are driven primarily by the aggregate demand factor and not by the oil factor. On the other hand the both the oil price and aggregate demand factors contribute to the 1974-75 oil price spike while the oil price factor is largely responsible for the oil price increases in 1980 and in 1990. These results suggest that a large fraction of oil price fluctuations are the result of oil demand rather than oil supply fluctuations. This is consistent with results of Barsky and Killian (2002) and Kilian (2009) who have argued for an important demand component in oil price fluctuations.

8. Conclusion

In this paper, I used matched sectoral data on output, prices, real wages, and labor input to identify and quantify the effect of aggregate shocks on sectoral economic

[17] Output in the agriculture sectors rises but not employment, while labor rises in government enterprises but not output.

activity. Using the restrictions of long-run monetary neutrality to help identify monetary shocks and long-run sign restrictions on sector outputs and real wages for productivity shocks, I estimated aggregate monetary and productivity factors from sectoral data. Among the finding are: much of the common low frequency movements in sector price growth, M2 growth, and interest rates was captured by the estimated monetary factor. This factor, however, explained little of the fluctuations in output growth, real wages, or labor growth. Apparently, long-swings in overall inflation are not related to fluctuations in real economic activity even in the short run. Productivity shocks on the hand have widespread effects across sectors and, in contrast to the results of Gali (1999) and Francis and Ramey (2005) are associated with increases labor input both at the aggregate and sectoral level. On the other hand, historical decompositions suggest that the productivity factor had only modest contribution to labor fluctuation over the sample. Finally, results for monetary and productivity factors were robust to the inclusion of oil prices and an oil factor in the model.

Among the findings of this paper is that what looked like an aggregate demand factor played an important role both aggregate and sectoral fluctuations. The source of and the economic significance of this demand factor are largely unexplored in this paper. To what extent this factor represents autonomous demand, fiscal policy, or financial and credit market effects is an interesting question for future research.

Appendix

A.1 State space representation of the common factor model

The common factor model outlined in equations (1) and (2) can be written in state space form as

$$Y_t = A(L)Y_t + HS_t + E_t \qquad \text{(A1)}$$

$$S_t = FS_{t-1} + V_t \qquad \text{(A2)}$$

where

$$Y_t = \left(\Delta p_{1,t}\ \Delta q_{1,t}\ \Delta w_{1,t}\ \Delta l_{1,t} \quad \cdots \quad \Delta p_{35,t}\ \Delta q_{35,t}\ \Delta w_{35,t}\ \Delta l_{35,t} \quad \Delta m2_t \quad r_t\right)',$$

$$E_t = \left(e_{1,p,t}\ e_{1,q,t}\ e_{1,w,t}\ e_{1,l,t} \quad \cdots \quad e_{35,p,t}\ e_{35,2,t}\ e_{35,w,t}\ e_{35,l,t} \quad e_{m,t} \quad e_{r,t}\right)',$$

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

$$V_t = \left(v_{m,t}\ v_{z,t}\ v_{f,t} \quad 0\cdots 0 \quad \cdots \quad 0\cdots 0\right)',$$

$$A(L) = \begin{pmatrix} A_1(L) & & 0 \\ & \ddots & \\ 0 & & A_{35}(L) \end{pmatrix}, \text{ where } A_i(L) \text{ is a VAR(1) for } \left(\Delta p_{i,t}\ \Delta y_{i,t}\ \Delta w_{i,t}\ \Delta l_{i,t}\right)',$$

$$\text{and } F = \begin{pmatrix} \rho_{m,1} & & & \rho_{m,2} & & & & \\ & \rho_{m,1} & & & \rho_{m,2} & & 0_{3,3(N-2)} & 0_{3,3} \\ & & \rho_{m,1} & & & \rho_{m,2} & & \\ & I_3 & & & 0_{3,3} & & 0_{3,3(N-2)} & 0_{3,3} \\ & 0_{3,3} & & & I_3 & & 0_{3,3(N-2)} & 0_{3,3} \\ & 0_{3(N-2),3} & & & 0_{(J+1)(N-2),J+1} & & I_{(J+1)(N-2)} & 0_{3(N-2),3} \end{pmatrix}.$$

$E_t \sim N(0, R)$, where

$$R = \begin{pmatrix} R_1 & & & & \\ & \ddots & & 0 & \\ & & R_{35} & & \\ & 0 & & \sigma^2_{m2} & \\ & & & & \sigma^2_r \end{pmatrix} \text{ and } R_i = E\left[\left(e_{i,p,t}\ e_{i,q,t}\ e_{i,w,t}\ e_{i,l,t}\right)\left(e_{i,p,t}\ e_{i,q,t}\ e_{i,w,t}\ e_{i,l,t}\right)'\right].$$

$v_{m,t} \sim N(0, \sigma^2_{s_m})$, $v_{z,t} \sim N(0,1)$,.

The factor loading matrix, H, reflects the restrictions given in equations (6)-(8).

A2 Imposing Long-run Neutrality Restrictions.

I impose the restrictions given by equations (6) and (7) by rewriting equations (3)-(4) so that the restrictions automatically hold. The resulting equations the sector variables are:

$$\begin{pmatrix} \Delta p_{i,t} - s_{m,t} \\ \Delta q_{i,t} \\ \Delta w_{i,t} \\ \Delta l_{i,t} \end{pmatrix} = A_i(L) \begin{pmatrix} \Delta p_{i,t-1} - s_{m,t-1} \\ \Delta q_{i,t-1} \\ \Delta w_{i,t-1} \\ \Delta l_{i,t-1} \end{pmatrix} + \left(\tilde{H}_{i,m}(L) \quad H_{i,z}(L) \quad H_{i,f}(L)\right) \begin{pmatrix} \Delta s_{m,t} \\ s_{z,t} \\ s_{f,t} \end{pmatrix} + \begin{pmatrix} e_{i,p,t} \\ e_{i,q,y} \\ e_{i,w,t} \\ e_{i,l,t} \end{pmatrix} \tag{A3}$$

$$\Delta m2_t - s_{m,t} = A_{m2}(L)(\Delta m2_{t-1} - s_{m,t-1}) + \left(\tilde{H}_{m2,m}(L) \quad H_{m2,z}(L) \quad H_{m2,f}(L)\right) \begin{pmatrix} \Delta s_{m,t} \\ s_{z,t} \\ s_{f,t} \end{pmatrix} + e_{m2,t} \tag{A4}$$

The parameters in (A3) and (A4) are unrestricted and can be estimated by OLS if the values of $s_{m,t}$, $s_{z,t}$, and $s_{f,t}$ were known. The restrictions implied by equations (6) and (7) hold when (A3)-(A4) are converted back to the original system.

A3. 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,.5)). The factor loadings on the nonmonetary common factors, $H_{i,z}(L)$, $H_{i,f}(L)$, are assumed to be normally distributed N(0,10c^j), where c = .9 and j is the lag. The variance/covariance of sectoral shocks, R_i, is distributed $IW(\nu\omega_i\hat{R}_i\omega_i', \nu)$ where $\nu = 5$, $\hat{R}_i$ is the variance/covariance matrix of residuals from a VAR(1) fit to sector i data, and ω_i is a diagonal matrix with $\text{sqrt}(1-\sum_{i=1}^{3}\alpha_{j,i})$ where $\sum_{i=1}^{3}\alpha_{j,i}$ is the proportion of the variance of variable j explained by the three largest principal components presented in Table 2. The prior distribution for σ^2_{m2} and σ^2_r is $IG(5/2, 2.5/2)$ while the prior distribution for σ^2_{sm} is $IG(5/2, 5/2)$.

The parameters on the lagged polynomials $\tilde{H}_{i,,m}(L)$ and $\tilde{H}_{m2,,m}(L)$ in equations (A3)-(A4) reflect the short-responses of sectoral variables to the monetary factor. For the benchmark model which assumes monetary neutrality, the prior distribution for parameters in $\tilde{H}_{i,,m}(L)$ and $\tilde{H}_{m2,,m}(L)$ were distributed N(0,6c^j) where c = 6 and j is the lag.

Section 6.1 presents alternative priors over the short-run response of sector output, prices, real wages, and labor input to a monetary factor shock. This prior assumes little adjustment in prices in the initial period, while output and employment rise and interest rates fall. To set this quantitatively, one can think of nominal money demand (in logs) as:

$$m_t = p_t + q_t - \varepsilon r_t \quad (\varepsilon = \text{semi-elasticity of money demand}), \qquad \text{(A5)}$$

or money, m_t, equals nominal income, $p_t + q_t$, less velocity, εr_t. An exogenous increase in money supply can be broken into a change in nominal income 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, the mean response in current period is: $\Delta p_t = \kappa\eta s_{m,t}$, $\Delta q_t = \Delta l_t = \kappa(1-\eta)s_{m,t}$, $\Delta r_t = -(1/\varepsilon)(1-\kappa)s_{m,t}$ where κ equals the fraction of the quantity of money demand increase due to nominal income, $1-\kappa$ equals the fraction of the quantity of money demand increase due to velocity, η equals the fraction of nominal income increase due to prices, while $1-\eta$ equals the fraction of nominal income increase due to output. To coincide with traditional VAR responses to money shock, I choose κ = 0.67, η = 0.0, and ε = 0.3. Thus, the prior distribution for coefficient on current period monetary factor in equation (A3) is $\tilde{h}_{i,p,m,0} \sim N(-1,1)$ and $\tilde{h}_{i,y,m,0}, \tilde{h}_{i,l,m,0} \sim N(0.67,1)$. The current period coefficient of the monetary factor in the interest rate equation $h_{r,m,0} \sim N(-10/9,.5)$. The priors for the coefficients on the lagged monetary factor in equations (A3) and in the interest rate equation are set to be the same distributions as in the benchmark model described in the previous paragraph.

A4. Bayesian estimation

The objective is to find the posterior distribution of both the parameters, Θ, and the unobserved state vector, $\mathbf{S}$, given the data, $\mathbf{Y}$, or $P(\Theta,\mathbf{S} \mid \mathbf{Y})$. 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). 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 multi-move 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

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

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

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

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 $\nu_m = T + 5$ and $\delta_m = (Y_m - X_m \tilde{\rho}_m)'(Y_m - X_m \tilde{\rho}_m) + 5$.

4. Given the state vector and the covariance matrix, R_i, draw parameters in equations (A3) for the thirty-five sectors. As the explanatory variables are the same across regressions, the posterior distributions have similar forms as those in step 2 and 3 with the linear regressions given by equations (A3). Parameter draws which resulted in a nonstationary system for (A3) were discarded as were draws in which the sign restrictions for $\eta_{i,q}$ and $\eta_{i,w}$ did not hold.

5. Given the state vector and the parameter vector for A(L), variance/covariance matrix R_i from $IW(\nu\omega_i\hat{R}_i\omega_i' + \sum_{t=1}^{T} e_{i,t}e_{i,t}', \nu + T)$ where $e_{i,t}$ is the vector of sector specific shocks in equation (A3)..

6. Repeat steps 1-5. This is done for a burn in period of 100,000 draws after which every fifth draw is used to form the posterior distribution consisting of total of 10,0000 draws.

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Table 1. Intermediate and final uses of sectoral output in 1992

	Sector	Fractions of output in different uses				
		Total intermediate uses	Personal consumption expenditures	Private fixed investment	Government expenditures	Net exports
		(1)	(2)	(3)	(4)	(5)
1	Agriculture	0.84	0.11	0.00	0.00	0.02
2	Metallic ores mining	0.77	0.00	0.00	-0.01	0.24
3	Coal mining	0.88	0.00	0.00	0.00	0.11
4	Crude oil and natural gas	1.42	0.00	0.00	0.00	-0.42
5	Nonmetallic minerals	1.01	0.00	0.00	0.00	-0.02
6	Construction	0.23	0.00	0.53	0.23	0.00
7	Food and kindred products	0.38	0.61	0.00	0.02	-0.01
8	Tobacco products	0.08	0.76	0.00	0.00	0.11
9	Textile	0.85	0.13	0.04	0.01	-0.04
10	Apparel	0.31	1.03	0.00	0.03	-0.41
11	Lumber and wood products	0.92	0.03	0.05	0.00	-0.01
12	Furniture and fixtures	0.13	0.50	0.38	0.07	-0.08
13	Paper	0.85	0.12	0.00	0.03	-0.01
14	Printing	0.60	0.29	0.00	0.08	0.02
15	Chemicals	0.66	0.26	0.01	0.05	0.01
16	Petroleum refining	0.56	0.36	0.00	0.10	-0.02
17	Rubber	0.89	0.13	0.00	0.02	-0.06
18	Footwear, leather and	0.41	1.73	0.00	0.02	-1.19
19	Stone	0.98	0.06	0.00	0.01	-0.06
20	Primary metal	1.08	0.00	0.00	0.00	-0.08
21	Fabricated metal	0.92	0.04	0.04	0.02	-0.02
22	Machinery	0.46	0.03	0.47	0.06	-0.02
23	Electrical machinery	0.68	0.21	0.17	0.07	-0.13
24	Motor vehicle	0.33	0.48	0.35	0.05	-0.20
25	Transportation equipment	0.25	0.09	0.14	0.36	0.22
26	Instruments	0.27	0.09	0.39	0.27	-0.01
27	Misc manufacturing	0.34	0.92	0.14	0.06	-0.48
28	Trans. and warehousing	0.57	0.24	0.02	0.06	0.11
29	Communication	0.46	0.44	0.02	0.06	0.02
30	Electric utility service	0.51	0.41	0.00	0.09	0.00
31	Gas utility service	0.64	0.31	0.00	0.04	0.01
32	Wholesale and retail trade	0.26	0.63	0.05	0.01	0.05
33	FIRE	0.36	0.59	0.02	0.02	0.02
34	Personal and busi. services	0.42	0.56	0.01	0.00	0.01
35	Govt. enterprises	0.58	0.37	0.00	0.06	0.00

Note: These ratios have been calculated from BEA's 1992 Benchmark I-O Table. The shares may not add up to 1 because changes in business inventories are not included in investment

Table 2. Percentage of the Sectoral Variances Explained by First Five Principal Compenents

	Sectoral Price Growth		Sectoral Output Growth		Sectoral Real Wage Growth		Sectoral Labor Input Growth		All sectoral data	
Principal component	percent	cumulative	percent	cumulative	percent	cumulative	percent	cumulative	percent	cumulative
1	0.48	0.48	0.44	0.44	0.33	0.33	0.29	0.29	0.21	0.21
2	0.11	0.59	0.12	0.56	0.11	0.44	0.14	0.43	0.17	0.38
3	0.08	0.67	0.08	0.64	0.09	0.53	0.11	0.54	0.08	0.46
4	0.05	0.72	0.06	0.70	0.07	0.60	0.09	0.63	0.06	0.52
5	0.05	0.77	0.05	0.75	0.07	0.67	0.07	0.70	0.05	0.57

Table 3. Average (across sectors) contribution to individual sector variables of the first five principal components from all sectoral data				
	Sectoral price growth	Sectoral output growth	Sectoral real wage Growth	Sectoral labor input growth
Principal component	percent	percent	percent	percent
1	0.04	0.30	0.04	0.22
2	0.22	0.05	0.14	0.03
3	0.02	0.04	0.03	0.05
4	0.04	0.02	0.03	0.04
5	0.02	0.03	0.03	0.06
Sum of 1st five components	0.34	0.44	0.27	0.42

Table 4. Percentage of variance of the aggregate (unweighted mean across sectors) variables explained by first five principal components from all sectoral data				
	Aggregate price growth	Aggregate output growth	Aggregate real wage growth	Aggregate labor input growth
Principal component	percent	percent	percent	percent
1	0.04	0.87	0.00	0.81
2	0.71	0.00	0.70	0.09
3	0.02	0.06	0.02	0.00
4	0.02	0.00	0.00	0.00
5	0.01	0.00	0.00	0.03
Sum of 1st five components	0.80	0.93	0.72	0.93

Figure 1a. Mean, 10th, and 90th percentiles of prior distribution of
responses to monetary factor shock

