0440

IMF WORKING PAPER

WP/90/72

INTERNATIONAL MONETARY FUND

Western Hemisphere Department

Trends and Cycles in the U.S. Economy

Prepared by Charles Adams*

Authorized for Distribution by Yusuke Horiguchi

August 1990

Abstract

This paper assesses the importance of aggregate demand and supply shocks in influencing economic activity in the United States. Aggregate supply shocks are modeled as exogenous shifts in labor supply and total factor productivity. Aggregate demand shocks arise either as a result of monetary factors or autonomous shifts in the components of spending. Compared with other studies using a similar methodology, the major finding is that aggregate demand shocks account for a substantial proportion of the unexplained variance of real GNP in the short run. Nevertheless, aggregate supply shocks also matter and become increasingly important as the forecast horizon is extended.

JEL Classification No.
0230

* The author would like to thank Bankim Chadha, Liam Ebrill, Owen Evans, and Ellen Nedde for helpful comments on an earlier draft.

Contents

Summary

This paper assesses the importance of aggregate demand and supply shocks in influencing economic activity in the United States. It uses a recently developed approach that does not rely on any particular theory about how the economy works in the short run.

Aggregate supply shocks are modeled as exogenous shifts in labor supply and total factor productivity. Aggregate demand shocks arise either as a result of monetary factors, such as changes in Federal Reserve policy, or autonomous shifts in the components of aggregate spending. Based on a very limited number of restrictions on long-run economic relationships, the contribution of these shocks to the unexplained variance of real GNP over different horizons is determined, and their dynamic effects on prices, interest rates, employment, and real GNP are traced out.

Compared with other studies that have used a similar methodology, the major finding of this paper is that aggregate demand shocks account for a substantial proportion of the unexplained variance of real GNP in the short run. Nevertheless, aggregate supply shocks are also found to matter and become increasingly important as the forecast horizon is extended. When the dynamic responses to shocks are considered, aggregate demand and supply shocks are found to have very different implications for real GNP, employment, interest rates, and prices, with effects that are consistent with the simulation properties of several large macroeconometric models.

I. Introduction

The relative contribution of aggregate demand and supply shocks in inducing fluctuations in economic activity is an important issue for analyzing developments in the U.S. economy. Increases in economic activity caused by aggregate demand shocks are likely to lead to stronger inflationary pressures if the economy is operating close to capacity, possibly calling for policy responses. Positive supply innovations on the other hand would be expected to cause a diminition of such pressures. In addition, whereas aggregate supply shocks are likely to change the medium-run growth path of the economy, those to aggregate demand should have only temporary effects.

Traditionally, short-run fluctuations in real GNP have been regarded as caused mainly by aggregate demand shocks. Wide swings in the prices of oil and other raw materials--together with declines in productivity growth--however, have focused attention on the role of aggregate supply shocks in explaining economic developments during the 1970s and 1980s. 1/ Economists now typically ascribe an important role to aggregate supply shocks in both the short run and the long run. Recently a number of studies has gone further, finding that as much as 60 to 80 percent of the unexplained variance in real GNP in the short run has been due to aggregate supply shocks. 2/ Long regarded as the dominant factor behind short-term output fluctuations, aggregate demand shocks risk being assigned a relatively minor role.

The purpose of this paper is to assess the importance of aggregate demand and supply shocks in influencing economic activity in the United States, using a recently developed approach that does not rely on any particular theory about how the economy works in the short run. Aggregate supply shocks are modeled as exogenous shifts in labor supply or total factor productivity. Aggregate demand shocks arise either as a result of monetary factors, such as changes in Federal Reserve policy, or autonomous shifts in the components of aggregate spending. Based on a very limited number of restrictions on long-run economic relationships, the contribution of these shocks to the unexplained variance of real GNP over different horizons is determined, and their dynamic effects on prices, interest rates, employment, and real GNP are traced out. In contrast to previous studies, allowance is made for an exogenous slowing of the growth rate of the U.S. economy during the 1970s, which is found to account to some extent for the large contribution attributed to aggregate supply shocks in recent studies.

1/ For a discussion of the role of aggregate demand and supply shocks in the industrial countries during the 1970s, see Bruno and Sachs (1985). In addition, see Sheffrin (1989) for an interesting discussion on the role of supply and demand shocks in generating fluctuations in real GNP in the United States.

2/ See Blanchard and Quah (1989), and Shapiro and Watson (1988).

The remainder of the paper is organized as follows. Section 2 describes the methodology used to identify aggregate demand and supply shocks. Section 3 outlines a four-equation model of the interaction between real GNP, employment, prices, and interest rates and explains how the assumptions used to identify aggregate demand and supply shocks are imposed. The estimated decomposition of the sources of fluctuations and the dynamic responses to shocks are presented in section 4. Section 5 concludes the paper. Technical material on the model, and a discussion of the time series properties of the data are contained in two annexes.

II. Identifying Aggregate Demand and Supply Shocks

This section outlines the methodology used to identify aggregate demand and supply shocks and the results from a number of recent studies. It begins by describing structural approaches to identifying these shocks, and then outlines the main features of the approach adopted in the paper.

The traditional approach to identifying the contribution of aggregate demand and supply shocks is to estimate a structural model. 1/ The contribution of shocks is then based on the estimated coefficients of the model and the variability of the shocks to aggregate demand and supply. Such a model can also be used to simulate the effects on real GNP and other variables of alternative assumptions about demand and supply shocks, and the effects of any policy adaptations. Unfortunately, there is considerable disagreement about the appropriate structural model to be used for such an exercise. The Keynesian and monetarist models are no longer accepted by all economists. And, while real business cycle models have received increasing attention, many economists are skeptical about their strong conclusions on the role of aggregate supply shocks. 2/

The choice of a structural model would not matter, of course, if it did not influence the estimated contribution of demand and supply shocks. On account of different prior assumptions about the short-run behavior of the economy, however, alternative models would be expected to reach different conclusions. Keynesian and monetarist models, for example, are formulated under the assumption that shifts in nominal aggregate demand are the major source of economic fluctuations, and are likely to ascribe a relatively minor role to aggregate supply shocks. Real business cycle models, on the other hand, assume that aggregate supply shocks are the only factors influencing real GNP in the short run and the long run.

