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Using the Aggregate Demand-Aggregate Supply Model to Identify Structural Demand-Side and Supply-Side Shocks: Results Using a Bivariate VAR

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Abstract

This paper uses the short-run restrictions implied by the aggregate demand-aggregate supply model as an aid in identifying structural shocks. Combined with the Blanchard-Quah restriction, this allows us to estimate the slope of the aggregate supply curve, the variances of structural demand and supply shocks, and the extent to which structural demand and supply shocks are correlated. An especially important finding is that demand and supply shocks are highly correlated and that demand shocks can account for as much as 82% of the long-run forecast error variance of real U.S. GDP.

Key Words: Structural VAR, Supply and Demand Shocks, Blanchard-Quah Decomposition

JEL Classifications: E3 - Prices, Business Fluctuations, and Cycles
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1. Introduction

Vector autoregression (VAR) analysis has been a popular tool for analyzing the dynamic properties of economic systems since Sims's (1980) influential work. Research on the relationship between VARs and structural econometric models has made possible the identification of unobservable structural shocks and an examination of the dynamic effects of these shocks on the observable data. For example, Blanchard and Quah (B-Q) (1989) use a bivariate VAR of real output growth and the unemployment rate to decompose real output into its temporary and permanent components. Similarly, Spencer (1996) applies the B-Q identification strategy to a bivariate VAR of output and the price level. A critical identifying assumption in the B-Q methodology is that the shock with no long-run effect on real output is the demand shock. Hence, it is natural to assume that the shock with a permanent effect on output is the supply shock. Studies that use a larger dimension VAR often impose more restrictions on the long-run or short-run effects of selected shocks.[1]

The second set of identifying assumptions in the B-Q methodology is that the variance-covariance matrix of structural shocks is an identity matrix. In a bivariate framework guided by the aggregate demand and aggregate supply (AD-AS) model, this is equivalent to assuming that the demand and supply shocks have identical variances and are uncorrelated. Our point of departure from the standard B-Q methodology is to argue that these normalizations are implausible in practice and can lead to a misinterpretation of the empirical results. To avoid this, we propose to use the complete set of restrictions from an AD-AS model in order to achieve full identification of the structural parameters of a VAR. Our alternative decomposition allows us to present an estimate of the slope of the AS curve (that is, a measure of the short-run output-inflation tradeoff), estimates of the variances of the structural supply and demand shocks, and an estimate of their covariance. We find that the aggregate supply curve is flat enough for the structural demand shock to have important short-run effects on output. We also find that the correlation between the structural demand and supply shocks is positive and high enough for most of the variation in real output (54% in the long run and 70% in the short run) to be attributed to simultaneous shifts of the aggregate demand and aggregate supply curves.

The paper is organized as follows. Section 2 reviews the standard Blanchard and Quah (1989) methodology and places special emphasis on the conditions necessary for the exact identification of the structural aggregate demand and aggregate supply shocks. Section 3 presents a basic AD-AS model and shows that it implies a set of identification restrictions that are sufficient to replace all the constraints normally placed on the covariance matrix of structural shocks. Sections 4 and 5 use United States data for the 1954*Q*1-200*Q*4 sample period and compare the results obtained from a standard B-Q decomposition to those obtained using the AD-AS model. Section 6 offers a summary and some conclusions.

2. Structural VARs with the Blanchard-Quah Restriction

Let y_t and p_t respectively represent measures of output and the price level, which have been differenced sufficiently to achieve stationarity. Now consider the following bivariate VAR in which e_{yt} and e_{pt} respectively are the random disturbances in the output and price level equations and the $a_{ij}(L)$ are polynomials of order n in the lag operator, L, or $a_{ij}(L) = \sum_{k=1}^{n} a_{ij} L^k$:

$$\begin{bmatrix} y_t \\ p_t \end{bmatrix} = \begin{bmatrix} y_0 \\ p_0 \end{bmatrix} + \begin{bmatrix} a_{11}(L) & a_{12}(L) \\ a_{21}(L) & a_{22}(L) \end{bmatrix} \begin{bmatrix} y_t \\ p_t \end{bmatrix} + \begin{bmatrix} e_{yt} \\ e_{pt} \end{bmatrix}. \tag{1}$$

Structural VARs recognize that the residuals e_{yt} and e_{pt} are composed of the underlying structural shocks that are responsible for variations in y_t and p_t. Assume that one of these structural shocks is a supply shock, e_t, while the other is a demand shock, h_t, so that

$$\begin{bmatrix} e_{yt} \\ e_{pt} \end{bmatrix} = \begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{bmatrix} \cdot \begin{bmatrix} e_t \\ h_t \end{bmatrix} \tag{2}$$

where: c_{ij} represents the contemporaneous effect of shock *j* on variable *i*.

The problem is to identify the four values of c_{ij} from the residuals of (1). It turns out that the solution to the problem is straightforward. From (2) it follows that

$$\begin{bmatrix} \text{var}(e_{yt}) & \text{cov}(e_{yt}e_{pt}) \\ \text{cov}(e_{yt}e_{pt}) & \text{var}(e_{pt}) \end{bmatrix} = \begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{bmatrix} \cdot \begin{bmatrix} s_e^2 & s_{eh} \\ s_{eh} & s_h^2 \end{bmatrix} \cdot \begin{bmatrix} c_{11} & c_{21} \\ c_{12} & c_{22} \end{bmatrix}. \tag{3}$$

Estimation of the VAR yields var(e_{yt}), var(e_{pt}) and cov($e_{yt}e_{pt}$). Hence, there are three independent equations that can be used to determine the four values of the c_{ij} along with the values of s_e^2, s_h^2 and s_{eh}. Thus, exact identification of the structural model requires that four restrictions be imposed on the VAR. The B-Q decomposition assumes that $s_e^2 = 1$, $s_h^2 = 1$, s_{eh} = 0 and that

$$c_{12}[1 - a_{22}(1)] + c_{22}a_{12}(1) = 0. \tag{4}$$

The assumptions that $s_e^2 = 1$ and $s_h^2 = 1$ necessarily restrict the variability of the demand and supply shocks to be equal. Moreover, the assumption s_{eh} = 0 requires that the shocks to aggregate demand and supply be uncorrelated with each other. Blanchard and Quah (1989) show that (4) is a 'long-run neutrality' restriction in that it guarantees that the demand shock, h_t, has no permanent effect on output. These four restrictions are sufficient to identify the c_{ij} and the time paths of the structural shocks $\{e_t\}$ and $\{h_t\}$.

On the surface, the four restrictions seem to be innocuous. However, the more recent time-series literature has shown that there are three important reasons to be concerned about the Blanchard-Quah restrictions:

1. *Uncorrelated demand and supply shocks*: The B-Q methodology forces the so-called 'demand' shock to have no long-run effect on output and to be orthogonal to all past values of demand and to current and past values of supply. Papers that use the B-Q methodology often find that such 'demand' shocks play a small role in the fluctuations of real economic activity. However, it is more appropriate to claim that the shock that has a temporary effect on GDP *and* that is orthogonal all supply and demand shocks at all leads and lags plays a small role in fluctuations in economic activity.