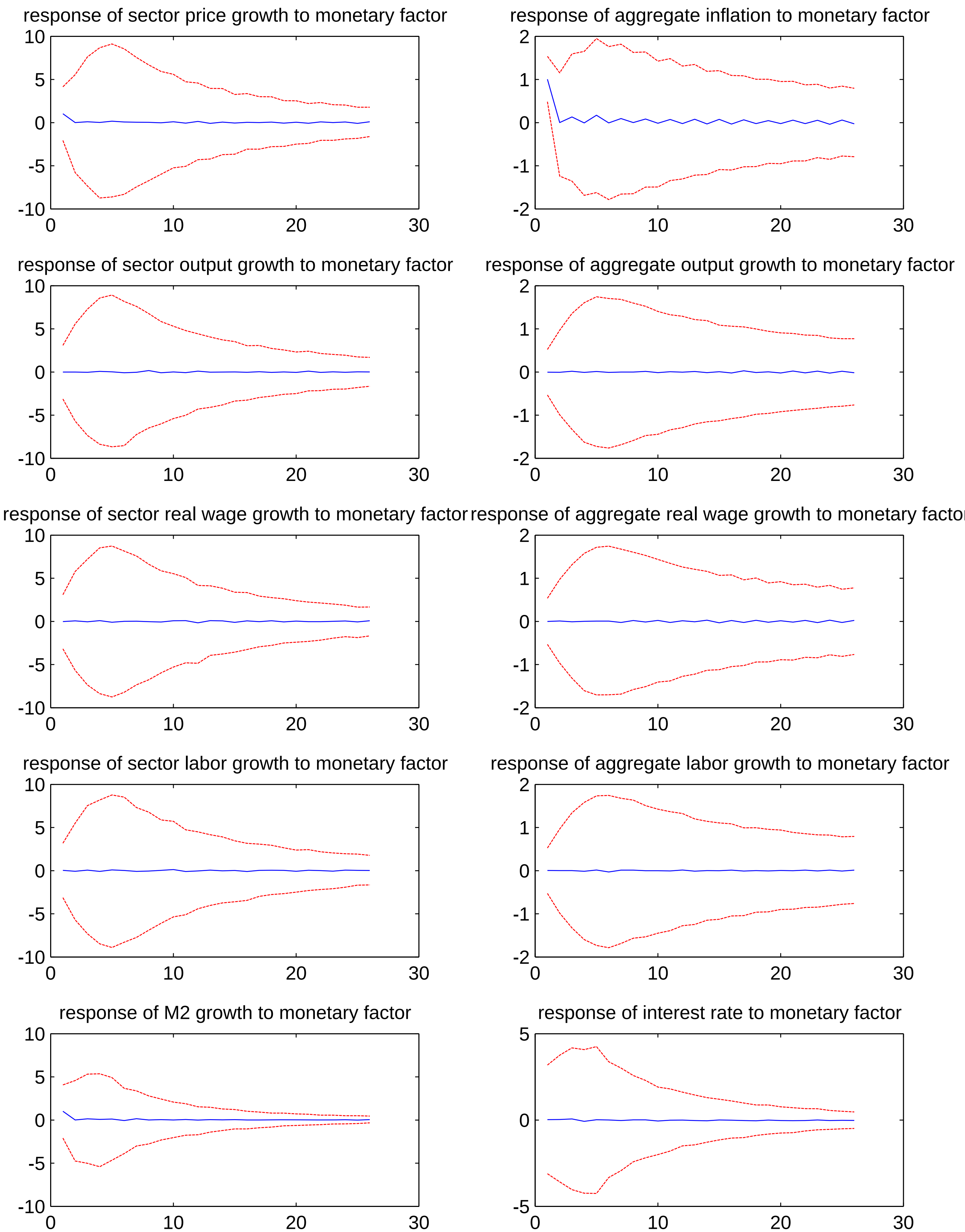


Figure 1b. Mean, 10th, and 90th percentiles of prior distribution of
responses to productivity factor shock

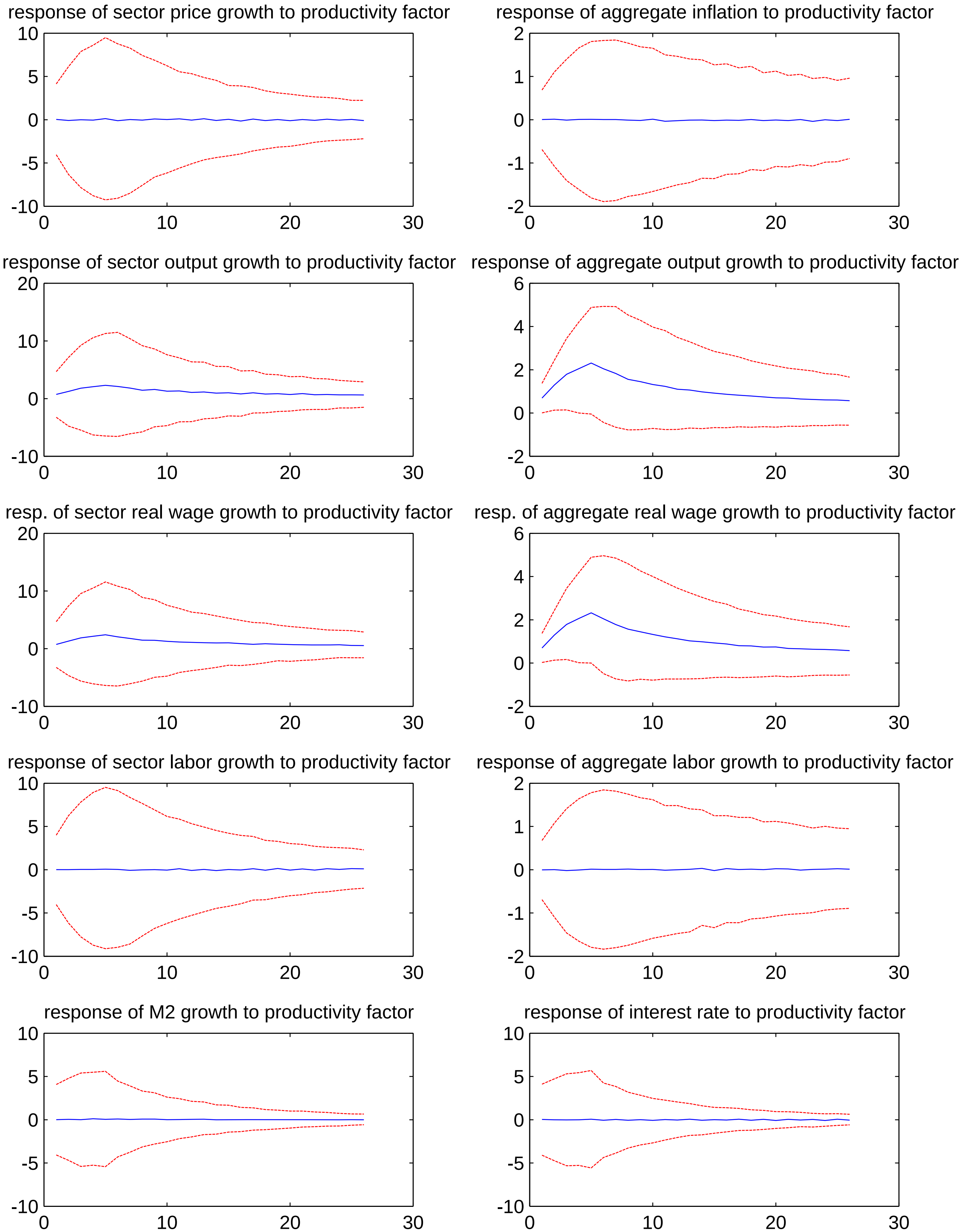


Figure 2. Mean, 10th, and 90th percentiles of the posterior distribution of aggregate factors

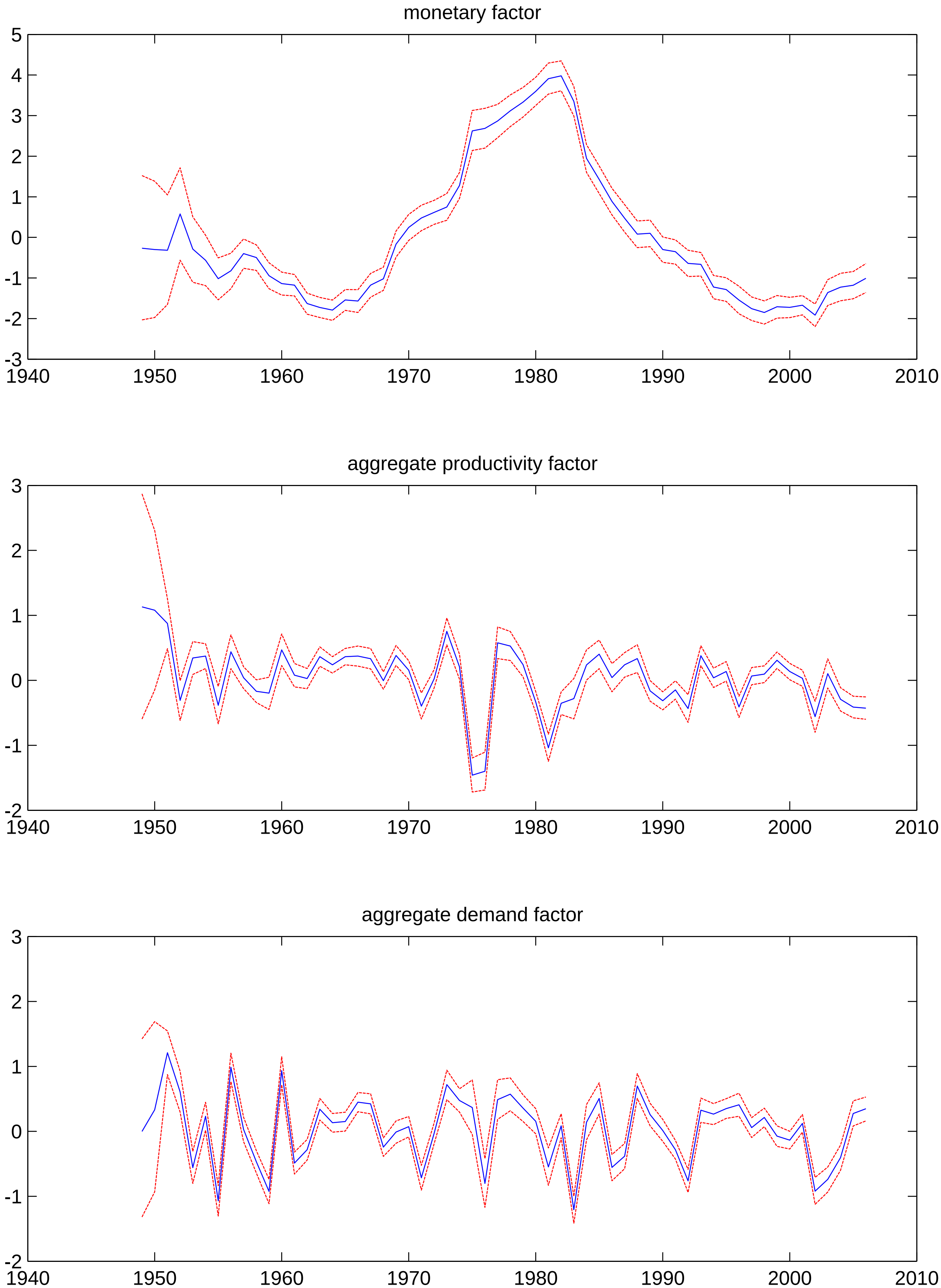


Figure 3. Mean, 10th, and 90th percentiles of posterior distributions for impulse responses to a monetary factor shock

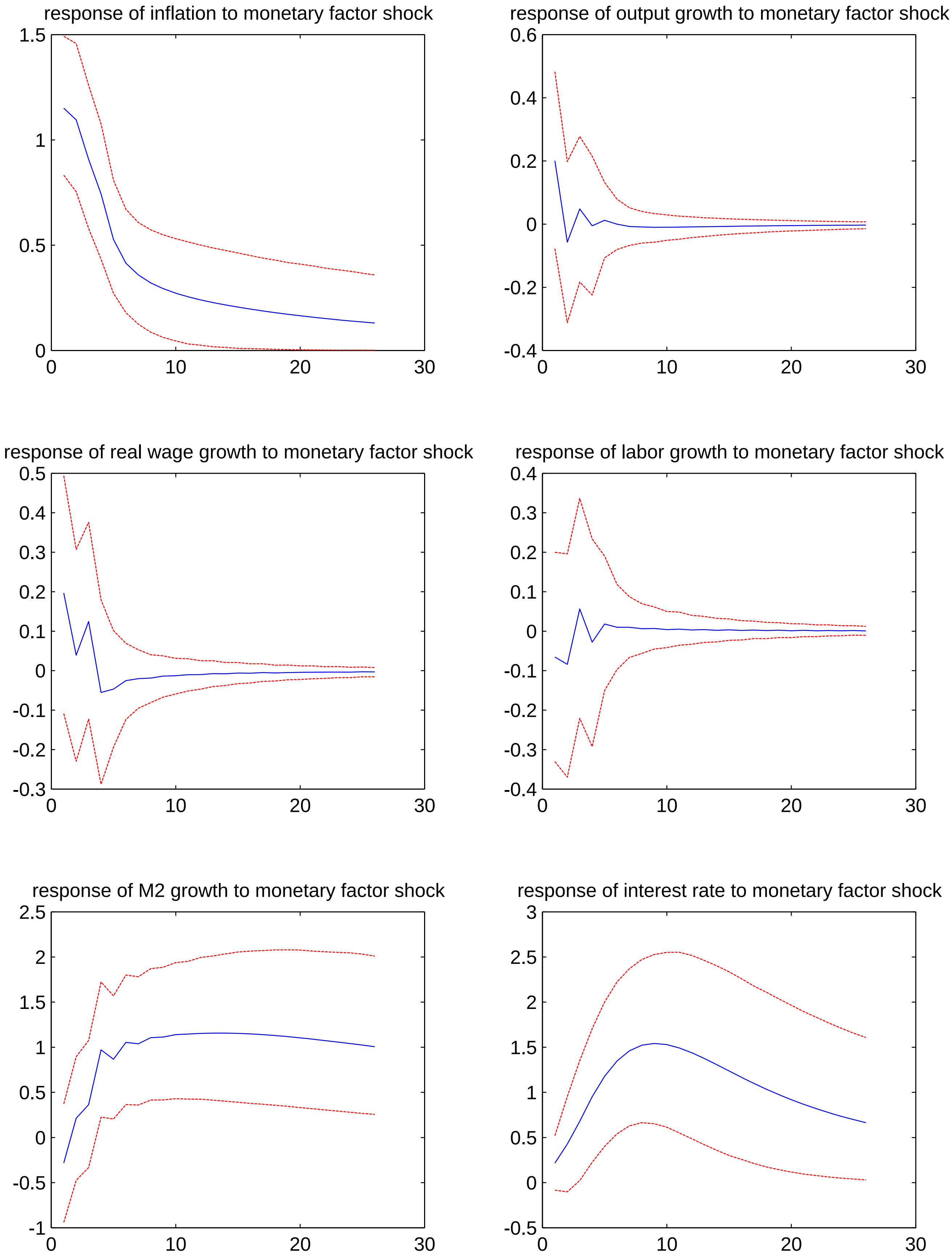


Figure 4. Mean, 10th, and 90th percentiles of posterior distributions for impulse responses to a productivity factor shock