1/ See, for example, Bruno and Sachs (1985).
2/ For a balanced discussion of these models, see Sheffrin (1989).

Given the difficulties associated with using any particular structural model, this appendix uses a relatively theory-free approach in which the only economic restrictions imposed relate to the long run, and are consistent with established views on the effects of aggregate demand and supply shocks. The methodology builds upon the work of Blanchard and Quah (1989) and can be illustrated using a simplified example of their approach. Blanchard and Quah (1989) base their analysis of the contribution of aggregate demand and supply shocks on a two-equation autoregression for real GNP and the unemployment rate, as given in equations (1) and (2).

$$\Delta y_t = a(L)\ \Delta y_{t-1} + b(L)\ u_{t-1} + e_t \tag{1}$$

$$u_t = c(L)\ \Delta y_{t-1} + d(L)\ u_{t-1} + f_t \tag{2}$$

Here Δ is the first-difference operator, y_t refers to the logarithm of real GNP, u_t is the unemployment rate, and L is the lag operator. 1/ The terms a(L), b(L), c(L), and d(L) refer to polynomals in the lag operator and capture the dynamics of the model. The errors in the equations are innovations or shocks and measure that part of the variables that cannot be predicted from their own lagged values. Under the assumption that the growth of real GNP and the level of the unemployment rate are stationary, 2/ the errors in equations (1) and (2) will also be stationary. Shocks to equations (1) and (2) will then have no influence on the long-run growth rate of real GNP or the long-run unemployment rate. Without additional restrictions, however, both shocks will influence the long-run level of real GNP.

Blanchard and Quah's decomposition of aggregate demand and supply shocks is based on the assumption that only supply shocks have long-run effects on the level of real GNP. 3/ Under these circumstances, Blanchard and Quah identify shocks with permanent effects on the level of real GNP as aggregate supply shocks, and those with only transitory

---

1/ The lag operator L is defined such that $L^n x_t = x_{t-n}$.

2/ Stationarity of a variable in the weak sense implies that its unconditional mean and variance do not vary over time. See Stock and Watson (1988).

3/ This assumption is consistent with most standard macroeconomic models. See, for example, Dornbusch and Fischer (1981) and Blanchard and Fischer (1989). Of course, the assumption is unlikely to be literally correct--shifts in investment will influence demand in the short run and supply in the long run--but will be a useful approximation provided there is not a problem of hysteresis. See Durlauf (1989).

effects as aggregate demand shocks. 1/ Given stationarity of unemployment, neither demand nor supply shocks has any long-run effect on the unemployment rate. 2/

Based on estimates of equations (1) and (2), Blanchard and Quah found that aggregate demand shocks accounted for only 35 percent of the variance of unpredictable changes in real output in the current quarter, leaving 65 percent to be explained by aggregate supply shocks. In contrast, aggregate demand shocks accounted for all the variance of unpredictable changes in the unemployment rate in the current quarter. By assumption, aggregate supply disturbances accounted for the whole of the unpredictable change in real output in the long run.

One difficulty with Blanchard and Quah's approach is that all the shocks to the economy are reflected in the two error terms of equations (1) and (2). Shapiro and Watson (1988) extended Blanchard and Quah's approach to allow for two aggregate supply shocks (a labor supply shock and a total factor productivity shock) and two aggregate demand shocks (a real shock associated with shifts in the economy's IS curve and a monetary shock that shifts the LM curve). 3/ Shapiro and Watson assumed that real output in the long run was affected only by aggregate supply shocks and distinguished labor supply and total factor productivity shocks by assuming that labor supply was exogenous in the long run. Using estimated equations for real GDP in the nonfarm business sector, employment (manhours), a short-term interest rate, and inflation, they found that aggregate demand shocks only accounted for about 25 percent of the variance of the unpredictable changes in output in the current quarter, leaving the remainder to be accounted for by aggregate supply shocks. Labor supply shocks were found to explain almost half of the unpredictable variance of output in the short run, but given the use of manhours as the measure of labor input, Shapiro and Watson's decomposition may have confused demand and supply shocks. 4/ Even though Shapiro and Watson allowed for two different kinds of demand shocks, they chose

---

1/ Blanchard and Quah (1989) recognized that their approach would incorrectly identify temporary supply shocks as demand shocks. They were, however, unable to distinguish between these shocks without imposing restrictions on the short-run behavior of their model.

2/ In order to ensure stationarity of the unemployment rate, Blanchard and Quah (1989) allowed for a discrete shift in the natural unemployment rate caused by demographic factors.

3/ In addition, Shapiro and Watson (1988) allowed for oil price shocks. These shocks, however, played a very limited role in their model.

4/ For further discussion of this point, see Hall (1988). Like Shapiro and Watson, we use manhours as our measure of labor supply but find that this does not lead to a dominant role for supply shocks.

not to identify these separately, arguing that the required identifying assumptions would be too controversial. 1/

Judd and Trehan (1989) extended Shapiro and Watson's approach to allow for two aggregate demand shocks, a foreign shock, and two aggregate supply shocks. In contrast to Shapiro and Watson (1988), Judd and Trehan found that aggregate demand shocks accounted for almost 50 percent of the unpredictable variance of output in the current quarter, which they attributed to the use of working-age population as their measure of labor supply. Reflecting the relatively closed nature of the U.S. economy, foreign shocks were not found to make a very large contribution to the unexplained variance of domestic variables.