The point is that demand and supply shocks identified in this way may not bear any reasonable relationship to known economic variables since shifts in aggregate demand and supply are likely to be correlated. Clearly, the assumption that demand and supply shocks are uncorrelated is implausible if the monetary or fiscal authority acts in regard to the current or past state of economic activity. Similarly, shifts in aggregate supply may result from aggregate demand shocks. In an intertemporal optimizing model, a temporary increase in demand will lead to a positive supply response as agents react to a temporary increase in real wages. New-Keynesian models also suggest reasons to believe that demand and supply shocks are correlated as some firms increase output (rather than price) in response to a positive demand shock. Our decomposition allows for the two shocks to be correlated *and* for the effects of the 'pure' demand and supply innovations to be estimated.

2. *ad hoc normalizations*: Waggoner and Zha (1997) show that the normalizations used to identify the shocks are not innocuous for two reasons. First, in the two-variable VAR represented by (3), there are actually four solutions for the values of the c_{ij}. The B-Q restrictions produce a system of quadratic equations so that the signs of the c_{ij} are not identified. In these circumstances, Taylor (2003) recommends the use of overidentifying restrictions or those normalizations that are consistent with an underlying economic model. Secondly, because of the restrictions on the signs of the c_{ij}, Waggoner and Zha (1997) argue that a normalization can have important effects on statistical inference. In particular, the choice of the c_{ij} can have profound effects on the shape of the likelihood and thus confidence intervals for the impulse responses. In the words of Hamilton, Waggoner and Zha (2002), "… the standard RATS procedures that have been used by applied researchers for twenty years to calculate confidence intervals for impulse response functions can produce seriously misleading results as a consequence of mishandling the normalization problem."

3. *Nonrobust impulse responses*: The impulse response functions of structural VARs are not especially robust to alternative decompositions. Breitung (2002), for example, provides a number of instances in the literature showing that the output responses to various shocks are heavily dependent on the form of the structural VAR. Part of the ambiguity can be attributed to the fact that the dimension of the VAR is smaller than the actual number of shocks in the economy. On the demand side, changes in monetary policy, government spending, tax rates and import demand will all have different influences on the dynamic process represented by (1). Similarly, supply shocks include the effects of technological innovation, changes in labor force participation, and changes in the capacity utilization rate. The key question is whether the single aggregated demand and supply shocks have the same properties as the myriad of structural shocks. In their original paper, Blanchard and Quah mention the conditions that need to be assumed to identify n orthogonal shocks in an $m < n$ dimensional VAR. More formally, Faust and Leeper (1997) derive the conditions that allow the various shocks to be aggregated. Although these conditions are not directly testable, Faust and Leeper provide indirect evidence that the necessary conditions are violated for the set of variables typically used in a structural VAR.

Our decomposition is designed to address the first two problems. In particular, we do not need to restrict the value of s_{eh} in order to obtain the identified demand and supply shocks. As we show below, the estimated value of s_{eh} for the United States is equal to 0.576. Moreover, instead of imposing *ad hoc* normalizations on the variance of the supply and demand shocks, we use the normalizations suggested by the AD-AS model: a one-unit demand shock shifts aggregate demand by one unit and a one-unit supply shock shifts aggregate supply by one unit. The impulse responses and confidence intervals attained by using these normalizations are quite different from those of the B-Q decomposition. However, our main result only adds to the notion that structural decompositions are not robust to structural identifying assumptions. We deem it important that the results of our decomposition are contrary to the prevailing view that supply shocks account for the preponderance of the long-run forecast error variance of real output. Unlike most structural decompositions of real GDP, allowing for ‘natural’ normalizations and a nonzero correlation between shifts in supply and demand, we show that demand shocks can account for more than 82% of the long-run forecast error variance of output. This is in stark contrast to the findings of those who force the correlations of shocks to be zero. Gali (1992), for example, finds that more then 80% of output variability can be attributed to supply shocks.

3. Identification of the AD-AS Model

Consider the following simple AD-AS model:

$$y_t^s = {}_{t\text{-}1}y_t + a(p_t - {}_{t\text{-}1}p_t) + e_t, \quad a > 0. \tag{5}$$

$$(y_t + p_t)^d = {}_{t\text{-}1}(y_t + p_t)^d + h_t \tag{6}$$

$$y_t^d = y_t^s \tag{7}$$

In the above model, y_t is the logarithm of output during period t, while ${}_{t\text{-}1}y_t$ is the level of output expected given information available at the end of period t-1. Similarly, p_t is the logarithm of the price level during period t, while ${}_{t\text{-}1}p_t$ is the price level expected given information available at the end of period t-1. The superscripts s and d represent supply and demand, respectively. We let e_t and h_t denote the serially uncorrelated structural aggregate supply and aggregate demand shocks, respectively. Equation (5) is a Lucas (1972) aggregate supply curve in which output increases in response to unexpected increases in the price level and positive realizations of the pure aggregate supply shock e_t. Equation (6) is the aggregate demand relationship; nominal aggregate demand equals its expected value plus a random demand disturbance, h_t.

Although equations (5) through (7) represent an overly simplified model of the aggregate economy, our goal is to suggest that a plausible macroeconomic model is consistent with the notion that demand shocks can play a predominant role in real GDP fluctuations. The essential feature of the model is the absence of a restriction forcing the demand and supply shocks to be contemporaneously uncorrelated. In an unpublished appendix (available from us on request), we report similar findings within a new-Keynesian framework. However, we believe that the evidence supporting a key role for demand shocks is more compelling in a non-Keynesian environment.

It is instructive to compare the four identifying restrictions embedded within the AD-AS model to those of Blanchard and Quah. Obviously, both models employ the long-run neutrality restriction that demand shocks have no long-run effect on output. Our normalization restrictions are that an e_t shock has a one-unit impact effect on y_t^s and an h_t shock has a one-unit impact effect on y_t^d. Finally, (6) implies that the slope of the aggregate demand curve is unity. To show how these restrictions exactly identify the system, note that equations (5) – (7) can be solved for output and the price level:

$$\begin{bmatrix} y_t \\ p_t \end{bmatrix} = \begin{bmatrix} {}_{t\text{-}1}y_t \\ {}_{t\text{-}1}p_t \end{bmatrix} + \begin{bmatrix} \frac{1}{1+a} & \frac{a}{1+a} \\ \frac{-1}{1+a} & \frac{1}{1+a} \end{bmatrix} \cdot \begin{bmatrix} e_t \\ h_t \end{bmatrix}. \tag{8}$$

Finally, if it is assumed that ${}_{t\text{-}1}y_t$ and ${}_{t\text{-}1}p_t$ are equal to linear combinations of their past observed values, then the system can be represented by equation (1). Hence, the relationship between the VAR residuals and the structural innovations of the AS-AD model is:

$$\begin{bmatrix} e_{yt} \\ e_{pt} \end{bmatrix} = \begin{bmatrix} \frac{1}{1+a} & \frac{a}{1+a} \\ \frac{-1}{1+a} & \frac{1}{1+a} \end{bmatrix} \cdot \begin{bmatrix} e_t \\ h_t \end{bmatrix} \tag{9}$$

so that

$$\begin{bmatrix} \text{var}(e_y) & \text{cov}(e_y, e_p) \\ \text{cov}(e_y, e_p) & \text{var}(e_p) \end{bmatrix} = \begin{bmatrix} \frac{1}{1+a} & \frac{a}{1+a} \\ \frac{-1}{1+a} & \frac{1}{1+a} \end{bmatrix} \cdot \begin{bmatrix} s_e^2 & s_{eh} \\ s_{eh} & s_h^2 \end{bmatrix} \cdot \begin{bmatrix} \frac{1}{1+a} & \frac{-1}{1+a} \\ \frac{a}{1+a} & \frac{1}{1+a} \end{bmatrix}. \tag{10}$$