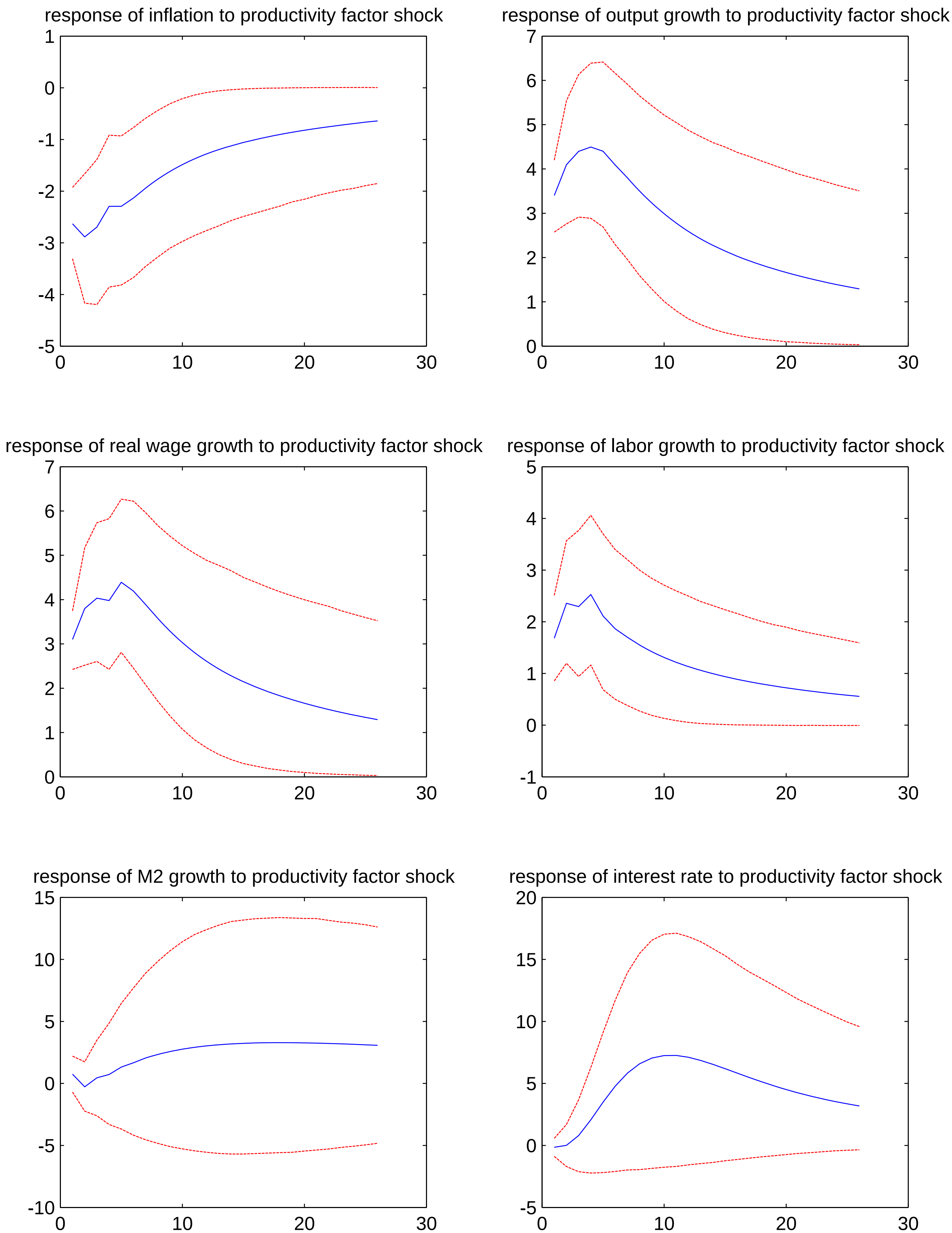


Figure 5. Mean, 10th, and 90th percentiles of posterior distribution for impulse responses to a shock in the third aggregate factor

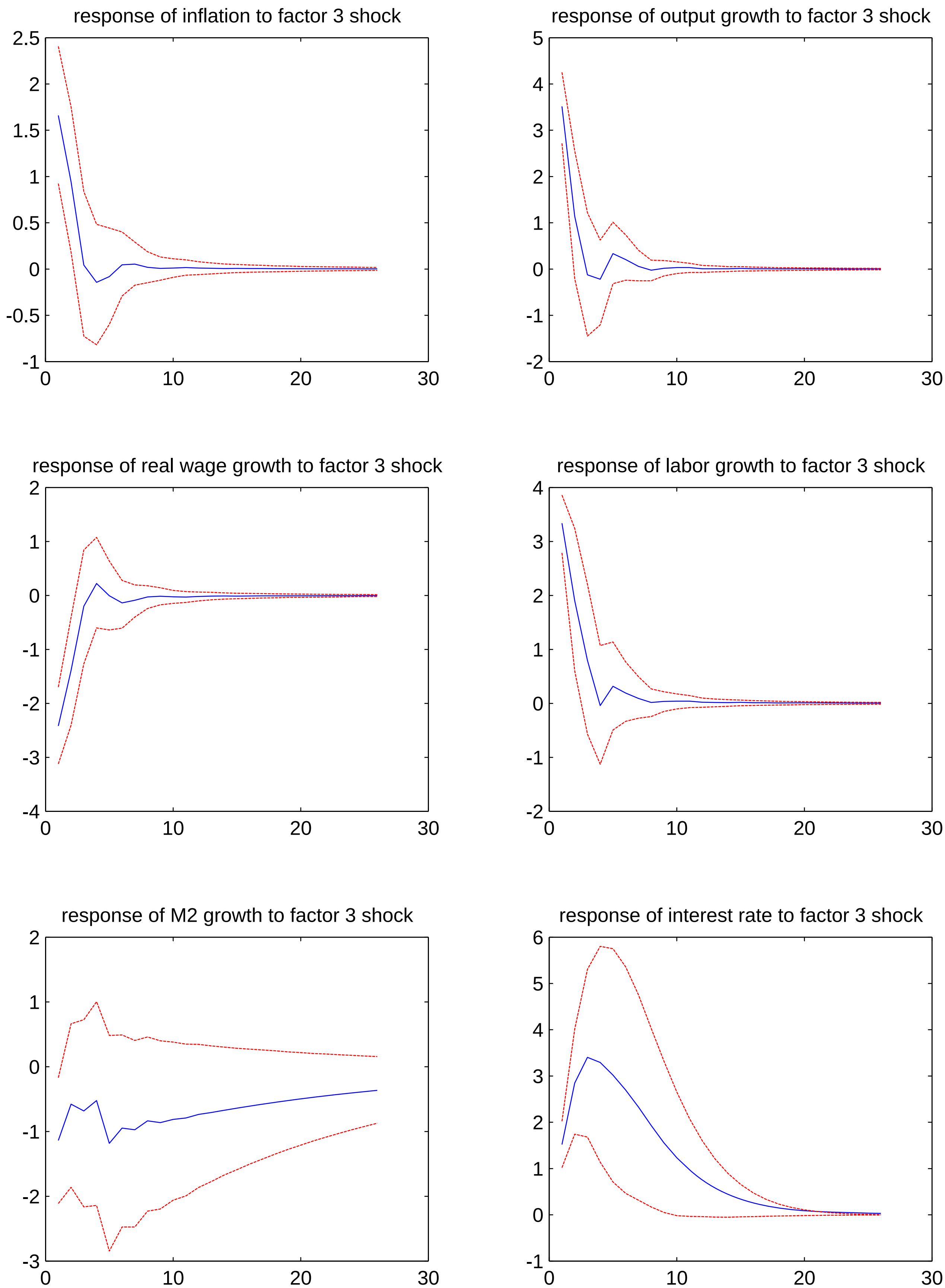


Figure 6. Historical decompositions of aggregate variables: contribution of monetary factor.
Actual (sample means removed) and mean, 10th, and 90th percentiles of the posterior distribution

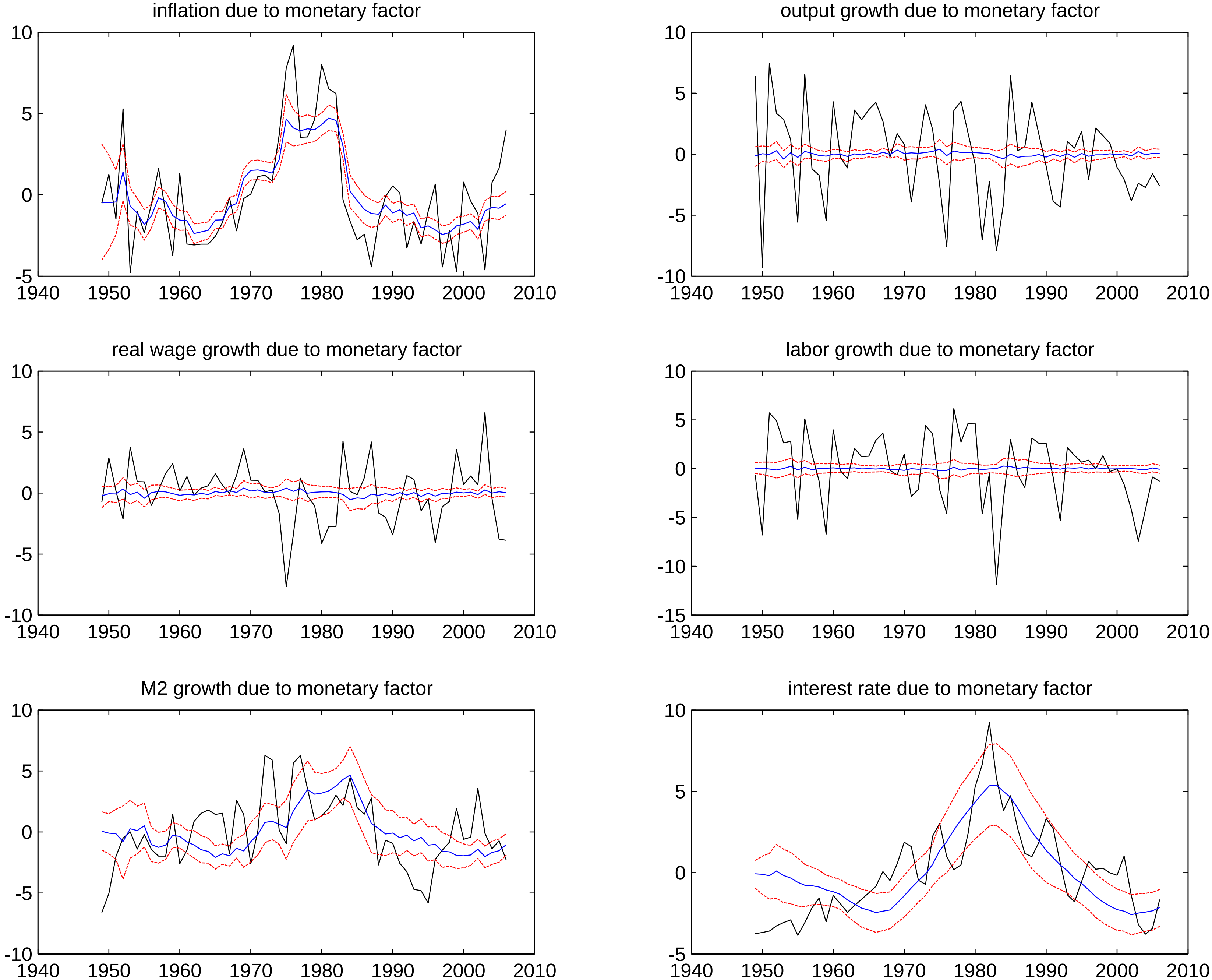


Figure 7. Historical decompositions of aggregate variables: contribution of productivity factor.
Actual (sample means removed) and mean, 10th, and 90th percentiles of the posterior distribution

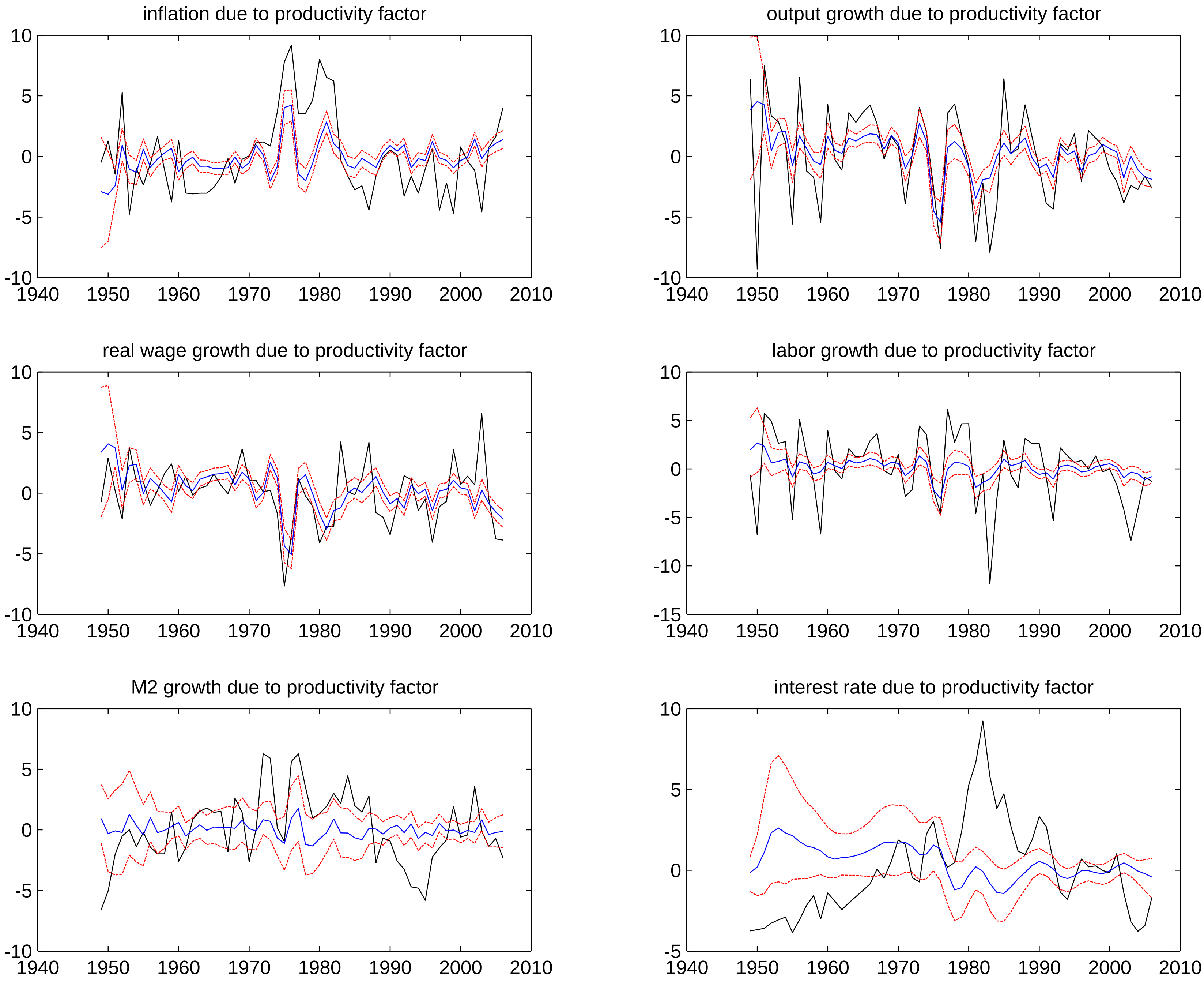


Figure 8. Historical decompositions of aggregate variables: contribution of third factor.
Actual (sample means removed) and mean, 10th, and 90th percentiles of the posterior distribution