The approach adopted in this appendix follows Shapiro and Watson (1988), but differs in a number of respects. Like Shapiro and Watson, it is assumed that there are two aggregate demand shocks (one identified with shifts in the IS curve, the other with shifts in the LM curve) and two aggregate supply shocks (a labor supply and a total factor productivity shock). These shocks are identified using the assumptions of exogeneity of the labor force in the long run and the long-run neutrality of real variables with respect to nominal shocks. 2/ In addition, allowance is made for an exogenous slowing of the U.S. economy in the early 1970s, since a failure to allow for such a slowdown may partly explain why Shapiro and Watson found that such a large proportion of the unpredictable variance in output was explained by aggregate supply shocks. 3/ It is important to know if the Shapiro-Watson finding reflects the effects of a once-for-all growth slowdown, an allowance for which would assign a bigger role to aggregate demand disturbances, or is the result of the cumulation of frequent and less pronounced supply disturbances.

III. Model Specification and Identification Assumptions

This section outlines the model used to identify the four aggregate demand and supply shocks and the way in which the identifying restrictions are imposed. After outlining the structure of the model, the number of assumptions required to exactly identify the four shocks is specified, and it is explained how the model can be rewritten to reflect these assumptions.

1/ Identification of these shocks would have required the assumption that the real interest rate was not affected by the rate of inflation in the long run.

2/ Given that inflation is found to be stationary, the second identifying assumption is that the real interest rate is independent of the long-run price level. This is a less controversial assumption than that of independence of the inflation rate and the real interest rate.

3/ For a discussion of the recent growth experience and the slowdown in the 1970s, see Denison (1979).

Even though the model uses few restrictions from economic theory, its long-run properties are based on the neoclassical theory of growth (see Solow (1957)). The long-run level of real GNP is assumed to be determined by a Cobb-Douglas production function as given by equation (3) where y, i, and k refer to the logarithms of real GNP, labor (hours), and capital, and λ denotes total factor productivity. (Here, and in what follows, upper bars denote long-run values).

$$\bar{y}_t = \alpha_0 + \alpha_1 \bar{i}_t + (1 - \alpha_1)\,\bar{k}_t + \bar{\lambda}_t \tag{3}$$

Equations like (3) have been used extensively to account for the sources of growth in the U.S. economy, giving rise to stylized representations of the growth process. As documented by Denison (1979), for example, measured changes in factor inputs account for only a small part of the long-run growth rate of real GNP. The bulk of this growth is accounted for by outward shifts in the production function, interpreted to be caused largely by improvements in technology.

Given approximate stability of the capital-output ratio in the long run, 1/ equation (3) can be rewritten with the capital-output ratio in the constant term (equation (4)). Written this way, real GNP is explained entirely by the long-run growth of labor supply and total factor productivity.

$$\bar{y} = \beta_0 + \bar{i}_t + (1/\alpha_1)\,\bar{\lambda}_t \tag{4}$$

The next two equations describe general processes followed by labor supply and total factor productivity in the long run.

$$\bar{i}_t = \delta_0 + \bar{i}_{t-1} + Z^i(L)E^i_t \tag{5}$$

$$\bar{\lambda}_t = \Sigma_0 + \bar{\lambda}_{t-1} + Z^\lambda(L)E^\lambda_t \tag{6}$$

Each equation relates the change in the long-run value of the variable to a distributed lag of its innovation.

1/ Stability of the capital-output ratio over long periods is one of the stylized features of the growth experience. See Solow (1957) and Denison (1979).

In the real business cycle models, equations (4) - (6) would completely describe the real side of the economy, with decision rules derived from the choice problem faced by representative agents. (See Kydland and Prescott (1982)). There is no independent role in these models for shifts in nominal aggregate demand; fluctuations in economic activity in the short run and the long run arise from shocks to total factor productivity and labor supply. Even though equations (4) - (6) describe the long-run properties of virtually all macroeconomic models built on the neoclassical synthesis, they do not capture the role of aggregate demand shocks in the short run. Aggregate demand shocks in the short run may influence the level of output by changing the inputs of labor and capital. Alternatively, these shocks may lead to various kinds of "off-the-production-function" behavior.

The role of aggregate demand shocks is captured through equations (7) and (8). These equations relate the deviations of output and labor input from their long-run values to all the shocks to the system, including those to aggregate demand (E_t^{d1} and E_t^{d2}).

$$y_t - \bar{y}_t = K^y(L)\ [E_t^{\lambda},\ E_t^{i},\ E_t^{d1},\ E_t^{d2}]' \tag{7}$$

$$i_t - \bar{i}_t = K^i(L)\ [E_t^{\lambda},\ E_t^{i},\ E_t^{d1},\ E_t^{d2}]' \tag{8}$$

Given that output and employment are nonstationary (see Annex II), these equations are differenced once to produce stationary series. 1/

$$\Delta y_t = Z^i(L)\ E_t^i + (1/\alpha_1)\ Z^{\lambda}(L)E_t^{\lambda} + \Delta K^y(L)\ [E_t^{\lambda},\ E_t^{i},\ E_t^{d1},\ E_t^{d2}]' \tag{7)'}$$

$$\Delta i_t = Z^i(L)\ E_t^i + \Delta\ K^i(L)\ [E_t^{\lambda},\ E_t^{i},\ E_t^{d1},\ E_t^{d2}]' \tag{8)'}$$

The two aggregate demand shocks are introduced into the model through equations for the real interest rate and inflation. (Equations (9) and (10)). In contrast to Shapiro and Watson (1988), the real interest rate is found to be nonstationary and must be differenced once to induce stationarity (see Annex II). In addition, support could not be found for Shapiro and Watson's assumption that inflation is nonstationary. 2/ As it turns out, the specification of inflation as a

---

1/ In writing down equations (7)' and (8)', and the equations that follow, constant terms are suppressed.

2/ The finding that the real interest rate is nonstationary differs from Shapiro and Watson (1988). Given that inflation appears to be stationary, the nonstationarity in the real rate reflects nonstationarity in the nominal interest rate. For further discussion of the stochastic properties of real interest rates, see Rose (1988).

stationary variable allows the data to identify a Phillip's curve and contributes to a larger role for aggregate demand shocks.

$$\Delta r_t = K^r(L)\ [E_t^{\lambda},\ E_t^{i},\ E_t^{d1},\ E_t^{d2}]' \tag{9}$$

$$\pi_t = K^{\pi}(L)\ [E_t^{\lambda},\ E_t^{i},\ E_t^{d1},\ E_t^{d2}]' \tag{10}$$

According to equations (9) and (10) the change in the real interest rate and the inflation rate are influenced by all the shocks to the system, but possibly with quite complicated dynamics. The two aggregate demand shocks included in these equations are open to a number of interpretations. In order to capture disagreement about the relative importance of real and nominal demand shocks, the E_t^{d1} shock is interpreted as a real shock and the E_t^{d2} shock as a nominal shock. In the IS/LM framework, the real shock can be viewed as shifting the IS curve. The nominal shock shifts the LM curve.