Again, estimation of the VAR yields var(e_y), var(e_p) and var(e_y,e_p). There are four parameters to be estimated-- s_e^2, s_h^2, s_{eh} and α--so that only one identification restriction is required. The assumption that the structural aggregate demand shock, h_t, has no long-run effect on output now implies that

$$\frac{a}{1+a}\,[1 - a_{22}(1)] + \frac{1}{1+a}\,a_{12}(1) = 0,$$

or: $\alpha = -a_{12}(1)/[1 - a_{22}(1)]$. (11)

Thus, the system is exactly identified, and we have not restricted the values of s_e^2, s_h^2, or σ_{eh}. As such, any additional restriction on these parameters, such as $\sigma_{eh} = 0$, results in an over-identified system. Another way to make the same point is to combine (3) and (10):

$$\begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{bmatrix} \begin{bmatrix} s_e^2 & s_{eh} \\ s_{eh} & s_h^2 \end{bmatrix} \begin{bmatrix} c_{11} & c_{21} \\ c_{12} & c_{22} \end{bmatrix} = \begin{bmatrix} \frac{1}{1+a} & \frac{a}{1+a} \\ \frac{-1}{1+a} & \frac{1}{1+a} \end{bmatrix} \cdot \begin{bmatrix} s_e^2 & s_{eh} \\ s_{eh} & s_h^2 \end{bmatrix} \cdot \begin{bmatrix} \frac{1}{1+a} & \frac{-1}{1+a} \\ \frac{a}{1+a} & \frac{1}{1+a} \end{bmatrix}. \quad (12)$$

Recall that Blanchard and Quah (1989) impose the four restrictions: $s_e^2 = 1$, $s_h^2 = 1$, $s_{eh} = 0$ and $c_{12}[1 - a_{22}(1)] + c_{22}a_{12}(1) = 0$. In contrast, our AS-AD model imposes three independent restrictions among the c_{ij}; in particular, $c_{11} = \alpha c_{12}$, $c_{11} = -c_{21}$ and $c_{11} = c_{22}$. These three restrictions, along with the long-run neutrality restriction, are sufficient to fully identify the model. As should be clear from (11), imposing the Blanchard-Quah restriction yields an estimate of the slope of the aggregate supply curve.

Because of the additional constraints introduced by employing the AD-AS model, it is not necessary to assume that the structural shocks are mutually uncorrelated. Hence, the model allows for the possibility that $E(e_t \cdot h_t) = s_{eh}$ ¹ 0. In section 5, this possibility is implemented using two distinct causal orderings. The first ordering assumes that the correlation between e_t and h_t is the result of causality that runs entirely from supply to demand. The second ordering assumes that a demand shock has a contemporaneous effect on supply but that supply shocks have no contemporaneous effect on demand.

The assumption that causality runs from the supply shock to the demand shock can be implemented by assuming that unexpected aggregate demand equals a pure aggregate demand shock, n_t, plus an unexpected change in aggregate demand that is induced by the aggregate supply shock, re_t, or $h_t = re_t + n_t$. There are at least two motivations for such an assumption.

The first comes from the life-cycle/permanent income hypothesis (LC/PIH). According to the LC/PIH, if a particular shock to aggregate supply has only a temporary effect on output, it has very little effect on the present value of expected future income and therefore has only a little, if any, effect on current aggregate demand. However, if a particular shock to aggregate supply has a permanent effect on output, then the present value of future income increases by enough for current demand to increase by an amount approximately equal to the increase in output supplied. The value of r therefore depends upon how the time series of structural supply shocks is divided between permanent and temporary shocks.[2]

The second motivation for a positive correlation between demand and supply shocks is the possibility that the monetary authority is attempting to stabilize the price level or the rate of inflation. If there is a positive aggregate supply shock, then in order to prevent the price level from declining, the monetary authority must increase aggregate demand. This would cause unexpected aggregate demand to be positively correlated with unexpected aggregate supply.[3]

The assumption that causality runs from the demand shock to the supply shock can be implemented by assuming that the aggregate supply shock consists of two distinct components: a pure supply shock, d_t, and a change in output that results entirely from the decision of some firms to respond to an unexpected change in demand by passively changing output, gh_t, or $e_t = gh_t + d_t$. All of the motivations for this assumption are Keynesian. For example, if there is real rigidity in the economy, then some firms do not adjust price in response to unexpected changes in demand; rather, they simply supply the additional output demanded.[4] The value of g therefore depends upon the share of firms in the economy that do not change their current price in response to an unexpected change in aggregate demand.

4. Estimation Results for the Standard B-Q Model

Data on real GDP and the GDP deflator for the period 1954*Q*1-2001*Q*4 were obtained from the United States Department of Commerce. Standard Dickey-Fuller tests of the logarithms of real GDP and the GDP deflator indicated that real GDP was difference stationary, while the GDP deflator had to be differenced twice to become stationary. Hence, the variables employed in the VAR are the log-first difference of real GDP and the log-second difference of the GDP deflator. The log likelihood ratio test, modified for small samples, used in Sims (1980) indicated that the optimal lag length is 10 lags.

The solid lines in Figures 1 and 2 are the impulse response functions for the structural aggregate supply and aggregate demand shocks as identified by the standard B-Q set of identifying restrictions discussed above.[5] The dashed lines denote upper and lower one-standard deviation bands. From Figure 1-A, notice that a 1% supply shock causes output to increase by about 0.75%, while in Figure 1-B a 1% demand shock causes output to increase by only about 0.35%. The effects of both shocks decline very rapidly. The effect of the supply shock is about zero by the fourth quarter and the effect of the demand shock becomes negative by the third quarter after the shock. The response of output to the demand shock remains below -0.10 for three quarters, so that after six quarters the cumulative effect on output of a 1% shock to demand is approximately zero.

The variance decompositions presented in Table 1 show that about 80% of the short-run variation in output and 72% of the long-run variation in output in the United States has been the result of the structural supply shock. The percentages are approximately reversed for the variation in inflation, with the demand shock accounting for 75% of the short-run variation and nearly 70% of the long-run variation in inflation.

What might one conclude from the results for the standard B-Q model? One possible conclusion is that demand shocks have been the primary source of variations in inflation, while supply shocks have been the primary source of variations in output. Although it is possible that this conclusion is sound, it hinges on the assumption that the demand and supply shocks are contemporaneously uncorrelated. In particular, the next section shows that the variance decomposition obtained from this model is identical to that obtained from the demand-supply model using causal ordering such that the causality runs exclusively from the structural supply shock to the structural demand shock. If it is assumed that the causality runs in the opposite direction, then most of the variation in output (in both the short and long-runs) will be the result of the structural demand shock.

Another conclusion that one might draw from the standard model is that demand shocks do not have nearly the same effect on output in the short run as do supply shocks. However, this conclusion rests on the assumption that the structural shocks are uncorrelated and have unit variances. If the assumption of unit variances is relaxed, the results of the standard model do not support this conclusion. The reason is that the responses to the 1% shocks presented in Figures 1 and 2 are actually the responses to one standard deviation shocks. If the standard deviation of the structural demand shock is less than 1%, then the effect of a 1% demand shock is larger than the response presented in the figures. Furthermore, as shown in the next section, if the structural shocks are actually correlated, the response of output to a supply shock presented in Figure 1-A could be the result of the demand curve shifting at the same time as the supply curve.