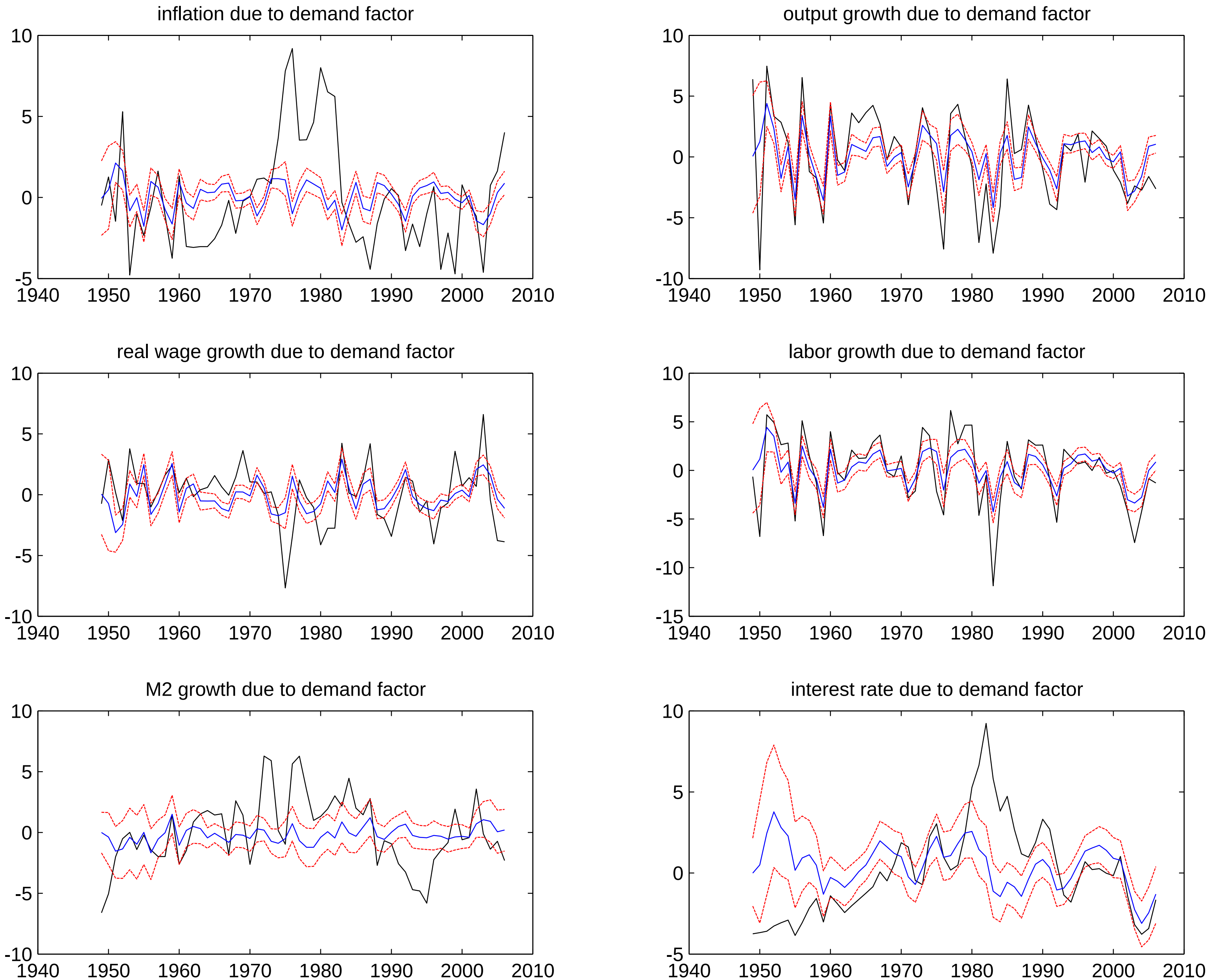


Figure 9. Historical decompositions of aggregate variables: contribution of all aggregate factors.
Actual (sample means removed) and mean, 10th, and 90th percentiles of the posterior distribution

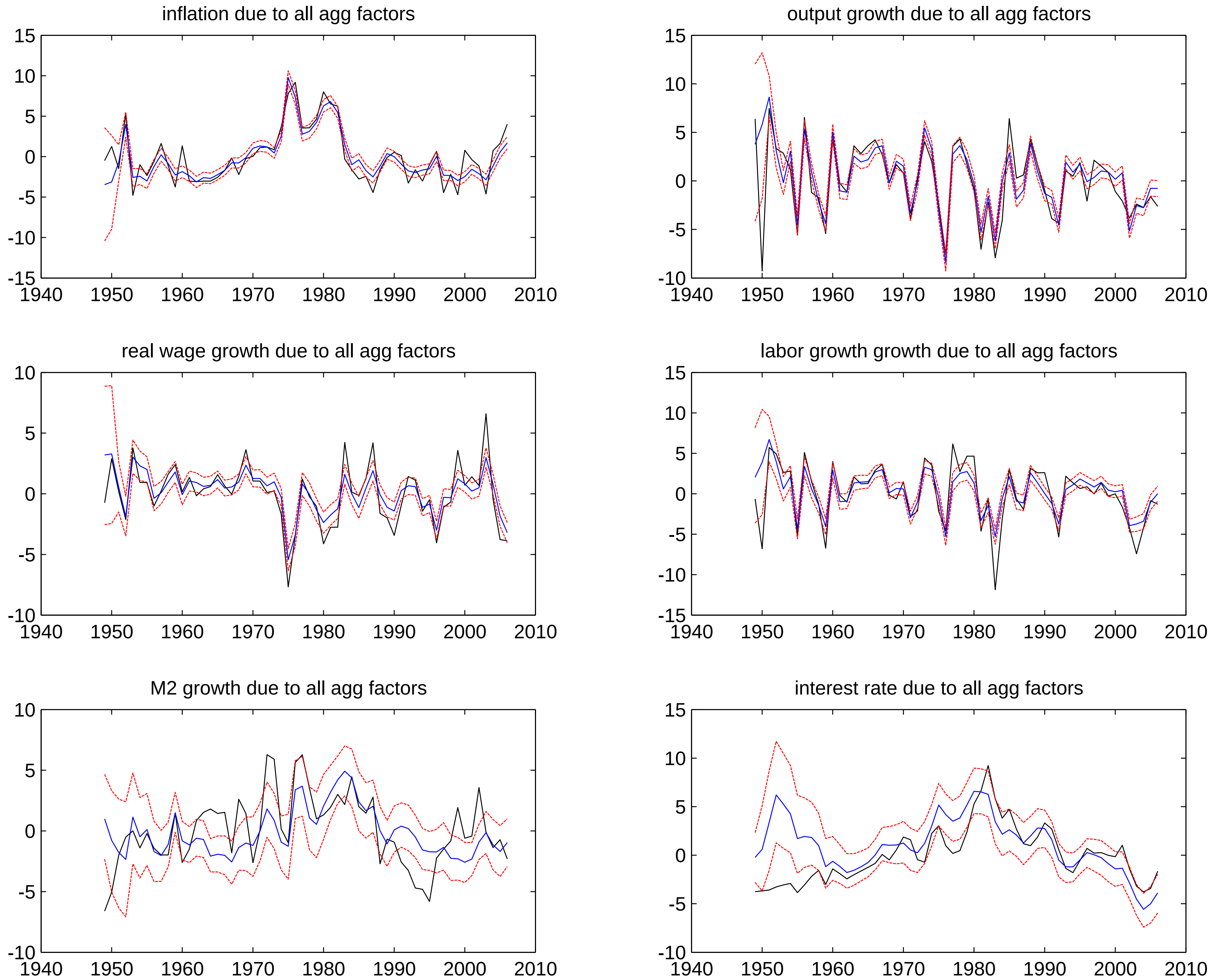
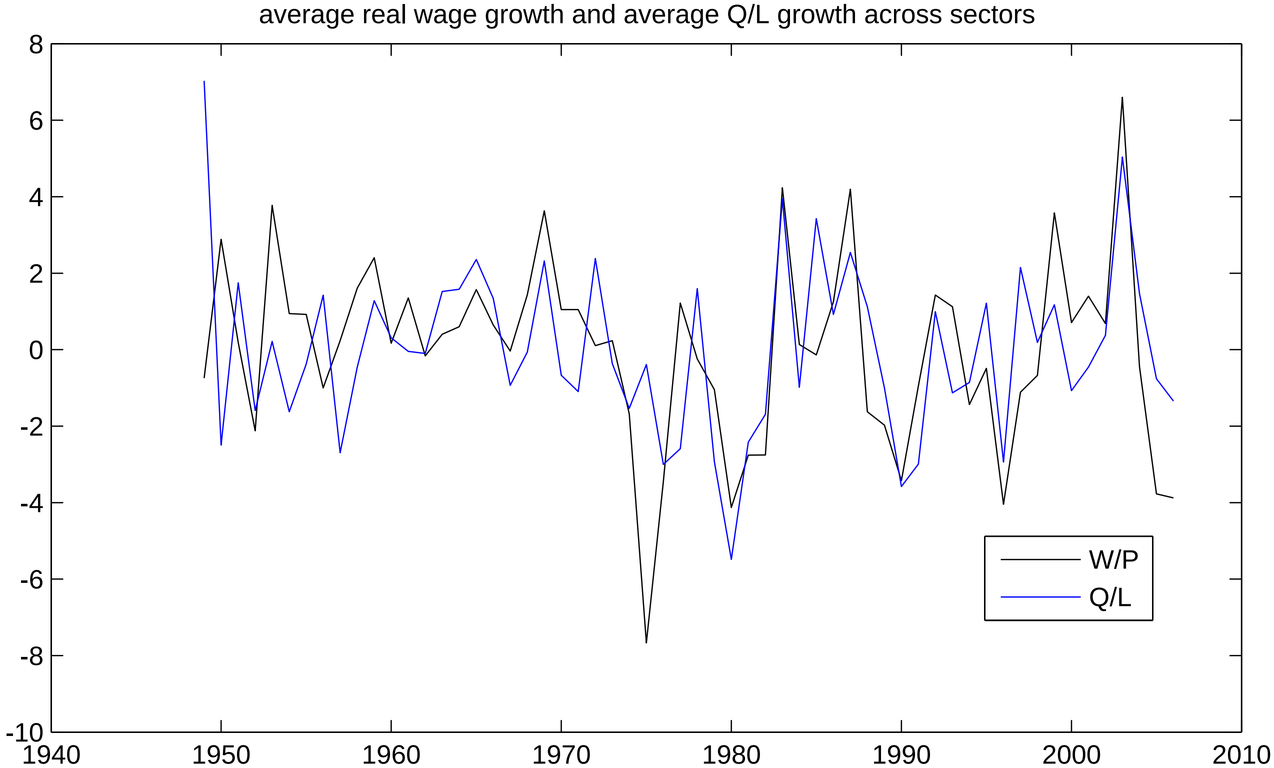


Figure 10. Average real wage and labor productivity across sectors
and long-run contribution of aggregate productivity factor.



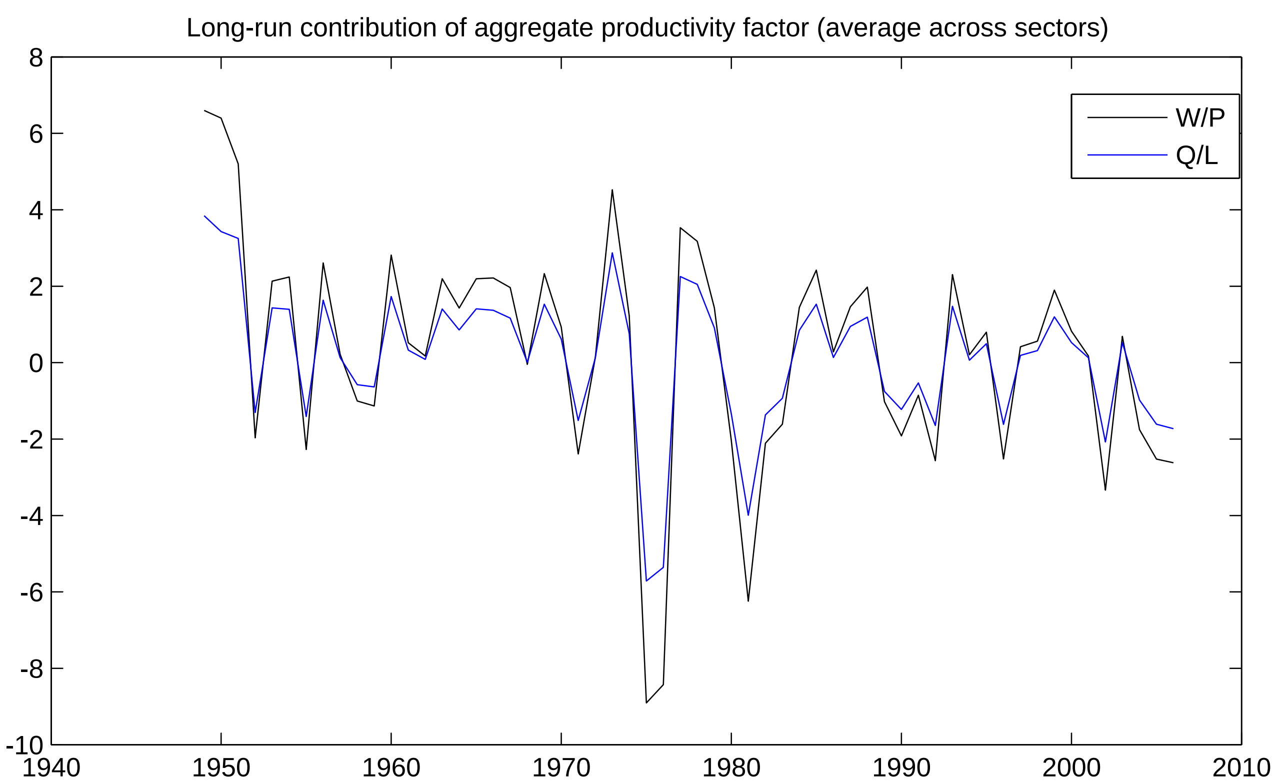


Figure 11. Sectoral impulse responses to monetary factor shock:
mean of the posterior distributions

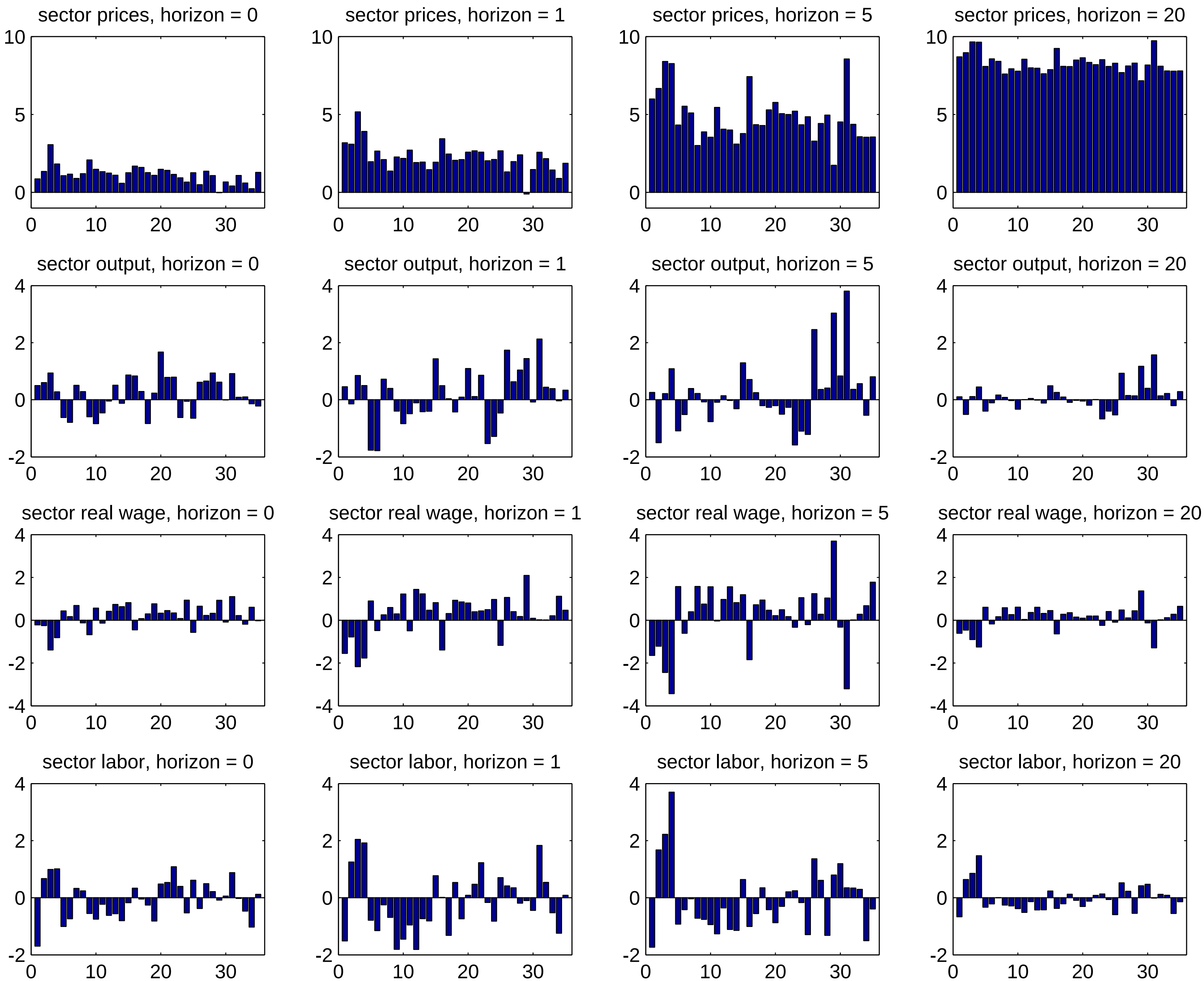


Figure 12. Sectoral impulse responses to a productivity factor shock:
mean of the posterior distributions