Equations (7) - (10) comprise the basic model from which the two aggregate supply shocks--labor supply and total factor productivity--and two aggregate demand shocks--IS and LM curve shifts--are identified. As discussed in Annex I, two kinds of identifying restrictions are used: restrictions on the variances and covariances of the shocks; and, restrictions on the causal relationships of the model. In total, 16 restrictions are needed to identify the 4 shocks. 1/

Four restrictions are provided by the normalization assumption that the shocks have unit variance; another six, are obtained from the assumption that the shocks are uncorrelated with each other. The remaining six restrictions refer to the long-run properties of the model. They are that: (a) the two demand shocks have no long-run effects on output (two restrictions); (b) shocks to aggregate demand and total factor productivity have no long-run effects on labor supply (three restrictions); and (c) the nominal demand shock has no long-run effect on the real interest rate (one restriction).

The identifying restrictions are imposed by writing the model so that particular shocks have no long-run impact on a given variable. This can be illustrated with reference to the employment equation where it is assumed that long-run labor supply is exogenous, and not affected by the shocks to total factor productivity or demand. The unrestricted employment equation is given by (11) where its residuals are identified as shocks to labor supply.

1/ The number of restrictions required to exactly identify the model is equal to the square of the number of underlying shocks. We do not impose overidentifying restrictions so the restrictions used to identify the model cannot be tested (see Annex I).

$$\Delta i_t = \sum_{j=1}^{n} \tilde{C}^i_{i,j}\, \Delta i_{t-j} + \sum_{j=0}^{n} \tilde{C}^i_{y,j}\, \Delta y_{t-j} + \sum_{j=0}^{n} \tilde{C}^i_{r,j}\, \Delta r_{t-j} + \sum_{j=0}^{n} \tilde{C}^i_{\pi,j}\, \pi_{t-j} + E^i_t \qquad (11)$$

The restriction that labor supply is not influenced in the long run by the shocks to total factor productivity or demand is imposed by setting the sums of the lag distributions on output, the real interest rate, and inflation in equation (11) equal to zero, leading to the order of differencing of these variables being increased and the lag length truncated.

$$\Delta i_t = \sum_{j=1}^{n} C^i_{i,j}\, \Delta i_{t-j} + \sum_{j=0}^{n-1} C^i_{y,j}\, \Delta^2 y_{t-j} + \sum_{j=0}^{n-1} C^i_{r,j}\, \Delta^2 r_{t-j} + \sum_{j=0}^{n-1} C^i_{\pi,j}\, \Delta\, \pi_{t-j} + E^i_t \qquad (12)$$

In a similar vein, the equations for output, the real interest rate, and inflation are restricted to reflect the identifying assumptions. The restriction that demand shocks have no long-run effect on the level of real GNP is imposed by setting the sums of coefficients on inflation and the real interest rate in the output equation to zero. The residuals from the employment equation are added to the equation to allow for the impact of labor-supply shocks.

$$\Delta y_t = \sum_{j=1}^{n} C^y_{i,j}\, \Delta i_{t-j} + \sum_{j=1}^{n} C^y_{y,j}\, \Delta y_{t-J} + \sum_{j=1}^{n-1} C^y_{r,j}\, \Delta^2 r_{t-j} + \sum_{j=1}^{n-1} C^y_{\pi,j}\, \Delta\pi_{t-j} + C^y_{i,j}\, E^i_t + E^\lambda_t \qquad (13)$$

The only restriction imposed on the real interest rate equation is that the nominal demand shock does not influence the real interest rate in the long run; 1/ the residuals from the labor supply and output equation are added to the equation to allow for the effects of labor supply and total factor productivity shocks. The real interest rate equation is given by:

$$\Delta r_t = \sum_{j=1}^{n} C^r_{i,j}\, \Delta i_{t-j} + \sum_{j=1}^{n} C^r_{y,j}\, \Delta y_{t-j} + \sum_{j=1}^{n} C^r_{r,j}\, \Delta r_{t-j} + \sum_{j=0}^{n-1} C^r_{\pi,j}\, \Delta \pi_{t-j} + C^r_{i,j}\, E^i_t + C_{r,\lambda}\, E^\lambda_t + E^{d1}_t \tag{14}$$

Finally, the residuals from the preceding equations are added to the inflation equation to allow all shocks to impinge on inflation. Given stationarity, none of the shocks have any impact on inflation in the long run, but each can effect the price level.

$$\pi_t = \sum_{j=1}^{n} C^\pi_{i,j}\, \Delta i_{t-j} + \sum_{j=1}^{n} C^\pi_{y,j}\, \Delta y_{t-j} + \sum_{J=1}^{n} C^\pi_{r,j}\, \Delta r_{t-j} + \sum_{j=1}^{n} C^\pi_{\pi,j}\, \pi_{t-j} + C_{\pi,i}\, E^1_t + C_{\pi,\lambda}\, E^\lambda_t + C_{\pi,d1}\, E^{d1}_t + E^{d2}_t \tag{15}$$

Equations (12) through (15) comprise the estimated vector autoregression. Given that contemporaneous values of right-hand-side variables appear in the first three of these equations, the system was estimated using lagged values of variables as instruments. 2/ The equations were estimated without including the disturbances from other equations and then transformed by a Cholesky decomposition.

1/ This restriction implies that the real interest rate is not influenced by the price level in the long run.

2/ Based on a specification search, six lags were used in the estimated equations.