Similarly, Table 1 shows that the structural demand shock has accounted for only 20% to 30% of the variation in output. This relatively small contribution of demand shocks to the historical variation in output, however, could be the result of two very different underlying causes. One possibility is that the aggregate supply curve is relatively steep, so that any given demand shock has a much smaller effect on output than does an equal-sized supply shock. The other possibility is that historical demand shocks have had only a relatively small variance. Because the standard procedure rests on the assumption that both structural shocks have unit variances, the procedure cannot determine the exact reason demand shocks have had a relatively small effect on output.

5. Estimation and Identification of the AD-AS model

The first row of Table 2 presents the estimates, along with their bootstrapped 95% confidence intervals, of the structural parameters obtained by using the restrictions of the AD-AS model. The point estimate of a, the slope of the aggregate supply curve, is 1.56. From equation (8), the immediate effect of a 1% supply shock on output is $1/(1 + a) = 0.39$. The effect of the structural demand shock on output is $a/(1 + a) = 0.61$. Hence, the point estimate of the output-inflation tradeoff parameter, which is the slope of the short-run aggregate supply curve in the AD-AS model, implies that the immediate effect on output of a structural demand shock is larger than that of an equal-sized structural supply shock. Notice that the variance of each structural shock is less than unity (i.e., s_e^2=0.90 and s_h^2= 0.72). More importantly, the covariance between the two shocks is 0.58; thus, the aggregate demand and supply curves tend to shift together.

Using the restrictions implied by the basic AD-AS model, we can obtain the $\{h_t\}$ and $\{e_t\}$ sequences. One attractive feature of our decomposition is that it yields a straightforward measure of excess demand, or ‘inflationary pressure’, as the sum h_t - e_t. Inflationary pressure and the actual inflation rate are shown in Figure 3. In order to depict a reasonably smooth series, the figure measures inflationary pressure as the annual average $0.25\sum_{i=0}^{3}(h_{t-i} - e_{t-i})$. Figure 3 clearly shows a preponderance of shocks generating inflationary pressure beginning in the late 1960s and lasting through 1975. After a decline in inflation in the mid-1970s, inflationary pressure resumes until the contractions of the late-1970's and early 1980s. Figure 4 shows the annualized values of the 'output gap' as the four-month moving average $0.25\sum_{i=0}^{3}(h_{t-i}+e_{t-i})$. Large values of $h_t + e_t$ should be associated with increases in output. An especially interesting feature of the figure is that sharply positive movements are associated with an economic turn around. The NBER dates the troughs of the business cycle occurring in our sample period are 1958*Q*2, 1961*Q*1, 1970*Q*4, 1975*Q*1, 1980*Q*3, 1991*Q*1 and 2001*Q*1. Clearly, sharp upward movements in the figure are associated with these dates.

Impulse Responses

In order to obtain impulse response functions, it is necessary to use orthogonal shocks to avoid any ambiguity regarding the type of shock under examination. Since $Ee_th_t \neq 0$, it is necessary to make an assumption concerning the source of the correlation between the shocks. Although there is an infinite number of possibilities, each one can be represented by a combination of two extreme possibilities. The first ordering is that the supply shock is causally prior to demand, while the second assumes that causality runs in the opposite direction.

It is straightforward to show that the case in which causality runs entirely from the supply shock to the demand shock yields an AD-AS model identical to the standard B-Q model discussed in section 4. Assume that the demand shock is a linear combination of an independent structural demand shock, n_t, and the aggregate supply shock:

$$h_t = re_t + n_t. \qquad (13)$$

Hence, v_t is the independent portion of the demand shock and r captures the correlation between h_t and e_t. If (13) is substituted into (10), the result is:

$$\begin{bmatrix} \mathrm{var}(e_y) & \mathrm{cov}(e_y, e_p) \\ \mathrm{cov}(e_y, e_p) & \mathrm{var}(e_p) \end{bmatrix} = \begin{bmatrix} \frac{1}{1+a} & \frac{a}{1+a} \\ \frac{-1}{1+a} & \frac{1}{1+a} \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 \\ r & 1 \end{bmatrix} \cdot \begin{bmatrix} s_e^2 & 0 \\ 0 & s_n^2 \end{bmatrix} \cdot \begin{bmatrix} 1 & r \\ 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \frac{1}{1+a} & \frac{-1}{1+a} \\ \frac{a}{1+a} & \frac{1}{1+a} \end{bmatrix}, \tag{14}$$

where: s_e^2 continues to be the variance of the total structural supply shock and s_n^2 is the variance of the independent structural demand shock. The B-Q constraint is not affected by the orthogonalization and is still given by (11).

Note that equation (14) is equivalent to

$$\begin{bmatrix} \mathrm{var}(e_y) & \mathrm{cov}(e_y, e_p) \\ \mathrm{cov}(e_y, e_p) & \mathrm{var}(e_p) \end{bmatrix} = \begin{bmatrix} \frac{1}{1+a} & \frac{a}{1+a} \\ \frac{-1}{1+a} & \frac{1}{1+a} \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 \\ r & 1 \end{bmatrix} \cdot \begin{bmatrix} s_e & 0 \\ 0 & s_n \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} s_e & 0 \\ 0 & s_n \end{bmatrix} \cdot \begin{bmatrix} 1 & r \\ 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \frac{1}{1+a} & \frac{-1}{1+a} \\ \frac{a}{1+a} & \frac{1}{1+a} \end{bmatrix}, \tag{15}$$

which implies that

$$\begin{bmatrix} \mathrm{var}(e_y) & \mathrm{cov}(e_y, e_p) \\ \mathrm{cov}(e_y, e_p) & \mathrm{var}(e_p) \end{bmatrix} = \begin{bmatrix} \frac{1+ar}{1+a} s_e & \frac{a}{1+a} s_n \\ \frac{-(1-r)}{1+a} s_e & \frac{1}{1+a} s_n \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \frac{1+ar}{1+a} s_e & \frac{a}{1+a} s_n \\ \frac{-(1-r)}{1+a} s_e & \frac{1}{1+a} s_n \end{bmatrix}. \tag{16}$$

This expression is identical to equation (3) under the identifying assumptions of the standard model if we assume that

$$\begin{bmatrix} \frac{1+ar}{1+a} s_e & \frac{a}{1+a} s_n \\ \frac{-(1-r)}{1+a} s_e & \frac{1}{1+a} s_n \end{bmatrix} = \begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{bmatrix}. \tag{17}$$

In addition, substituting (17) into (4), the B-Q constraint of the standard model, yields exactly (11), the B-Q constraint of the AD-AS model with causality running entirely from the supply shock to the demand shock. Therefore, the standard model is identical to the AD-AS model with causality running entirely from the supply shock to the demand shock. That is, all the variations in output resulting from common shifts of the AD and AS curves are attributed to the structural supply shock in the standard model.

The parameter estimates obtained from employing (14) are presented in the second row of Table 2. The values of a and s_e^2 are the same as those in the basic model. The estimate of the variance of the independent demand shock, s_n^2 = 0.35, is slightly less than one-half of the variance of the total demand shock, s_h^2, reported in the first row. Hence, if we use this ordering, slightly more than one-half of the variation in unexpected aggregate demand is the result of shifts in the AD curve induced by structural shocks to aggregate supply. The estimate of r is 0.64, implying that a 1% structural supply shock not only shifts the AS curve 1% to the right but also shifts the AD curve 0.64% to the right.