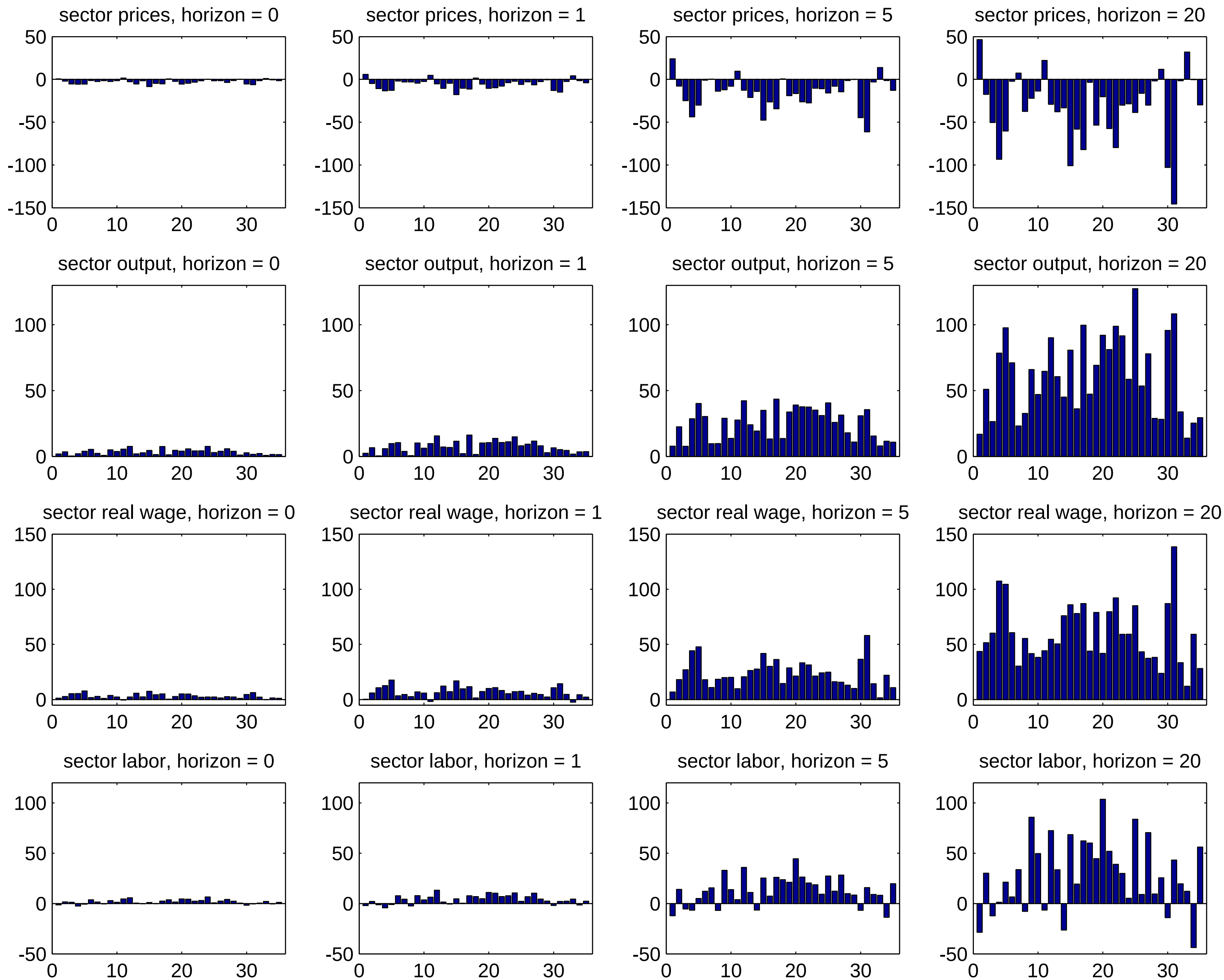


Figure 13. Sectoral impulse responses to a "demand" factor shock:
mean of the posterior distributions

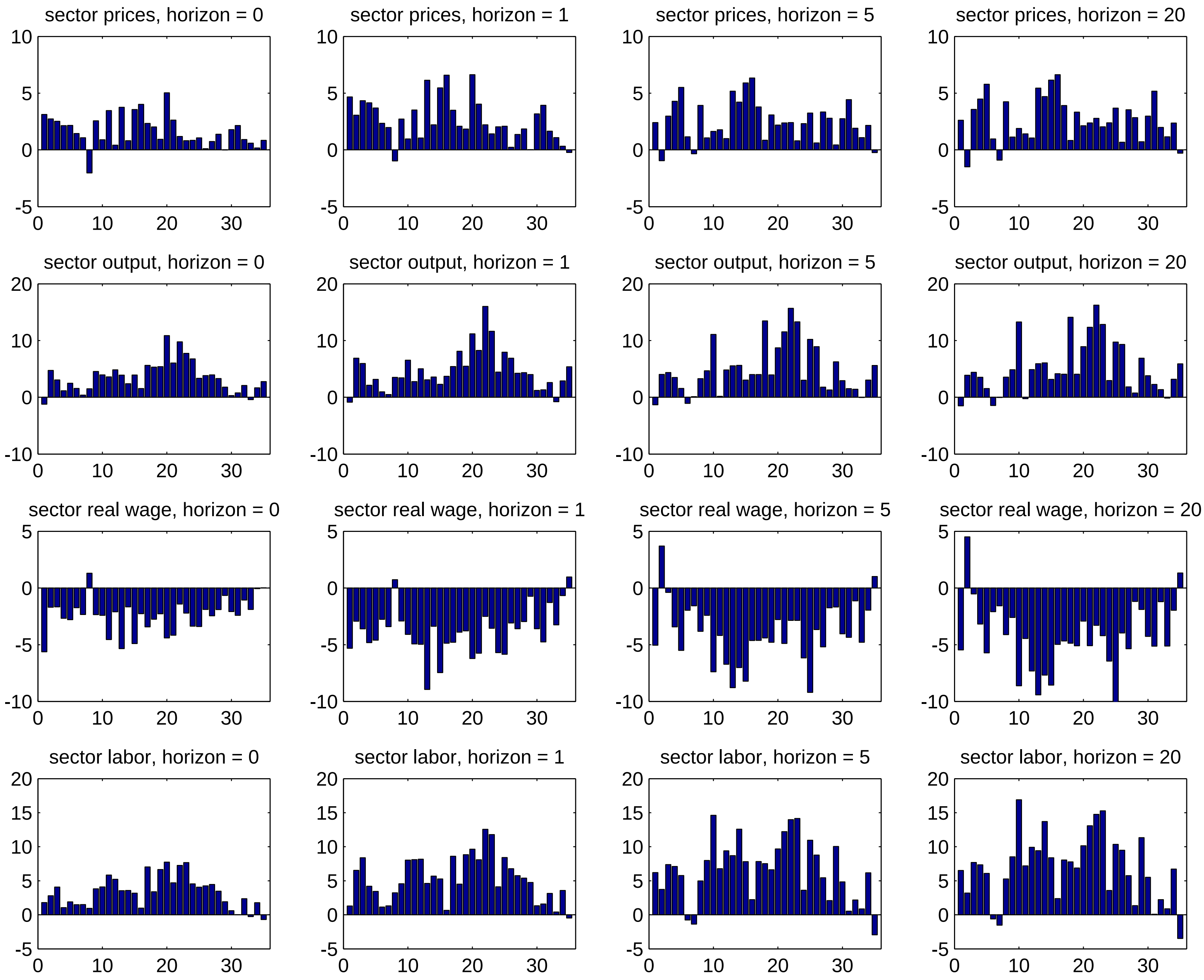


Figure 14. Response to a monetary factor shock across good types:
mean, 10th, and 90th percentiles of the posterior distributions

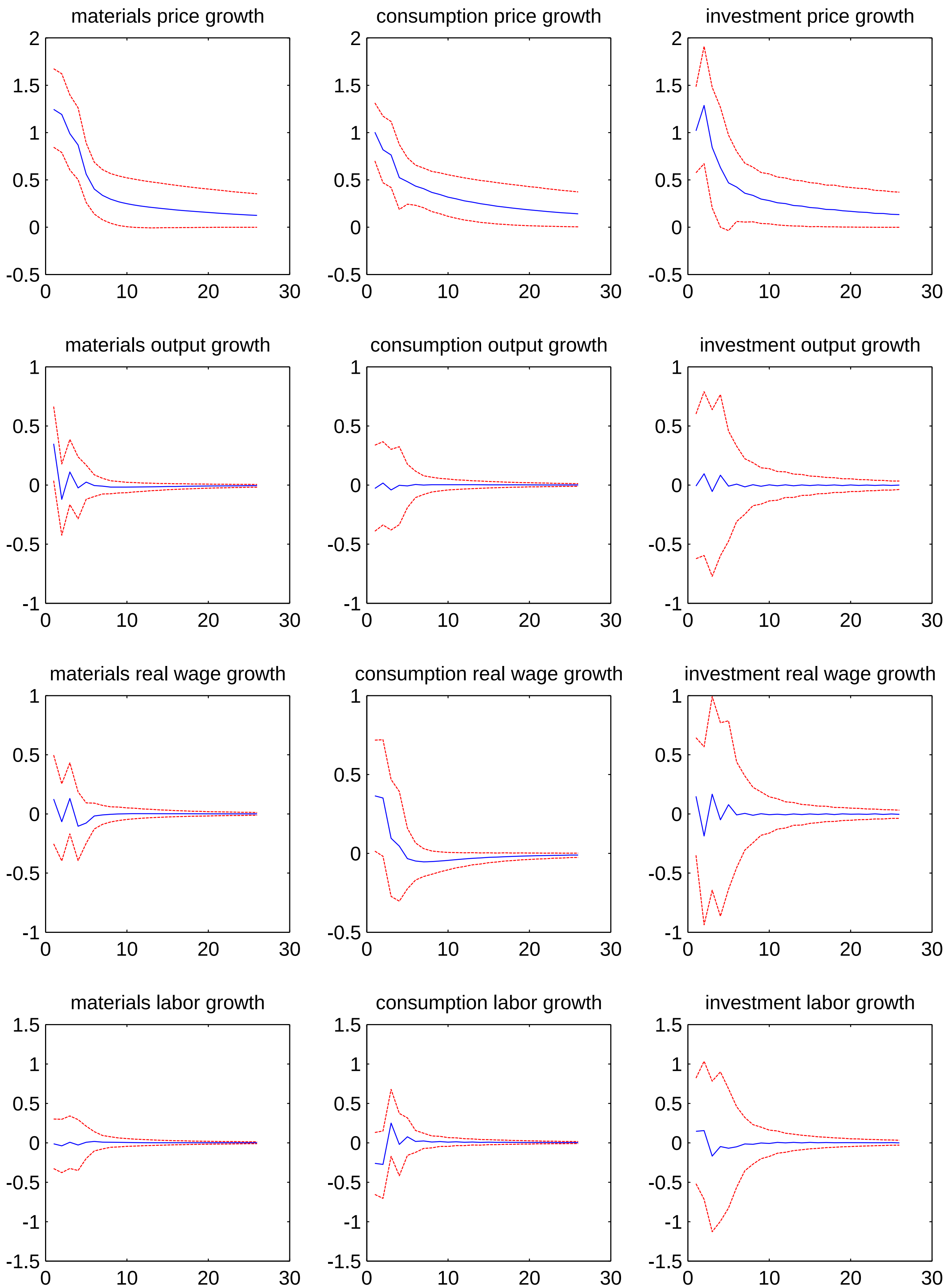


Figure 15. Response to a productivity factor shock across good types:
mean, 10th, and 90th percentiles of the posterior distributions

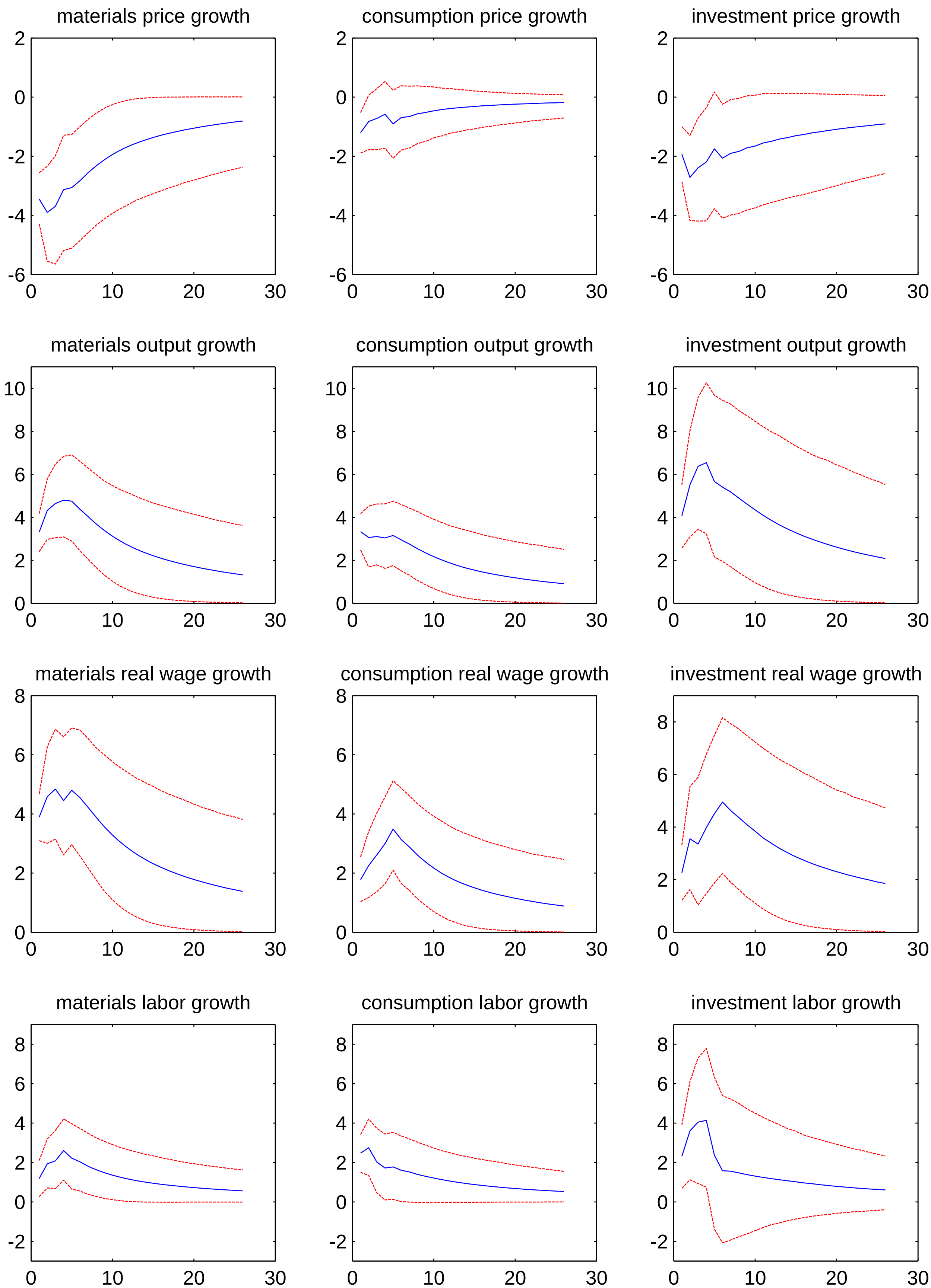


Figure 16. Response to a "demand" factor shock across good types:
mean, 10th, and 90th percentiles of the posterior distributions