IV. Decomposition of Aggregate Demand and Supply Disturbances

This section presents the decomposition of aggregate demand and supply shocks and the dynamic responses to innovations in each of these shocks. It begins by describing the data used in the study and then presents the shock decompositions and impulse response functions.

The data series for the study comprise the logarithms of real GNP, manhours of employment, and the GNP deflator, and the level of the short-term nominal interest rate. Series are quarterly and cover the period 1953:1 to 1989:4. With appropriate transformations (see Annex II), these series give rise to the measure of the ex ante real interest rate used to identify the aggregate demand shocks. 1/

In preliminary investigations, we experimented with alternative measures of the labor supply variable to determine whether the use of manhours led to a confusion of demand and supply disturbances. When the civilian population of working-force age was used, we did not get very different results, which can be interpreted as suggesting that the use of manhours does not bias the results to finding a relatively large role for supply shocks. 2/ There were, however, some differences in the impulse response functions when the civilian population variable was used, confirming the findings of Judd and Trehan (1989).

Since the modeling strategy depends crucially on identifying the stationarity properties of the data, a number of unit root tests were undertaken for each series (see Annex II). In addition, tests were undertaken to determine whether there were any cointegrating relationships among the series, which might imply that the number of unit roots in the system of equations fell short of the number of integrated variables.

The tests suggested that the null hypothesis of a unit root in the logarithms of prices, real GNP, manhours, and the level of the nominal interest rate could not be rejected at standard levels of significance. In contrast to Shapiro and Watson (1988), the real interest rate was found to contain a unit root. 3/ No cointegrating relationships were

---

1/ We experimented with a number of different measures of the real interest rate. These included: the (ex post) real interest rate, which under rational expectations should differ from the ex ante real interest rate by an error that is orthogonal to agents' information sets; and the real interest rate derived using the models' predictions of inflation. In practice, the ex post real interest rate seemed to work best and was used in the estimations.

2/ For further discussion of this point see Hall (1988).

3/ Judd and Trehan (1989) were unable to reject the null hypothesis of a unit root in the nominal interest rate. Our finding that the inflation rate is stationary implies, under the maintained assumption of rational expectations, that the real and nominal interest rate contain the same unit root.

found among the logarithms of real GNP, manhours, prices, and the level of the real interest rate, which we interpret to imply that the specification of the vector autoregression in equations (12) to (15) is appropriate. 1/

Given that the growth rate of real GNP declined sharply during the late 1960s or early 1970s, we also experimented to determine whether the unit root in real GNP was picking up the effects of this slowdown. The tests suggested that the amount of persistence in real GNP was affected, but that the null hypothesis of a unit root could still not be rejected (Annex II). In addition, the vector autoregression was estimated with and without a dummy variable for the growth slowdown, 2/ thus allowing the data to determine whether the decomposition of aggregate demand and supply disturbances was picking up the effects of a once-for-all supply shock. The results from these estimations suggested that the growth slowdown did influence the decompositions of demand and supply shocks, and that when allowance was made for a slowdown during the late 1960s or early 1970s aggregate demand shocks became more important (see below).

The estimates of the vector autoregression given by equations (12) to (15) do not of themselves contain much interesting information. In contrast to traditional econometric approaches, the purpose of the estimation is not to 'explain' the dependent variables but to identify a set of residuals that is uncorrelated with the lagged values of the variables in the model (see Sims (1980)). These residuals are the shocks to the system that result from shifts in aggregate demand and supply.

In what follows, the moving-average representation of the vector autoregression in which the current value of each variable is expressed as an infinite distributed lag of all the shocks to the system is used. 3/ The moving-average representation is then applied to determine the importance of shocks at alternative forecast horizons, and the response of variables to shocks to labor supply, total factor productivity, the IS curve, and the LM curve.

1/ Had we found cointegrating relationships, we would have had to modify the vector autoregression to include the levels of cointegrated variables. The system would then have corresponded to a vector error-correction model (VECM).

2/ Allowance was made for a slowdown in either the late 1960s or early 1970s. See Denison (1979) for a discussion of the timing of the growth slowdown in the United States.

3/ With the autoregressive representation of the system written in matrix notation as

$$Y_t = \sum_{s=1}^{n} C_s Y_{t-s} + U_t,$$

the moving-average form is obtained by pre-multiplying by the inverse of the C_s matrices.

One way to measure the importance of a shock is to determine its contribution to the errors in forecasting a variable. 1/ Hence, for example, if shocks to aggregate demand are an important source of the errors in forecasting real GNP over a one to two year horizon this would suggest an important role for these shocks in explaining short-run output fluctuations.

Table 1 presents the variance decompositions for the model and shows the relative importance of different shocks in accounting for the unexplained variance of variables at different frequencies. By construction, the proportion of the error in forecasting a variable accounted for by the four shocks sums to one hundred, so the rows of each table sum to one hundred. The assumptions used to identify the four shocks are also evident from the table. For example, the long-run error in forecasting real GNP is accounted for entirely by supply shocks, reflecting the assumption that aggregate demand shocks have no long-run effect on the level of real GNP.

Several conclusions can be reached on the basis of the variance decompositions. At forecast horizons of up to four quarters, aggregate demand shocks account for between 60 to 75 percent of the unexplained variance in real GNP, leaving the remainder to be explained by supply shocks. Aggregate supply shocks begin to play a larger role as the forecast horizon is extended, explaining almost 80 percent of the forecast error in real GNP by the twentieth quarter.