We do not depict the impulse response functions for this case. If causality runs from supply shocks to demand shocks, the impulse response functions are simply proportional to those shown in Figures 1 and 2. The shapes are identical since a decomposition using (14) is identical to that using the standard B-Q restrictions. The scale changes since the standard deviations of the shocks are below unity. Moreover, the variance decompositions obtained from (14) are identical to those reported in Table 1.

The other way to obtain orthogonal shocks is to assume that the demand shock is causally prior to the supply shock. This case is implemented by assuming that the supply shock is a linear combination of an independent structural supply shock, d_t, and a change in aggregate supply induced by the aggregate demand shock, gh_t, or

$$e_t = gh_t + d_t. \tag{19}$$

If (19) is substituted into (10), the result is

$$\begin{bmatrix} \text{var}(e_y) & \text{cov}(e_y, e_p) \\ \text{cov}(e_y, e_p) & \text{var}(e_p) \end{bmatrix} = \begin{bmatrix} \frac{1}{1+a} & \frac{a}{1+a} \\ \frac{-1}{1+a} & \frac{1}{1+a} \end{bmatrix} \begin{bmatrix} 1 & g \\ 0 & 1 \end{bmatrix} \begin{bmatrix} s_d^2 & 0 \\ 0 & s_h^2 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ g & 1 \end{bmatrix} \begin{bmatrix} \frac{1}{1+a} & \frac{-1}{1+a} \\ \frac{a}{1+a} & \frac{1}{1+a} \end{bmatrix}, \quad (20)$$

where: s_h^2 continues to be the variance of the total structural demand shock and s_d^2 is the variance of the independent structural supply shock.

The results obtained using equation (20) are presented in the third row of Table 2. The values of a and s_h^2 are the same as those in the basic model because the Blanchard-Quah restriction is defined as the assumption that any shift in the aggregate demand curve, given no shift in aggregate supply, has no long-run effect on output. The estimate of the variance of the independent supply shock, $s_d^2 = 0.43$, is slightly less than one-half of the variance of the total supply shock, s_e^2, reported in the first row. Therefore, with this orthogonalization, slightly more than one-half of the variation in unexpected aggregate supply is the result of shifts in the curve induced by structural shocks to aggregate demand. The estimated value of g is 0.80, implying that a 1% demand shock not only causes the AD curve to shift by 1% of GDP, but also causes the AS curve to shift by 0.80% of GDP.

Figures 5 and 6 present the impulse response functions obtained from this orthogonalization. A comparison of these responses to those shown in Figures 1 and 2 indicates that the orthogonalization has important implications for the role of supply and demand shocks. When causality runs from demand to supply, a 1% demand shock induces a relatively large response of output and a relatively small response of inflation. This result is obtained because a 1% structural demand shock shifts the aggregate demand curve 1% and the aggregate supply curve by γ%. Hence, the immediate effect of a 1% structural demand shock is to cause output to increase by slightly more than 0.9%, while there is almost no effect on inflation. In contrast, supply shocks have relatively small effects on output since they have no contemporaneous effect on demand.

The variance decompositions with this orthogonalization are reported in Table 3. In the AD-AS model with causality from demand to supply, 90% of the short-run variation in output and nearly 83% of the long-run variation in output is the result of the structural demand shock. Over 90% of the variation in inflation is the result of the structural supply shock.

6. Summary and Conclusions.

This paper demonstrates how it is possible to use the AD-AS model to identify a structural VAR and compares the identification with that obtained using the standard Blanchard-Quah decomposition. Our decomposition imposes the 'natural' normalizations that a demand shock has a one-unit effect on demand and a supply shock has a one-unit effect on supply. Moreover, the procedure has the advantage that it does not force the correlation between demand and supply shocks to be zero. As such, we are able to estimate of the correlation between unexpected shifts in the AD and AS curves as well as a point estimate of the slope of the short-run aggregate supply curve.

We find that the aggregate supply curve is flat enough so that demand shocks are just as capable as supply shocks of having an important effect on output in the short run. Even if it is assumed that all the correlation between the structural demand and supply shocks is the result of one-way causality from supply to demand, a 1% demand shock continues to cause output to increase by 0.61%, but a 1% supply shock (including its induced shift of AD) causes output to increase by 0.78%.

Perhaps, the most important finding is the high correlation between demand and supply shocks. If it is assumed that causality runs from the structural supply shock to the structural demand shock, the structural demand shock accounts for 28% of the long-run variation in output. We prove that a causal ordering such that structural supply shocks shift the demand curve is mathematically equivalent to the standard B-Q model (up to a scalar). On the other hand, if the ordering is such that causality runs from demand to supply, then the structural supply shock (which in this case is an independent structural supply shock) accounts for 18% of the variation in output. Our own view is that each of these causal orderings is extreme; rather, it is likely that demand shocks can contemporaneously affect supply and visa versa. Because this paper uses a bivariate model, it is not possible to determine the reason why the curves are shifting together unless additional restrictions are imposed on the data. Since the standard B-Q decomposition is just one of the two extreme orderings, without further evidence, it is not possible to claim that demand shocks play a limited role in real output variability.

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Table 1
Variance Decomposition for Standard Model
(and AD-AS Model with causality from Supply to Demand)

	Variation in Output due to		Variation in Inflation due to	
Horizon (Quarters)	Supply Shock	Demand Shock	Supply Shock	Demand Shock
1	0.810	0.190	0.248	0.752
2	0.801	0.199	0.277	0.723
3	0.797	0.203	0.277	0.723
4	0.785	0.215	0.283	0.717
5	0.769	0.231	0.270	0.730
6	0.756	0.244	0.277	0.723
7	0.749	0.251	0.277	0.723
8	0.749	0.251	0.292	0.708
9	0.734	0.266	0.299	0.701
10	0.729	0.271	0.299	0.701
11	0.728	0.272	0.303	0.697
12	0.721	0.279	0.303	0.697
13	0.720	0.280	0.305	0.695
14	0.721	0.279	0.305	0.695
15	0.722	0.278	0.305	0.695
16	0.724	0.276	0.306	0.694

Table 2 Point Estimates of Structural Parameters of AD-AS Model 1956:3-2001:4										
	Model Name	α	s_e^2	s_{eh}	s_h^2	s_n^2	r	s_d^2	g
(1)	Basic AD-AS	1.559 (0.449, 3.019)	0.896 (0.546, 1.316)	0.576 (0.350, 0.673)	0.716 (0.470, 0.818)	–	–	–	–
(2)	Causality from Supply to Demand	1.559 (0.449, 3.019)	0.896 (0.546, 1.316)	–		0.346 (0.118, 0.504)	0.643 (0.334, 0.922)	–	–
(3)	Causality from Demand to Supply	1.559 (0.449, 3.019)	–	–	0.716 (0.470, 0.818)	–	–	0.433 (0.116, 0.952)	0.804 (0.616, 0.948)

The numbers in parenthesis are 95% confidence intervals from bootstrapping.
α = sensitivity of aggregate supply to an unexpected change in inflation.
s_e^2 = variance of total structural shock to aggregate supply.
s_{eh} =covariance between total structural shocks to aggregate supply and demand.
s_h^2 = variance of total structural shock to aggregate demand.
s_n^2 = variance of independent structural shock to aggregate demand.
r = effect of shock to aggregate supply on total shock to aggregate demand if causality runs from supply shock to demand shock.
s_d^2 = variance of independent structural shock to aggregate supply.
g = effect of shock to aggregate supply on total shock to aggregate demand if causality runs from supply shock to demand shock.