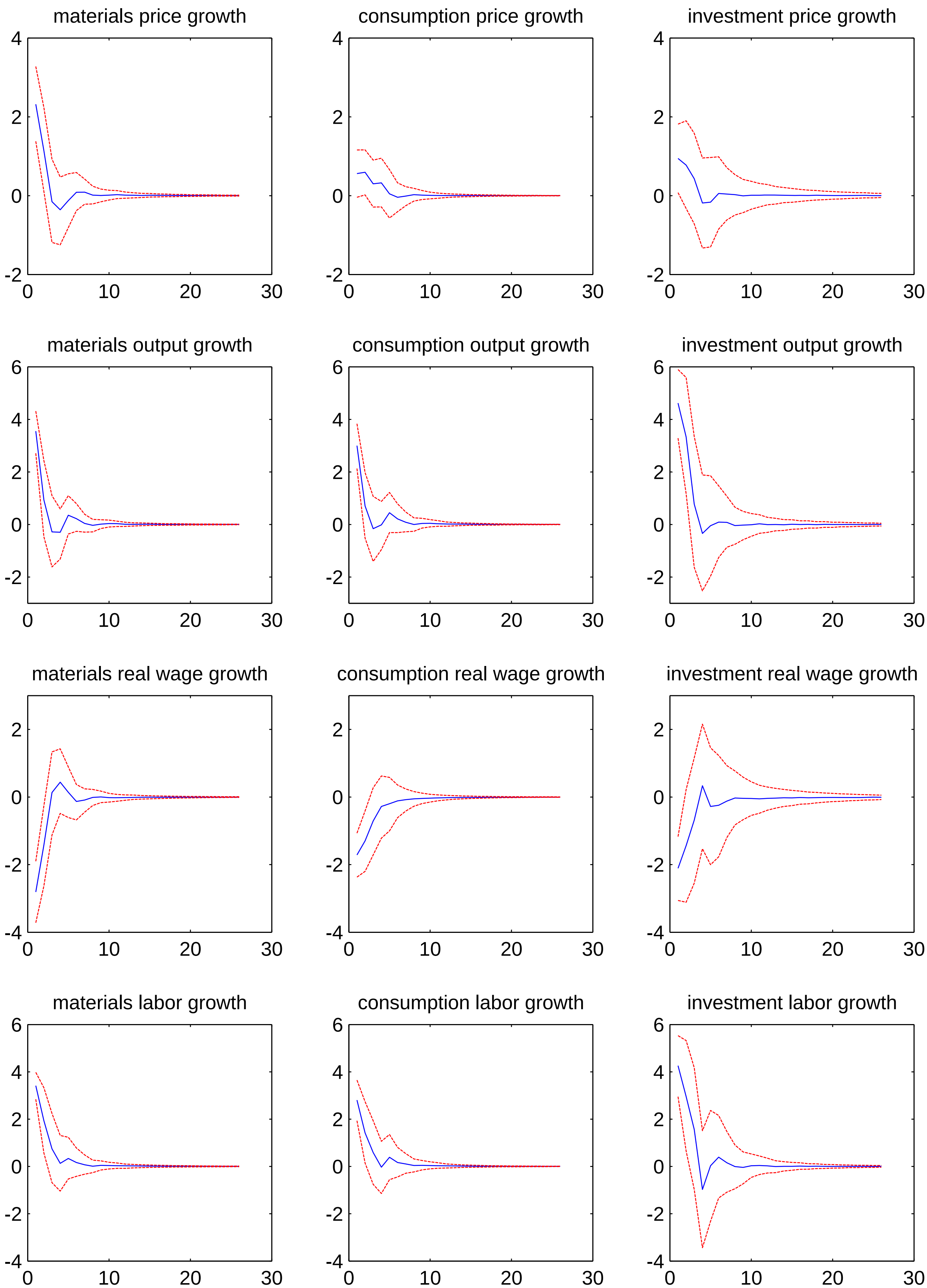


Figure 17. Mean, 10th, and 90th percentiles of prior distribution of responses to monetary factor shock for "traditional" VAR prior

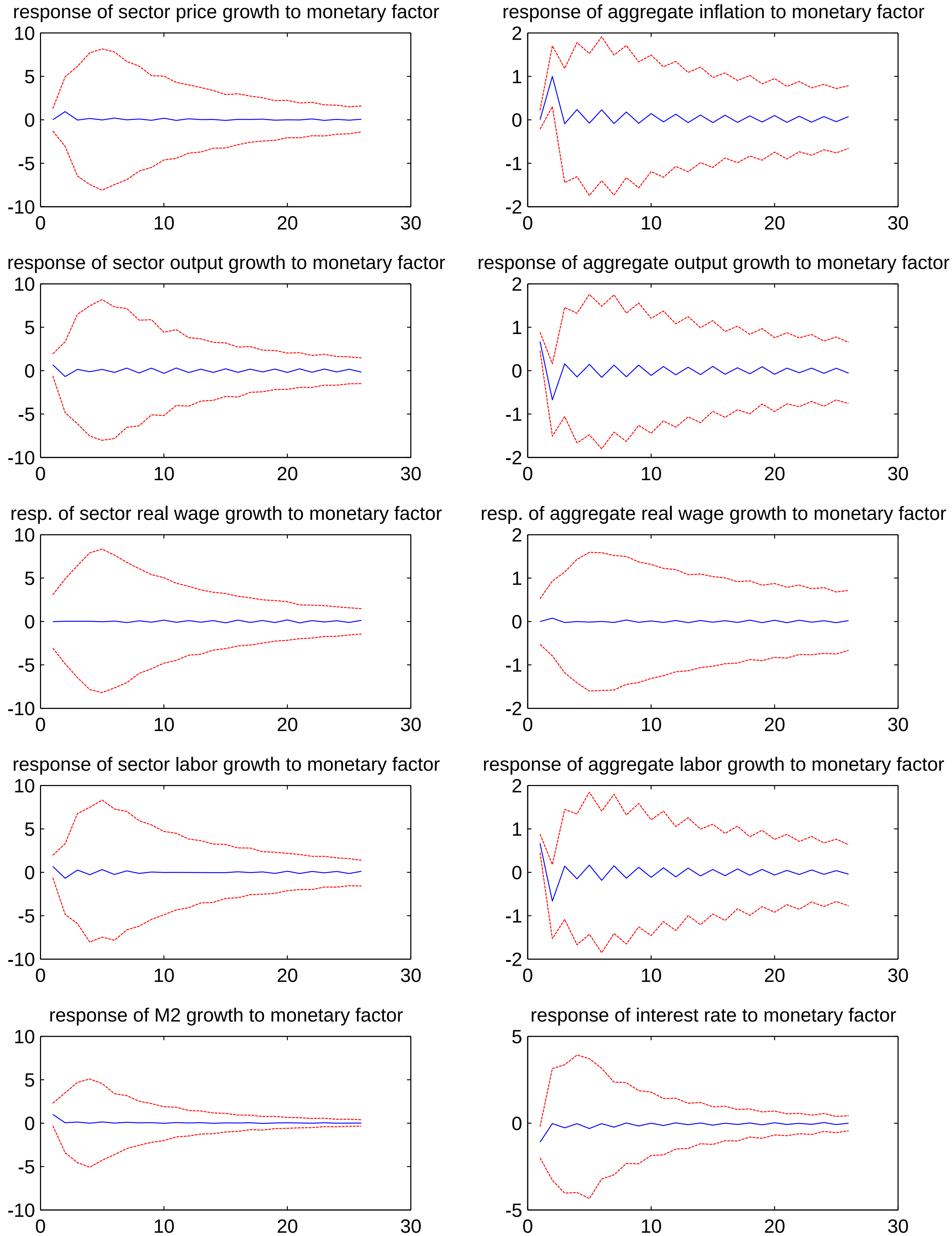


Figure 18. Mean, 10th, and 90th percentiles of posterior distributions
for impulse responses to a monetary factor shock for "traditional" VAR prior

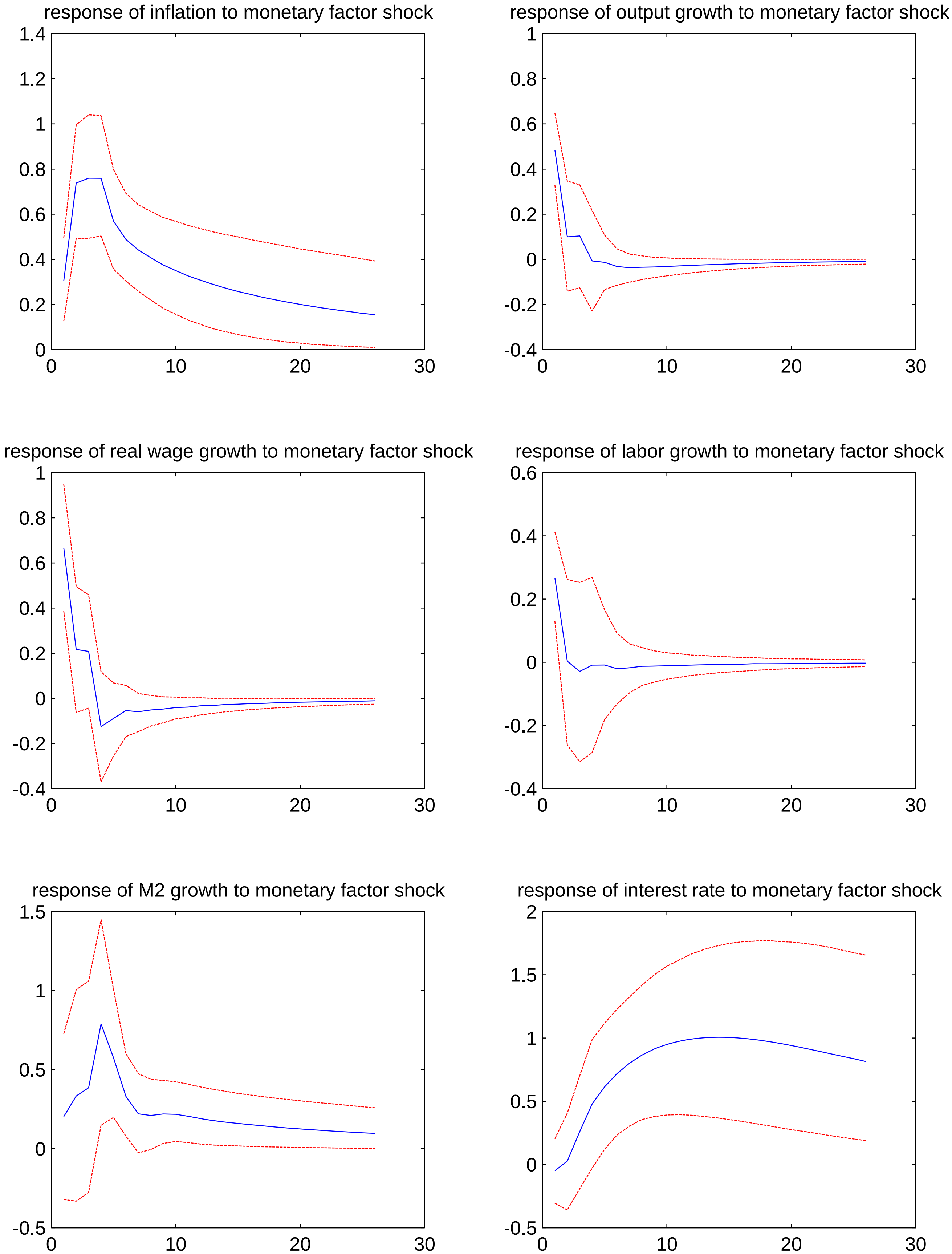


Figure 19. Historical decompositions of aggregate variables for "traditional" VAR prior: contribution of monetary factor.
Actual (sample means removed) and mean, 10th, and 90th percentiles of the posterior distribution

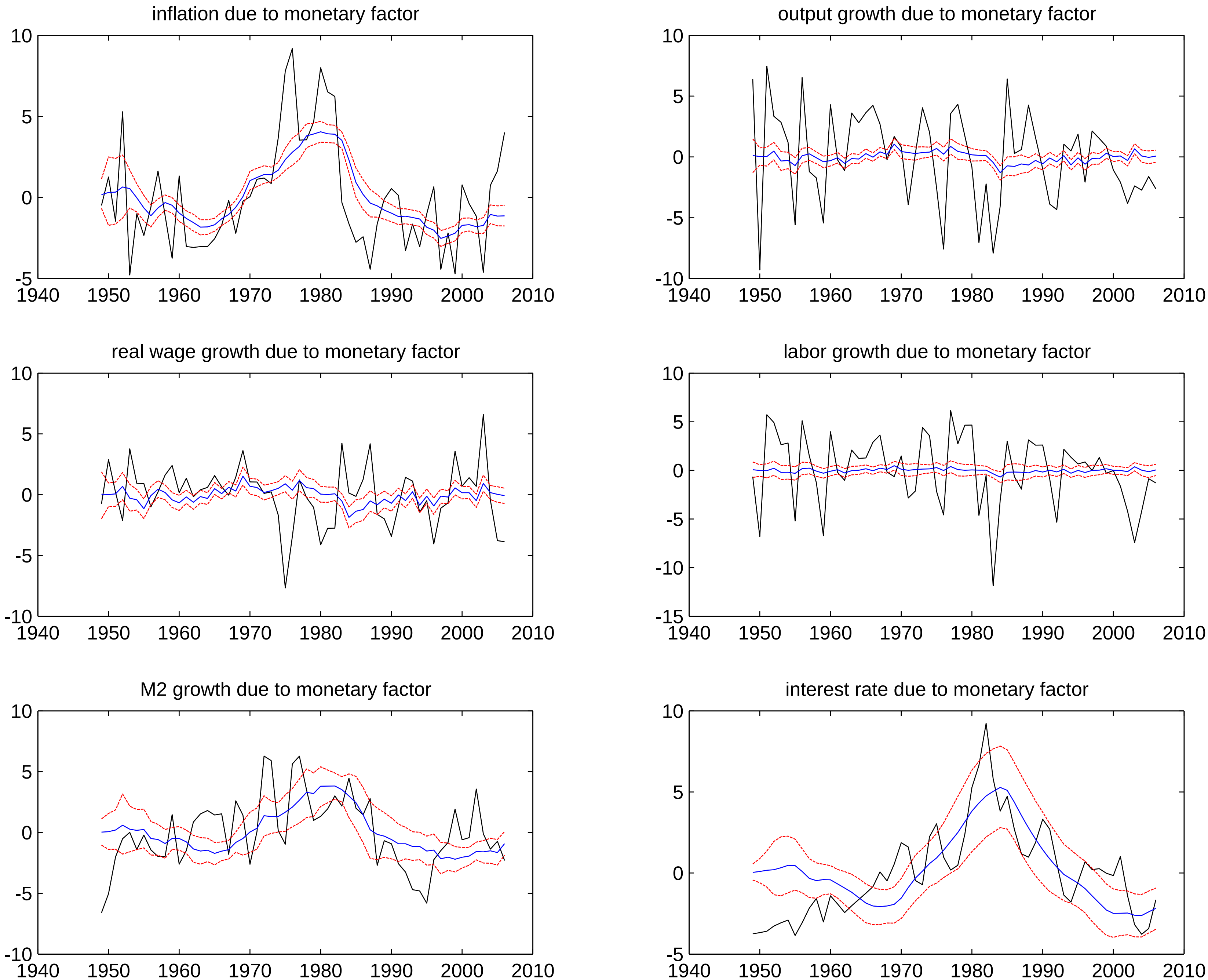


Figure 20. Sectoral impulse responses to a monetary factor shock for "traditional" VAR prior: mean of the posterior distributions