The finding that aggregate demand shocks explain a significant fraction of the short-run error in forecasting real GNP is very different from the conclusion reached by Shapiro and Watson (1988). The difference reflects to some extent the allowance for a once-for-all decline in the trend growth of real GNP in the early 1970s, which reduces the amount of persistence in real GNP. But this cannot account fully for the difference, since Judd and Trehan (1989) found an

---

1/ The contribution of a variable x to explaining the errors in forecasting y will depend on the estimated coefficients in the moving-average representation for y and the variance of x. With the moving average representation of the system given by

$$Y_t = X_t B + S_0 A_s U_{t-s}$$

where B and S_0 denote appropriately dimensioned matrices of coefficients, and $X_t B$ is the deterministic part of the system, the k-period ahead forecast error is given by:

$$\sum_{s=0}^{k-1} A_s U_{t-s}$$

Table 1. Decomposition of Variance

Percentage of Forecast Error Explained by Shocks to:

	Supply Shocks		Demand Shocks	
Quarter	Labor Supply	Total Factor Productivity	Real Demand	Nominal Demand
		I. Real GNP		
1	--	22	75	3
4	5	36	58	1
8	22	50	17	4
10	27	50	17	6
20	29	52	9	10
40	30	63	5	7
∞	39	62	--	--
		II. Employment		
1	13	--	79	8
4	28	2	60	10
8	61	5	26	8
10	71	5	18	6
20	88	2	7	3
40	94	2	3	2
∞	100	--	--	--
		III. Inflation		
1	6	7	--	87
4	9	9	6	76
8	9	8	7	76
10	8	10	7	75
20	7	11	6	76
40	6	12	6	76
∞	6	12	6	76
		IV. Real Interest Rate		
1	21	33	33	13
4	15	14	59	12
8	12	9	66	13
10	11	8	68	13
20	7	8	74	11
40	4	11	77	7
∞	--	12	88	--

important role for aggregate demand shocks with no allowance for such a slowdown. 1/ The difference seems to be explained, in addition, by the incorporation of inflation into the model as a stationary variable and the treatment of the real interest rate as stationary. With inflation entering in level rather than first difference terms, the data appears to identify a Phillips curve linking inflation and the level of real GNP, and assigns a more important role to aggregate demand shocks.

Aggregate demand shocks also are the most important factor explaining the short-run forecast errors for employment, accounting for between 70 to 90 percent of their unexplained variance four quarters ahead. 2/ This proportion, however, falls sharply as the forecast horizon is extended and labor supply shocks dominate by the eighth quarter. Aggregate demand shocks also dominate the unexplained variance of inflation over nearly all forecast horizons, but only account for 45 percent of the one quarter ahead forecast error for real interest rates.

The table also contains interesting information on the decomposition of aggregate demand and supply shocks. Total factor productivity shocks are a relatively important source of the errors in forecasting real GNP at all horizons, and account for a little over 60 percent of the errors in the long run. Labor supply shocks account for a significant fraction of the errors in forecasting employment at horizons beyond eight quarters, and for 40 percent of the error in forecasting long-run GNP. Rejecting the predictions of monetary models, nominal demand shocks explain only a relatively small proportion of the forecast errors for real GNP and employment. 3/ These shocks, however, account for most of the unexplained variance in inflation.

Table 2 displays the impulse response functions for the model and traces out the impact on each variable of a one standard deviation innovation in a shock. Responses are presented as deviations from the baseline in percentage points. The tabulation shows that the level of real GNP responds very differently to aggregate demand and supply shocks. Positive aggregate supply shocks tend to have a small impact on real GNP in the short run that builds up relatively smoothly over time. 4/ Positive aggregate demand shocks, on the other hand, temporarily raise real GNP above the baseline and then lead to some cycling

---

1/ Contrary to what was expected, the allowance for the growth slowdown in the early 1970s only increased the contribution of demand shocks to the unexplained variance of real GNP over a one- to eight-quarter horizon by between 5 and 15 percentage points.

2/ This result is consistent with Blanchard and Quah's (1989) finding that the unexplained innovation in the unemployment rate was strongly influenced by demand shocks in the short run.

3/ This result was found to be sensitive to the number of lagged instruments used in estimating the real interest rate equation.

4/ There is some evidence of a hump-shaped pattern in the response to supply shocks (see Blanchard and Quah (1989)).

Table 2. Impulse Response Functions

Response to one standard deviation shock to

Quarter	Labor Supply	Total Factor Productivity	Real Demand	Nominal Demand
		I. Real GNP		
1	--	0.4	0.7	0.1
4	0.3	0.7	0.5	-0.1
8	0.8	0.9	-0.1	-0.1
10	0.8	0.9	-0.1	--
20	0.6	1.0	--	0.1
40	0.6	1.1	--	--
∞	0.6	1.2	--	--
		II. Employment		
1	0.2	--	0.6	0.2
4	0.8	--	0.8	0.3
8	1.5	0.3	0.1	0.2
10	1.6	0.3	--	0.1
20	1.6	0.3	--	0.1
40	1.6	0.1	--	0.1
∞	1.6	--	--	--
		III. Real Interest Rate		
1	--	-0.4	0.4	-0.3
4	-0.2	-0.3	0.6	0.3
8	-0.1	--	0.5	0.3
10	-0.1	-0.1	0.5	0.2
20	--	-0.2	0.4	0.1
40	--	-0.2	0.4	--
∞	--	-0.2	0.4	--
		IV. Inflation		
1	-0.1	0.1	--	0.3
4	-0.1	-0.1	0.1	0.1
8	--	--	0.1	0.1
10	--	--	--	0.1
20	--	--	--	0.1
40	--	--	--	--
∞	--	--	--	--

around it. The effects of aggregate demand shocks die out relatively quickly; within seven quarters, real GNP has returned very close to the baseline following an increase in aggregate demand. These results are consistent with the simulation properties of several macro-econometric models. 1/

Aggregate demand and supply shocks also have different implications for inflation. Positive aggregate demand shocks tend to be associated with temporary upward pressure on inflation, with nominal shocks having more impact than real shocks. Positive aggregate supply shocks, particularly due to labor supply increases, are associated with a slight moderation of inflationary pressures. Also of interest is that positive aggregate demand shocks raise real interest rates, while positive supply shocks tend to lower them. 2/ Aggregate demand shocks give rise to real interest rate overshooting--in the sense that interest rates respond more to a shock in the short run than they do in the long run. Only real shocks, however, have a permanent impact on the real interest rate.

V. Conclusions

The purpose of this paper has been to determine the relative importance of aggregate demand and supply shocks in inducing movements in real GNP in the United States. Rather then adopt a structural approach, a relatively theory-free model was specified in which the only restrictions related to long-run economic relationships.