Table 3
Variance Decomposition for AD-AS Model
with Causality from Demand to Supply Shock

	Variation in Output due to		Variation in Inflation due to	
Horizon (Quarters)	Supply Shock	Demand Shock	Supply Shock	Demand Shock
1	0.098	0.902	0.940	0.060
2	0.093	0.907	0.952	0.048
3	0.091	0.909	0.952	0.048
4	0.125	0.875	0.950	0.050
5	0.146	0.854	0.929	0.071
6	0.143	0.857	0.931	0.069
7	0.144	0.856	0.930	0.070
8	0.144	0.856	0.923	0.077
9	0.146	0.854	0.916	0.084
10	0.150	0.850	0.915	0.085
11	0.156	0.844	0.910	0.090
12	0.170	0.830	0.909	0.091
13	0.171	0.829	0.906	0.094
14	0.172	0.828	0.906	0.094
15	0.172	0.828	0.906	0.094
16	0.175	0.825	0.904	0.096

Endnotes

[1] For example, using the IS-LM-Phillips Curve framework, Gali (1992) distinguishes the supply shock from IS, money-demand, and money-supply shocks by assuming that each of these latter shocks has no long-run effect on output. To identify the IS shock, he assumes that money-demand and money-supply shocks have no contemporaneous effect on output.

[2] See, for example, McCallum (1989) and McCallum and Nelson (1999) for derivations that show that current aggregate demand depends upon expected future output. Gali (1992) takes this possibility into account by including the aggregate supply shock in both the IS curve and the aggregate supply curve.

[3] See, for example, Clarida, Galí, and Gertler (1999: p. 1674) and Cover and Pecorino (2003).

[4] For a discussion of the importance of real rigidity for Keynesians models see Romer (2001, pp. 304-310) and Ball, Mankiw and Romer (1988, pp. 13-19).

[5] There are four real solutions with different signs for the c_{ij} solved from equations (3) and (4). As discussed in Taylor (2003), we pick the one that implies a positive long-run effect of demand shocks on price and a positive long-run effect of supply shocks on output.