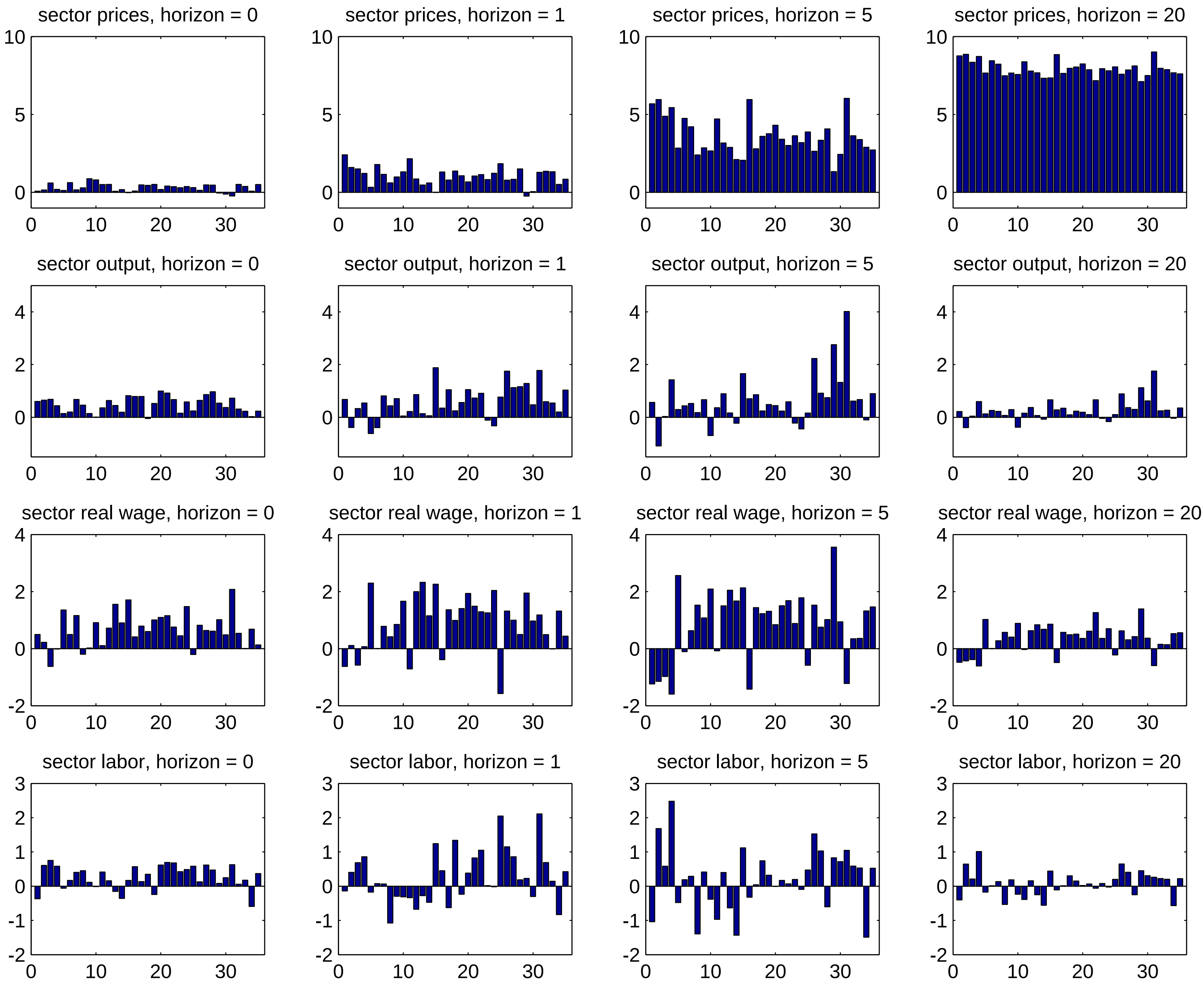


Figure 21. Historical decompositions of aggregate variables for four factor model: contribution of fourth factor. Actual (sample means removed) and mean, 10th, and 90th percentiles of the posterior distribution

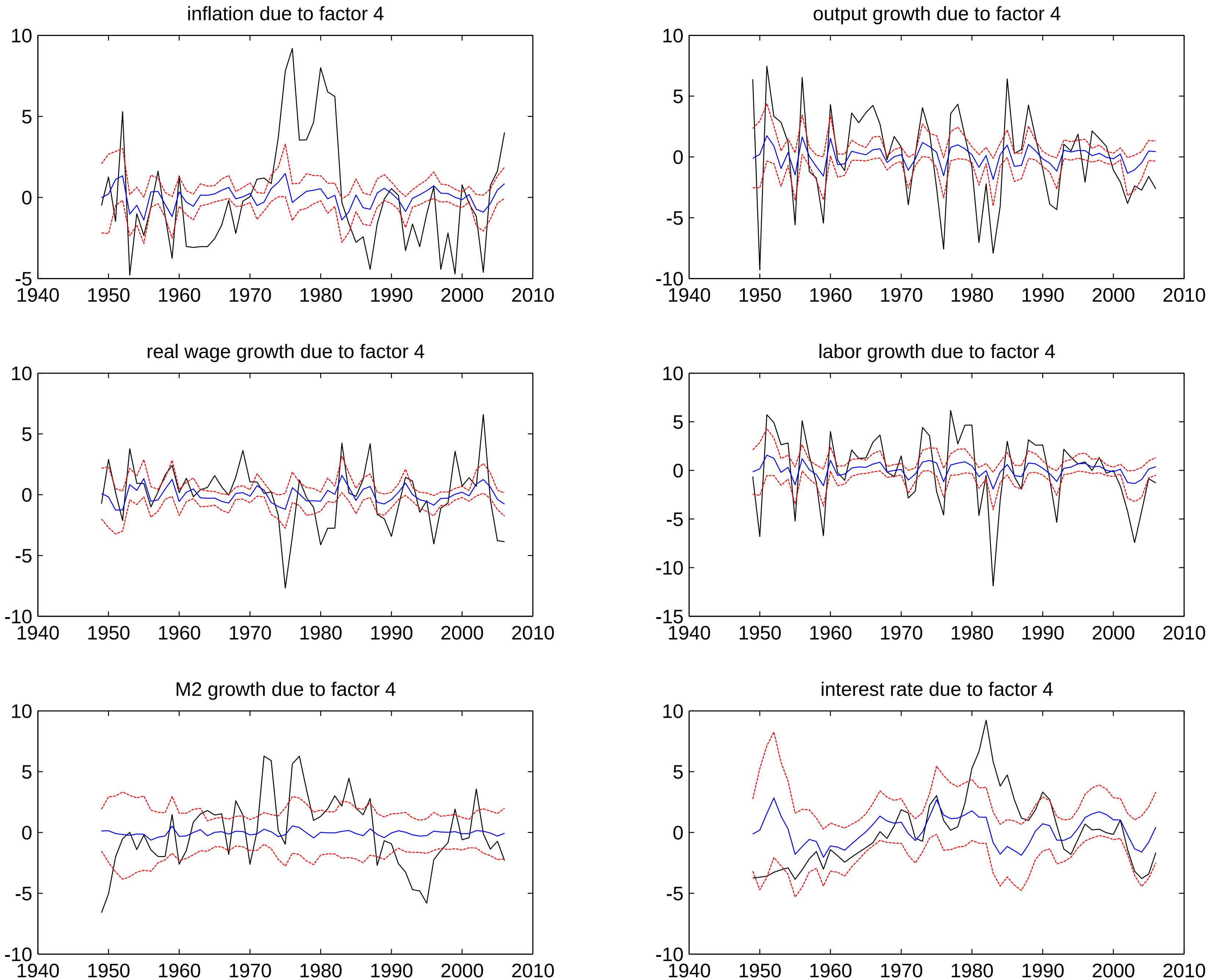


Figure 22. Historical decompositions of aggregate variables for four factor model that includes oil prices and traditional VAR prior. Actual (sample means removed) and mean, 10th, and 90th percentiles of the posterior distribution

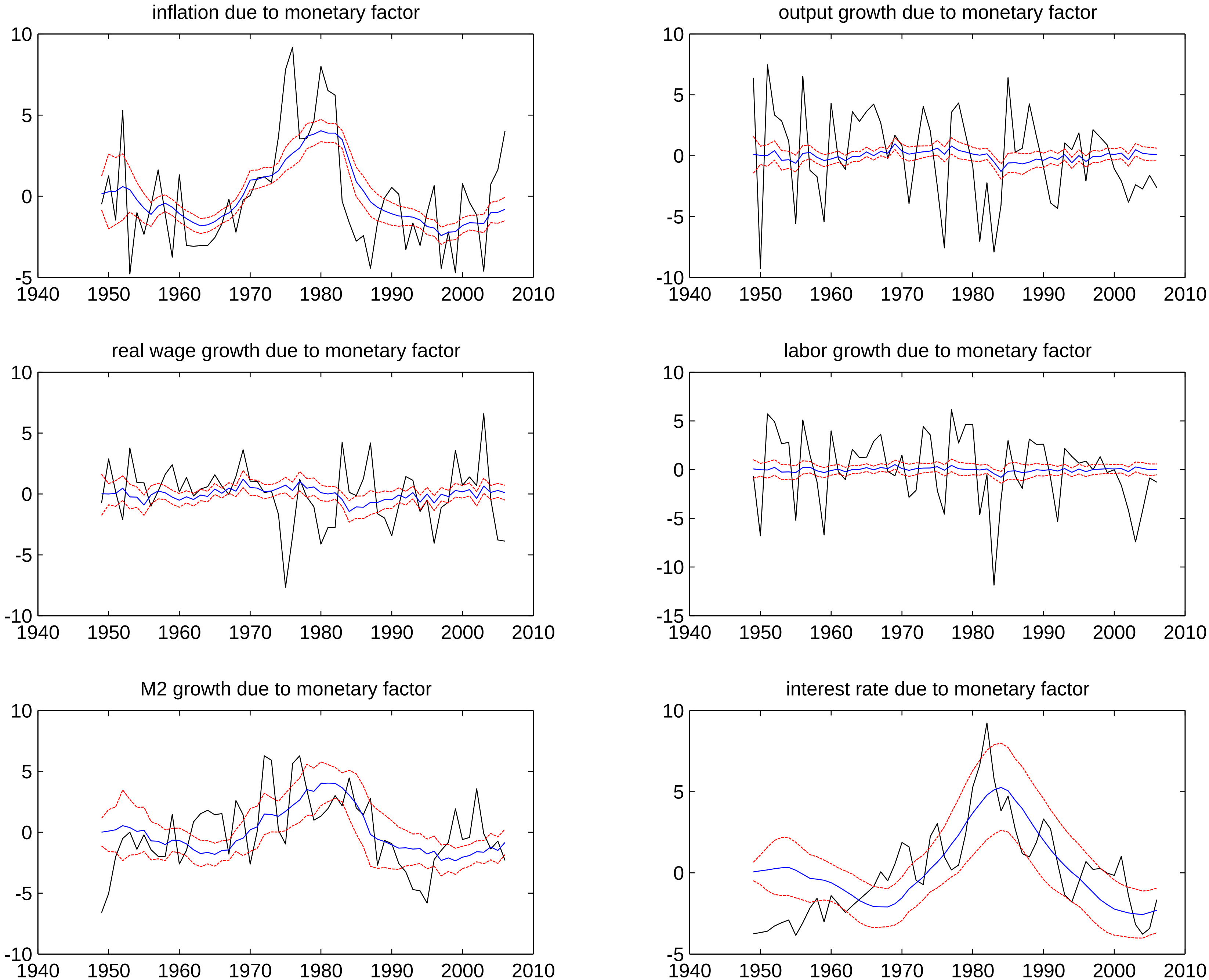


Figure 23. Historical decompositions of aggregate variables for four factor model with oil prices and traditional VAR prior.
Actual (sample means removed) and mean, 10th, and 90th percentiles of the posterior distribution

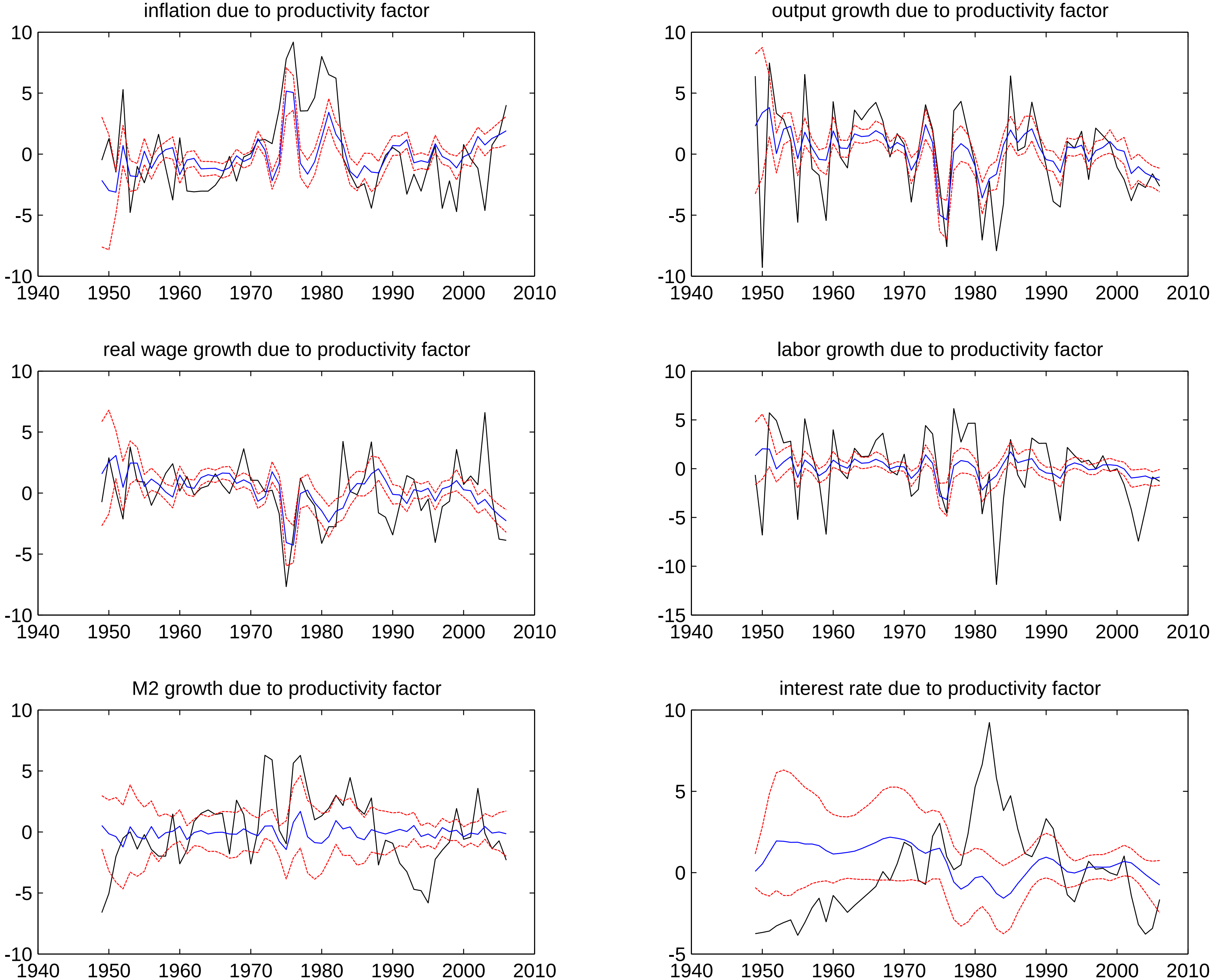


Figure 24. Historical decompositions of aggregate variables for four factor model with oil prices and traditional VAR prior. Actual (sample means removed) and mean, 10th, and 90th percentiles of the posterior distribution