Compared with other studies that have used a similar methodology, the major finding is that aggregate demand shocks account for a substantial proportion of the unexplained variance of real GNP in the short run. Nevertheless, aggregate supply shocks are also important, and become increasingly so as the forecast horizon is extended. As regards the decomposition of demand shocks, real shocks were found to account for most of the unexplained variance of output in the short run. Shocks to nominal aggregate demand explained most of the unexplained variance in inflation at all horizons.

When the dynamic responses to shocks were considered, aggregate demand and supply shocks were found to have very different implications for real GNP, prices, and the real interest rate. Positive demand shocks were found to lead to temporary increases in real GNP, interest rates, and inflation. Positive supply shocks on the other hand tended to have small effects on real GNP in the short run that cumulated over time. Aggregate supply shocks also tended to be associated with modest downward pressure on inflation and real interest rates.

1/ See Bryant (1988).

2/ In the neoclassical theory of growth, increases in labor supply might be expected to raise the real interest rate in the short run but have no effect in the long run. See Solow (1957).

Model Structure and Identifying Assumptions

This annex discusses the general structure of the model estimated is section 4, and the number of restrictions required to identify the four unobserved shocks to demand and supply.

Following Blanchard-Quah (1989) and Judd and Trehan (1989) an underlying structural model is specified that relates the four endogenous variables (real GNP, employment, the real interest rate, and inflation) to the four unobserved shocks to labor supply, total factor productivity, and real and nominal aggregate demand. This model is described by equation (1) where Y denotes a (4x1) vector of endogenous variables, B(L) is an infinite-order matrix in the lag operator L, and S is a (4x1) vector of shocks.

$$Y_t = A(L)\ S_t \qquad (1)$$

The vector of shocks S appearing in this equation is assumed to follow the stochastic process given by equation (2), where U denotes a vector of innovations to these shocks and is assumed to be white noise.

$$S_t = B(L)\ U_t \qquad E(UU') = V \qquad B\ (0) = I \qquad (2)$$

By substituting equation (2) into (1), the structural model can be written in terms of the innovations to the shocks, U, rather than the shocks themselves (equation (3)). In equation (3), the matrix polynomial D(L) is a convolution of the intrinsic dynamics of the structural model as given by A(L), and the extrinsic dynamics of the shocks as given by B(L).

$$Y_t = A(L)\ B(L)\ U_t = D(L)\ U_t \qquad (3)$$

The structural model given by equation (3) is not directly observable and would require a large number of assumptions to be directly identified. The approach adopted in section 4 is to estimate a vector autoregression for Y_t and use its moving-average representation to infer the structure of equation (3).

The estimated vector autoregression for Y_t is given by equation (4), and its moving average representation is given in equation (5).

$$C(L)\ Y(L) = V_t \qquad (4)$$

$$Y(L) = C(L)^{-1} V_t = M(L) V_t \quad E(VV') = X \tag{5}$$

The identification of the unobserved vector of shocks U in equation (3) (strictly, the innovations in these shocks) can be achieved by equating the equation for Y_t as given by (5) to the underlying structural model given by equation (3). This gives rise to:

$$M(L) V_t = D(L) U_t \tag{6}$$

where, on account of equality between the number of shocks and endogenous variables, the matrices M(L) and D(L) are dimensioned conformably. Equation (6) will hold for any set of residuals V_t that satisfies $V_t = J U_t$ and $M(L) = D(L) J^{-1}$. That is to say equation (6) will hold when written as

$$M(L) V_t = D(L) J^{-1} J U_t = D(L) U_t \tag{7}$$

The identification of the four unobserved shocks reduces to determining the matrix J which satisfies equation (7). In general, with K variables and shocks, the matrix J is dimensioned K x K so a total of K x K identifying restrictions is required. A total of K x (K+1)/2 restrictions is provided by the assumption that the structural disturbances are uncorrelated and have unit variance. The remaining (K x K) - (K x (K+1)/2) = K(K-1)/2) restrictions come from assumptions about the long-run effects of shocks as discussed in the text.

Stationarity Properties of the Data

This annex examines the stationarity properties of the variables appearing in the vector autoregression estimated in section 4. Tests are recorded to determine whether each series is trend or difference stationarity, and whether the unit root in the process for real GNP is robust to a discrete change in the long-term growth rate of the economy. The data comprise the logarithms of real GNP, employment, prices, and the level of the (short-term) nominal interest rate. With appropriate transformations, these series encompass all the variables appearing in the vector autoregression of section 4. 1/

1. Trend versus difference stationarity

The tests for trend versus difference stationarity follow Perron, 2/ and are based on estimates of equations (1) through (2). In these equations y(t) denotes the tested variable, a(J) j = 1,5 denote parameters, T is a time trend, and N is the number of observations.

$$y_t = a_1 + a_2 y_{t-1} + v_t \qquad (1)$$

$$y_t = a_3 + a_4(T - N/2) + a_5 y_{t-1} + e_t \qquad (2)$$

Equation (1) is used to test the null hypothesis that a series is a unit root process with drift ($a_1 \neq 0$, $a_2 = 1$). Equation (2) includes a time trend and is used to test for difference stationarity ($a_4 = 0$, $a_5 = 1$) versus trend stationarity ($a_4 \neq 0$, $a_5 < 1$).

The tabulation below shows two different test statistics for equation (1): $Z(ta_2)$ is a t test for the null hypothesis that the series has a unit root ($a_2 = 1$), Z(F) is an F test the joint hypothesis that the series is a unit root without drift ($a_2 = 1$ and $a_1 = 0$). All statistics are shown for two values of the Newey-West truncation parameter (h = 1 and 3). Under the null hypothesis of a unit root, the test statistics have non-standard distributions requiring critical values tabulated by Dickey and Fuller. Statistical significance at the 5 percent level is indicated by an asterisk.