Figure 1: Output Responses with the B-Q Restrictions

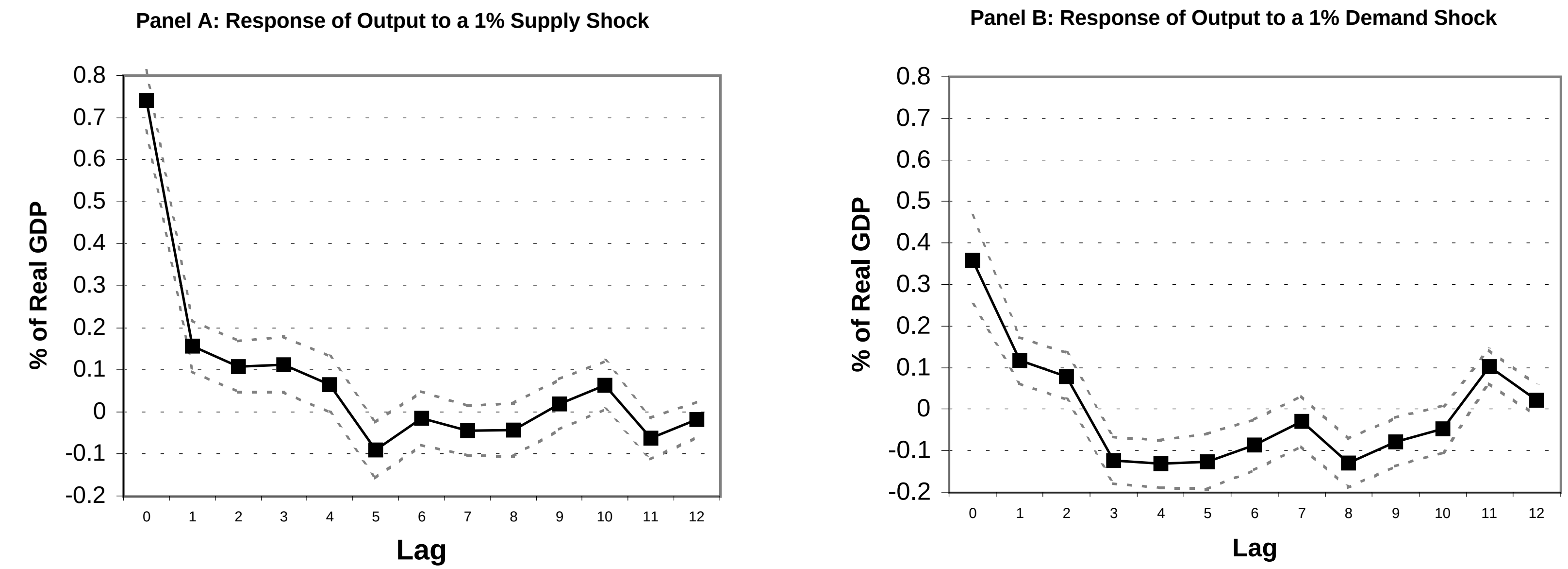


Figure 2: Inflation Responses with the B-Q Restrictions

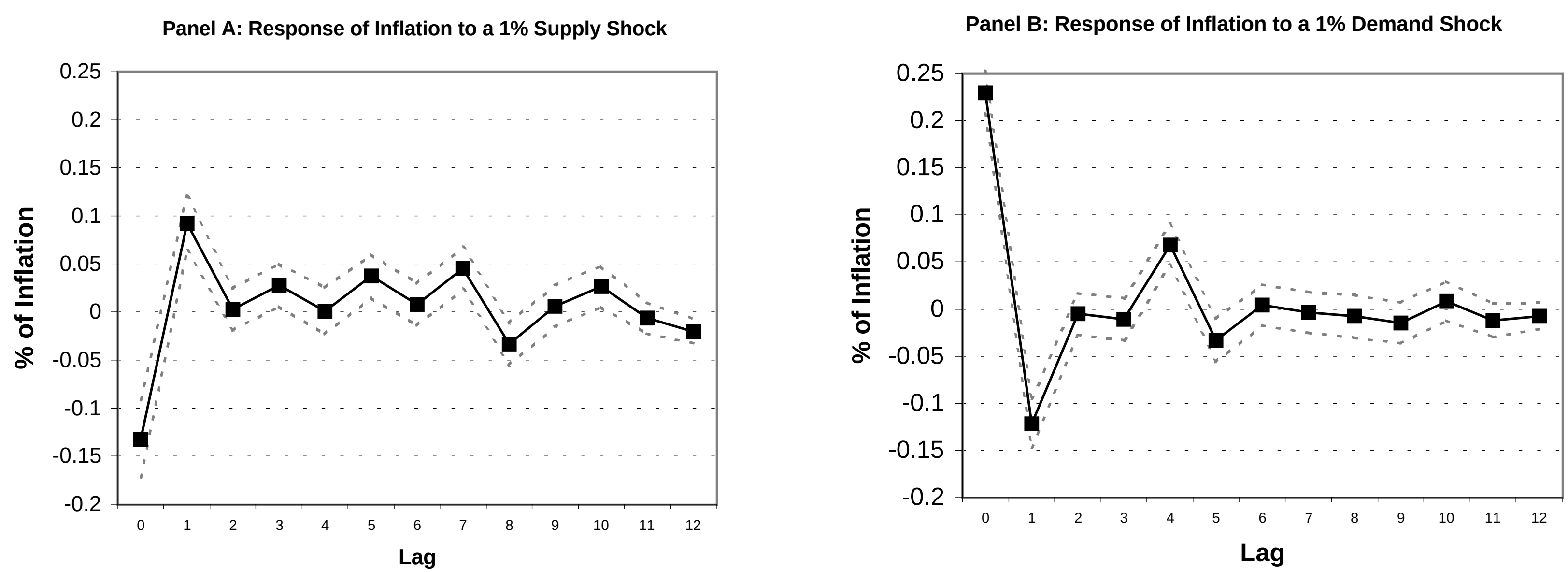


Figure 3: Actual Inflation and Inflationary Pressure

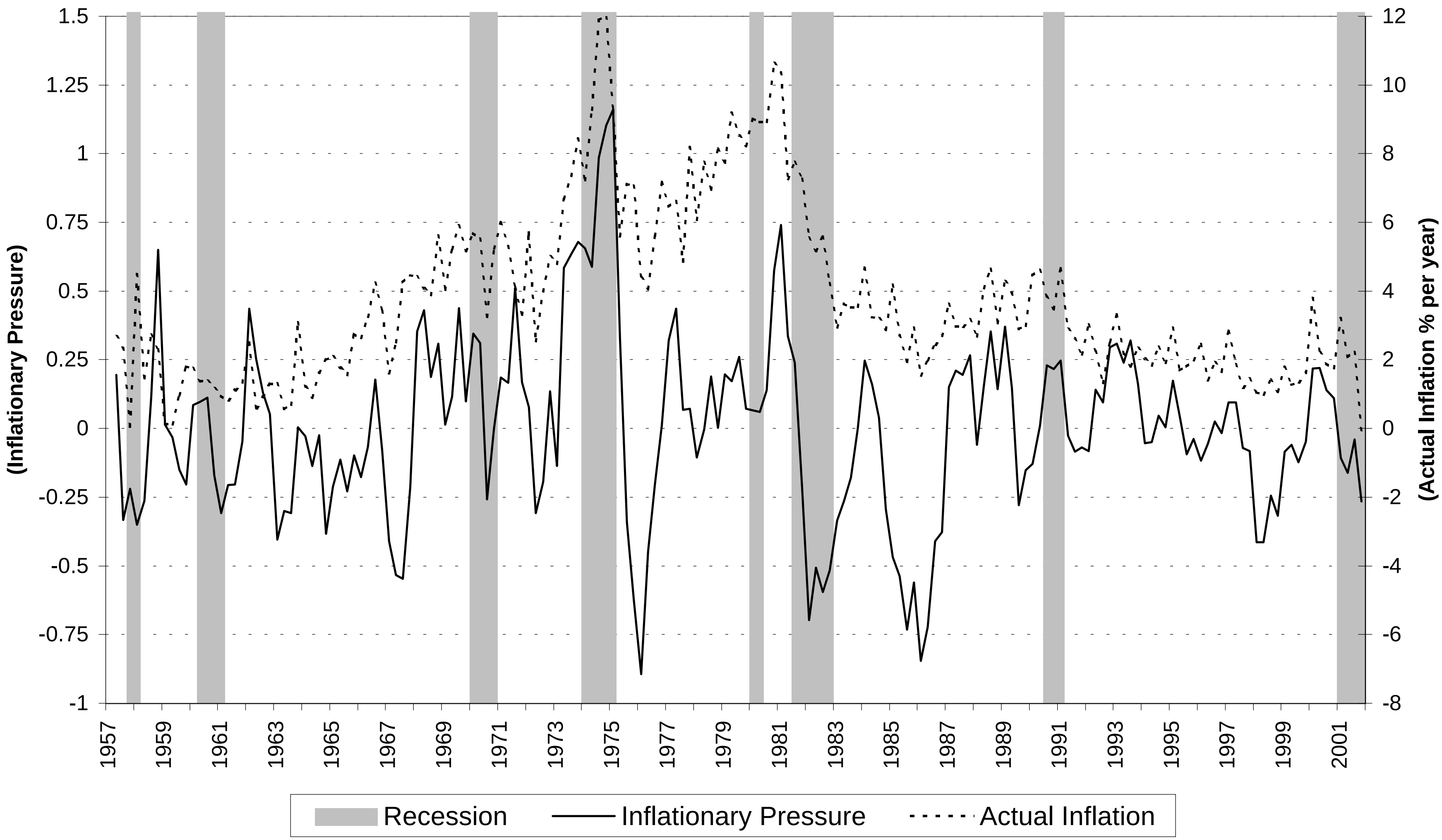


Figure 4: Output Gap
(1-year moving average)