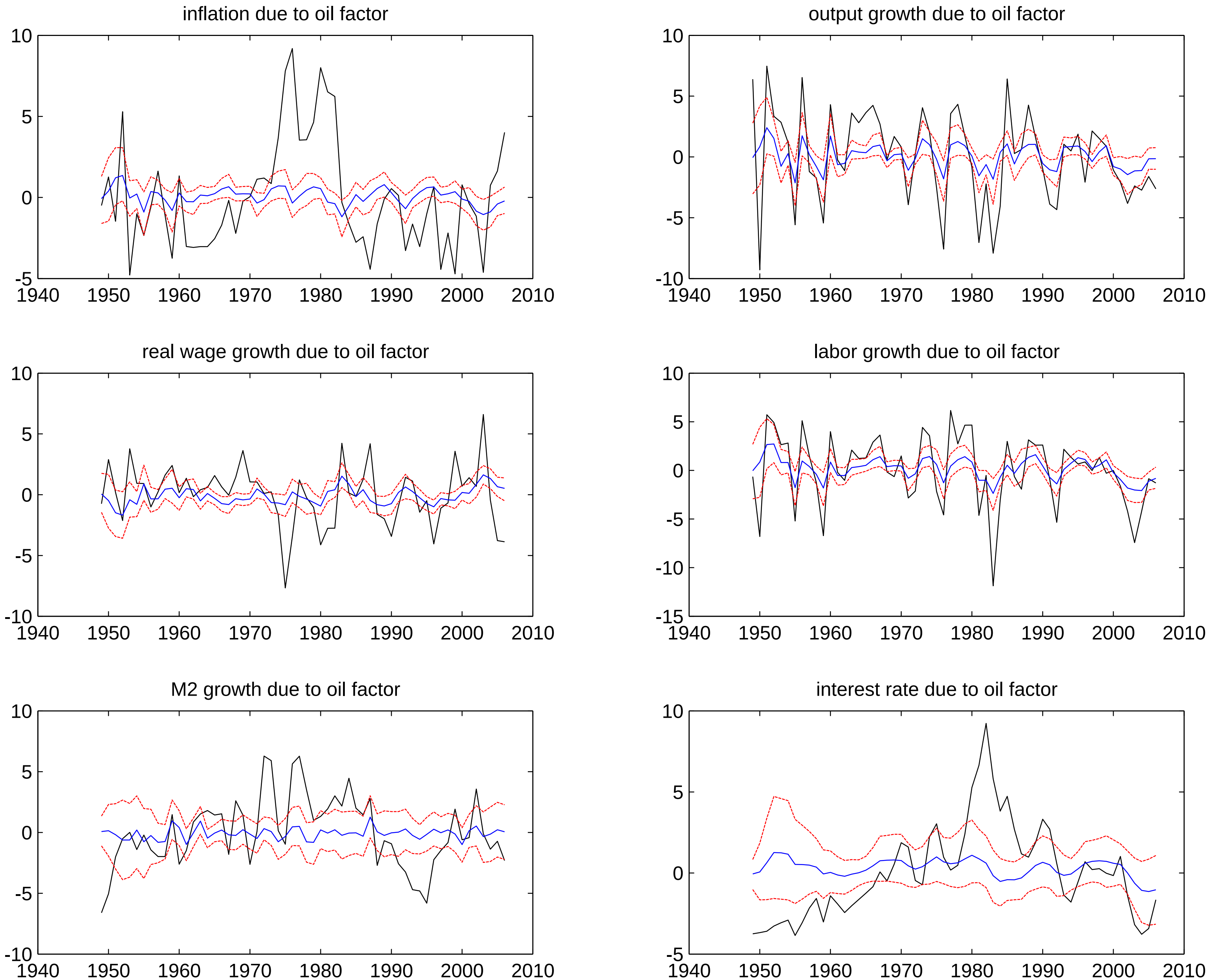


Figure 25. Mean, 10th, and 90th percentiles of posterior distributions
for impulse responses of aggregate variables to a oil factor shock for "traditional" VAR prior

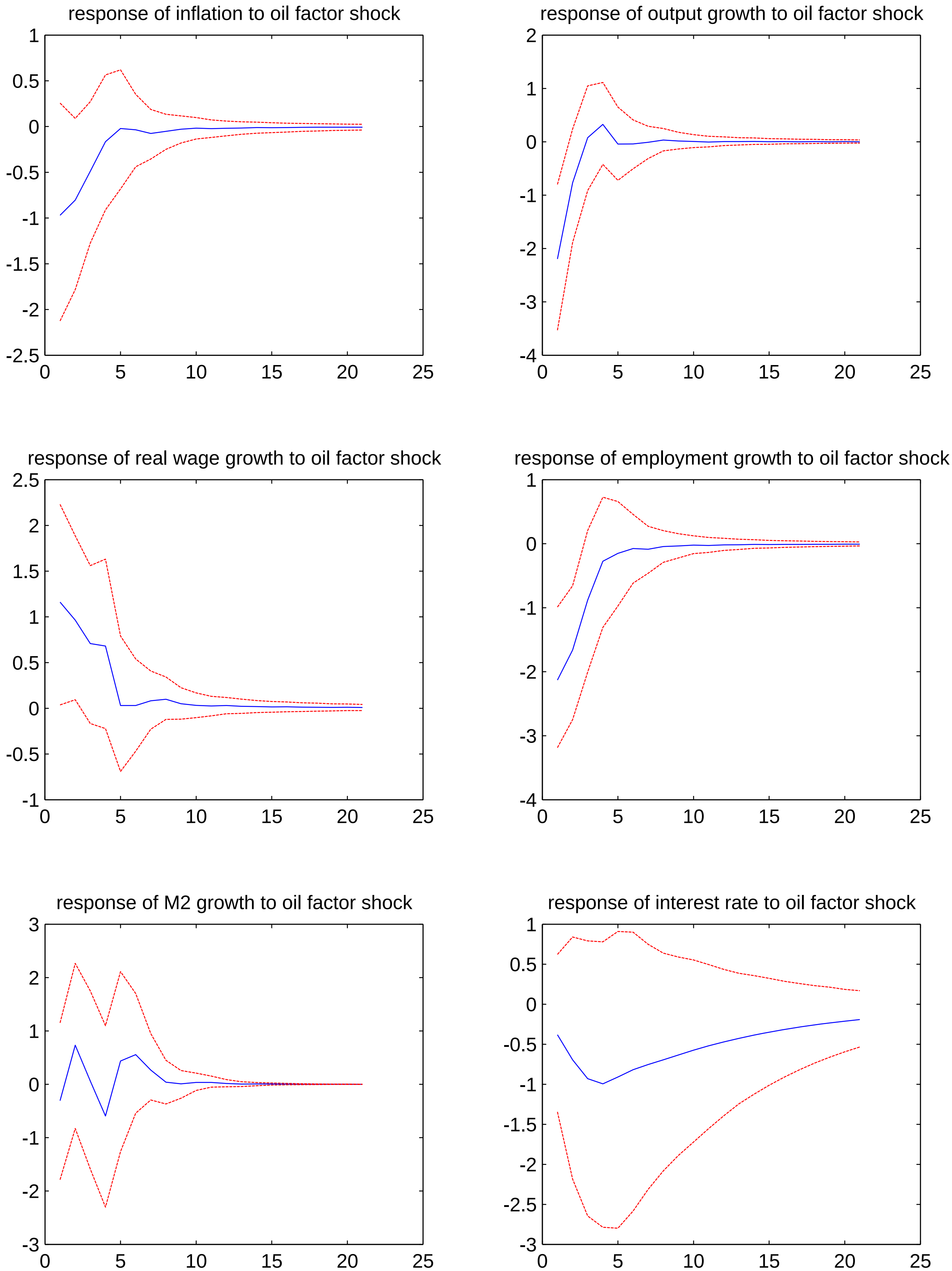


Figure 26. Sectoral impulse responses to a oil factor shock:
mean of the posterior distributions

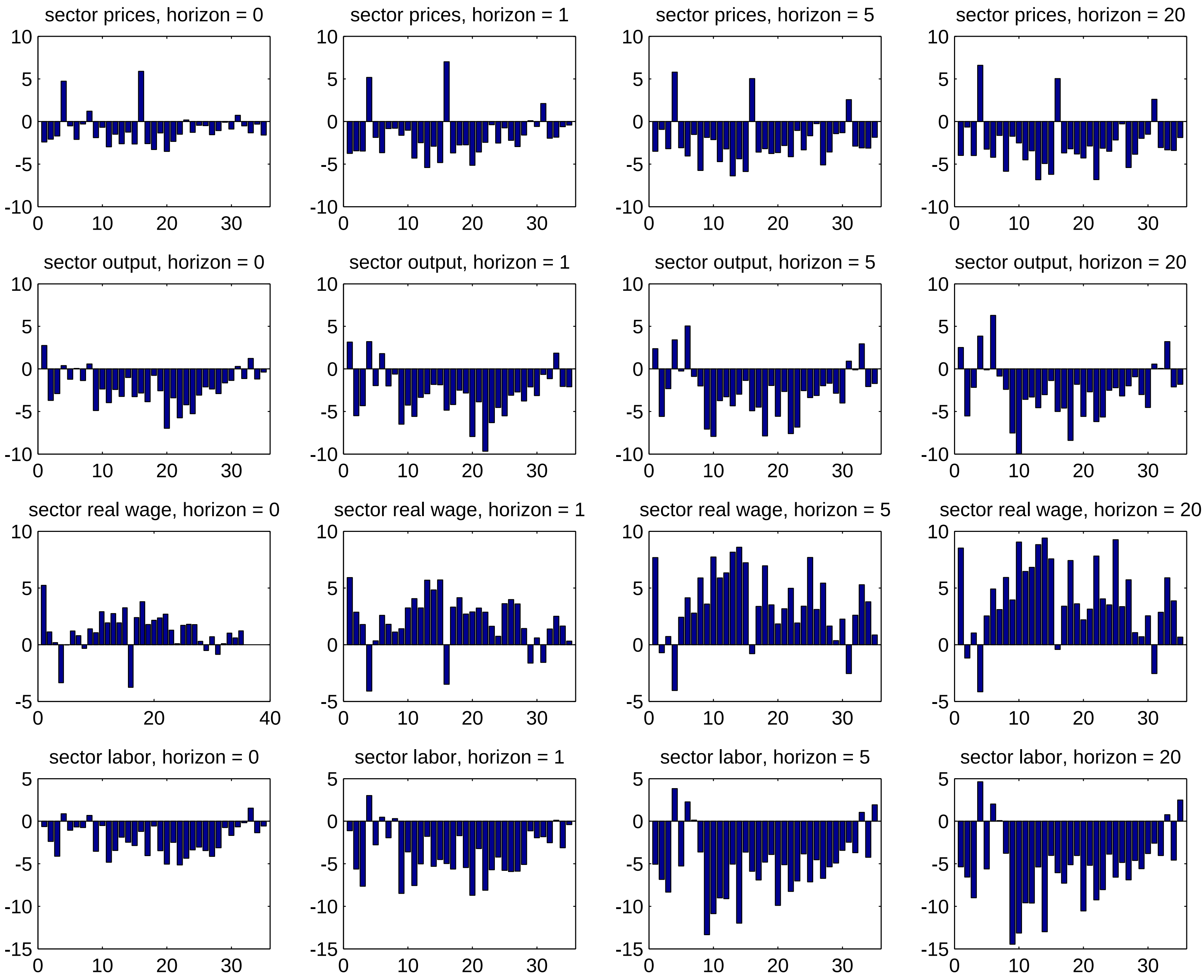


Figure 27. Response of change in oil prices to factor shocks (traditional VAR prior)

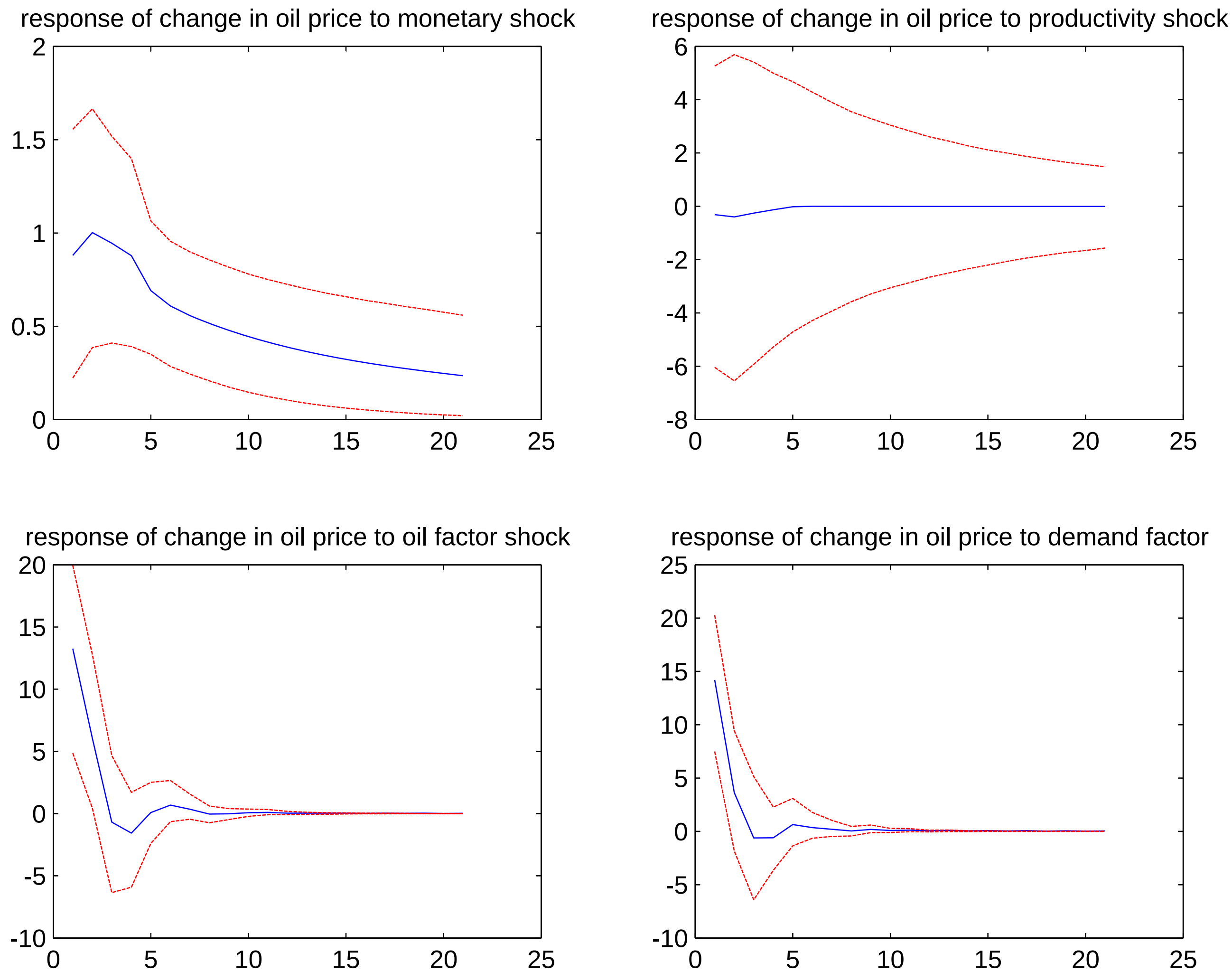


Figure 28. Historical decompositions of oil price changes for four factor model with oil prices and traditional VAR prior. Actual (sample means removed) and mean, 10th, and 90th percentiles of the posterior distribution