1/ The inflation rate is obtained by taking the first difference of the logarithm of prices; the (ex post) real interest rate is equal to the nominal interest rate in period t less the first difference of the logarithm of prices from period t to t+1. Under the assumption of rational expectations, the stationarity properties of the ex post and ex ante real interest rates coincide.

2/ See Perron (1986).

Stationarity Tests

Variables	$Z(ta_2)$ h=1	$Z(ta_2)$ h=3	Z(F) h=1	Z(F) h=3
Real GNP	-1.58	-1.37	35.45*	22.87*
Prices	3.43	2.55	129.18*	74.35*
Inflation	-5.58*	-4.78*	15.28*	10.88*
Interest rate	-1.98	-2.21	2.12	2.56
Employment	0.13	-0.18	8.79*	5.10*

The results from the tests recorded in the above tabulation can be summarized as follows. The null hypothesis of a unit root for the level of each series can not be rejected in any case. When prices are first differenced, the null hypothesis of a unit root in the inflation process is rejected, suggesting a unit root in the price level. All variables, with the exception of the nominal interest rate, appear to be characterized by drift.

Tests for difference versus trend stationarity are recorded in the following table.

Stationarity Tests

Variables	$Z(ta_5)$ 1=1	$Z(ta_5)$ 1=3	Z(F) 1=1	Z(F) 1=3
Real GNP	-2.92	-3.25	5.08	5.80
Prices	-1.81	-1.61	9.76	6.04
Inflation	-6.11*	-5.42*	18.11*	14.06*
Interest rate	-2.99	-3.45	4.47	5.95
Employment	-1.99	-2.80	2.10	3.99

This table shows two test statistics for equation (2): $Z(ta_5)$ is a t-test for the null hypothesis that a series has a unit root when a time trend is added to the equation: $a_5 = 1$; Z(F) is a F-test for the joint hypothesis that a series has unit root and a coefficient on the time trend of zero: $a_4 = 0$ and $a_5 = 1$.

Based on the test statistics recorded in the above table the null hypothesis of a unit root in the level of each series can not be rejected. In addition, the joint hypothesis of a unit root and no time trend cannot be rejected for the level of any series.

2. Unit root in real GNP

This test examines whether the finding of a unit root in the process for real GNP is picking up the effects of a once-for-all decline in the growth rate of GNP in the late 1960s or early 1970s. 1/ The test, which follows Perron, 2/ is based on the residuals from equation (3).

$$y_t = a_6 + a_7 T1 + a_8 T2 + yp_t \tag{3}$$

where the coefficients a_7 and a_8 refer to two time trends, T1 and T2, included to capture a break in the growth rate of real GNP at some point in the sample. The augmented Dickey-Fuller test is applied to determine whether the residuals form this equation have a unit root (see equation (4)).

$$yp_t = a_9 \, yp_{t-1} + \sum_{j=1}^{k} c_j \, \Delta \, yp_{t-j} + q_t \tag{4}$$

The table below summarizes test results for a unit root in the residuals of equation (3), $a_9 = 1$ in equation (4), under two alternative assumptions about a break in trend growth. The statistics in the first row are for a break in 1973:1; those in the second, are for a break in 1969:1. (k refers to the number of lags added to equation (4) for the augmented Dickey-Fuller tests). Also shown are the estimates of a_9 in equation (4).

1/ The discussion in the text explains why these periods were chosen.
2/ See Perron (1986).

Break in Real GNP Trend

TB	a_6	a_7	a_8	a_9	ta_9	k
73:1	7.11	0.0083	0.0077	0.94	-2.19	4
69:1	7.12	0.0079	0.0077	0.96	-1.84	4

The table shows that the null hypothesis of a unit root in real GNP can not be rejected, whether the break in trend is assumed to occur in 1973 or 1969.

References

Blanchard, O., and D. Quah, "The Dynamic Effects of Aggregate Demand and Supply Disturbances", American Economic Review, 89-4, pp. 655-673 (1989).

Blanchard, O., and S. Fischer, Lectures on Macroeconomics, MIT Press, 1989.

Bruno, M., and J. Sachs, The Economics of Worldwide Stayflation, Cambridge, Harvard University Press (1985).

Bryant, R.C., et al., Empirical Macroeconomics for Interdependent Economies (Brookings Institution, Washington, D.C., 1988).

Denison, E., Accounting for Slower Economic Growth: The United States in the 1970s, Washington, D.C., Brookings Institution (1979).

Dornbusch, R., and S. Fischer, Macroeconomics, McGraw Hill 1981.

Durlauf, S., "Output Persistence, Economic Structure, and the Choice of Stabilization Policy," Brookings Papers on Economic Activity (Washington: The Brookings Institution, 1989).

Hall, R.E., "Comment on Sources of Business Cycle Fluctuations," National Bureau of Economic Research Annuals of Macroeconomics (NBER 1988), pp. 148-151.

Judd, J.J., and B. Trehan, "Unemployment-Rate Dynamics: Aggregate Demand and Supply Interaction," Economic Review, Federal Reserve Bank of San Francisco, No. 4, 1989.

Kydland, F.E., and E.C. Prescott, "Time to Build and Aggregate Fluctuations," Econometrica 50, pp. 1345-1370 (1982).

Perron, P., "Trends and Random Walks in Macroeconomic Time Series: Further Evidence From a New Approach," University of Montreal Discussion Paper, 1986.

Rose, A.K., "Is the Real Interest Rate Stable?," Journal of Finance, pp. 1095-1125, 1988.

Shapiro, M.D., and M. Watson, "Sources of Business Cycle Fluctuations," National Bureau of Economic Research Annuals of Macroeconomics (NBER, MA, 1988).

Sheffrin, S., The Making of Economic Policy (Basil Blackwell, Cambridge, 1989).

Sims, C.A., "Macroeconomics and Reality," Econometrica, 1980, Vol. 40.

Solow, R.M., "Technical Change and the Aggregate Production Function," _Review of Economics and Statistics_, No. 39, pp. 312-20.

Stock, J.H., and M.W. Watson, "Variable Trends in Economic Time Series," _Journal of Economic Perspectives_, Vol. 2, No. 3, pp. 147-175.