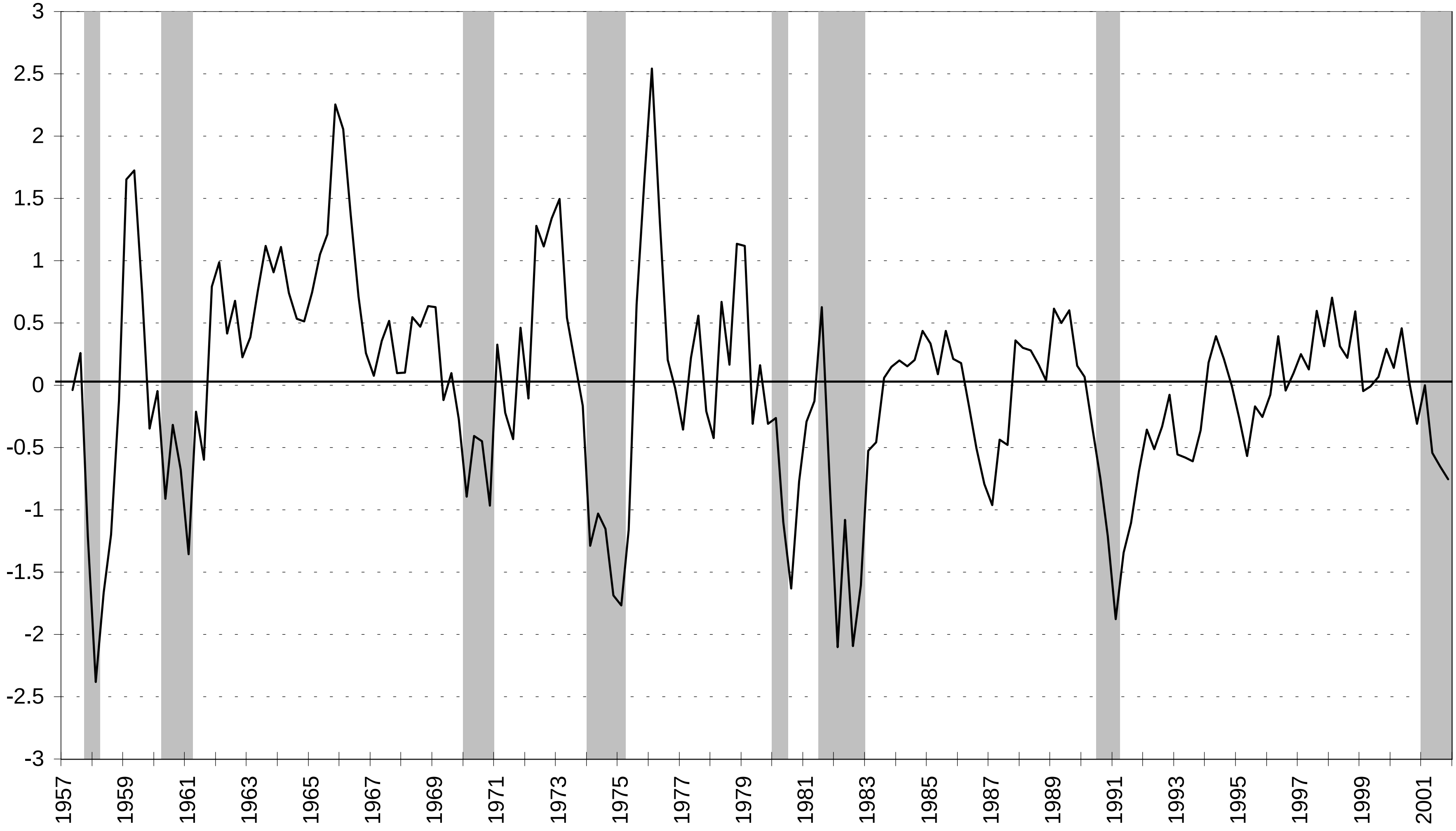


Figure 5: Output Response in the AD-AS Model

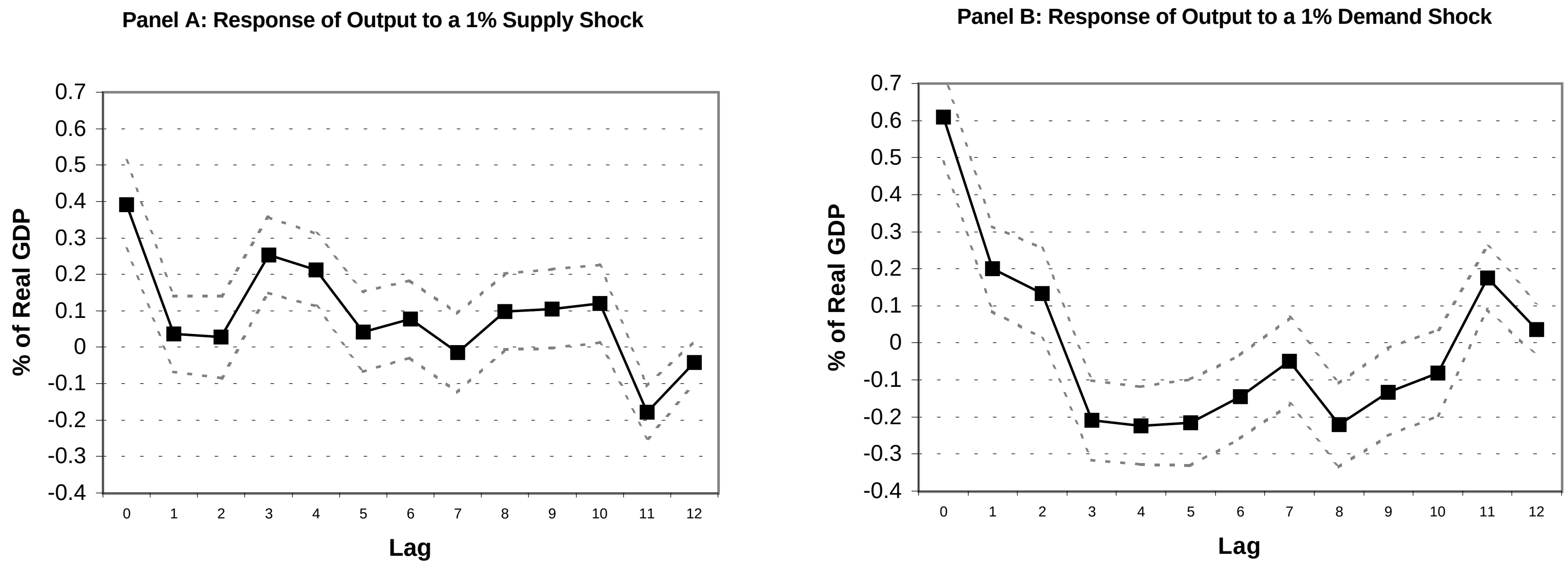
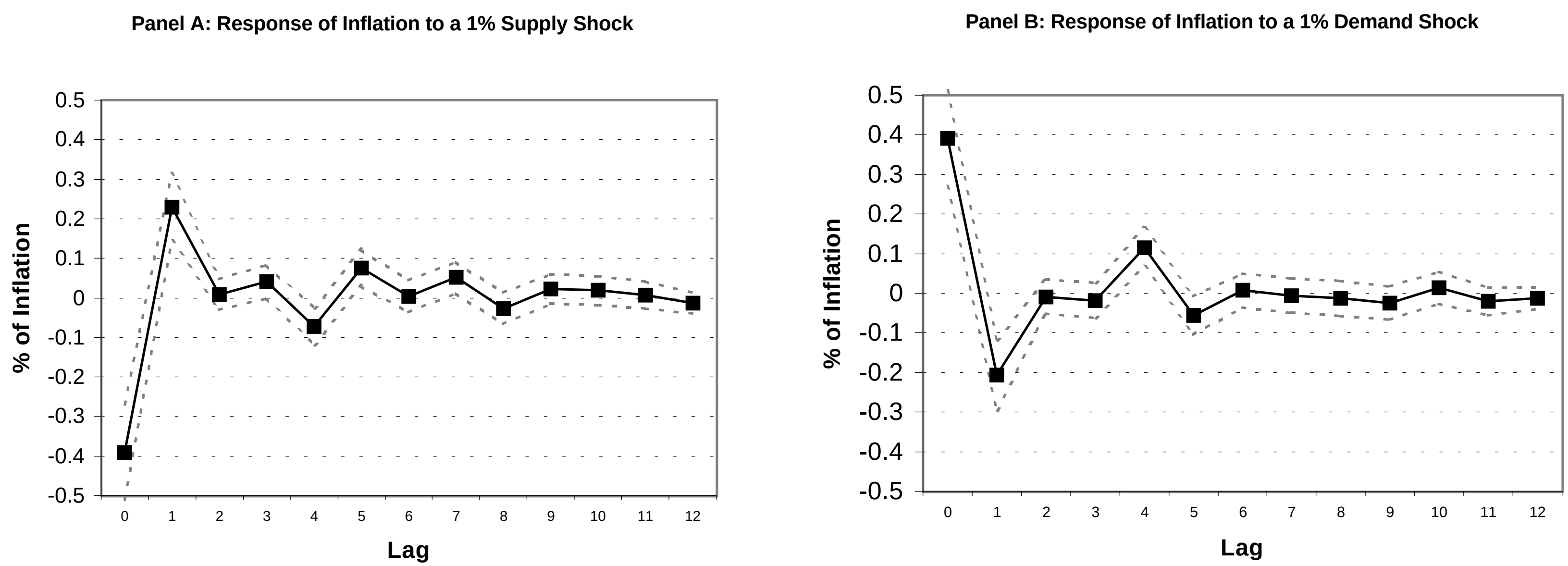


Figure 6: Inflation Response in the AD-AS Model



Note: In Figures 5 and 6, demand shocks are causally prior to supply shocks