

RESEARCH PAPER

AGGREGATE SUPPLY AND DEMAND SHOCKS: A NATURAL RATE
APPROACH

by Arturo Estrella

Federal Reserve Bank of New York
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Abstract

Aggregate Supply and Demand Shocks: A Natural Rate Approach

There is wide agreement that the dynamics of inflation and unemployment are influenced by supply and demand shocks, such as oil price and monetary policy surprises, and by systematic factors such as overlapping contracts. There is less agreement about the relative importance of those determinants. The natural rate model of this paper uses a structural VAR approach to decompose movements in U.S. postwar unemployment and inflation into three orthogonal components. These components correspond, respectively, to systematic or predictable changes, supply shocks, and demand shocks. Orthogonality facilitates the detailed analysis of the individual components. Specifically, supply and demand shocks are shown to be correlated with observable variables in sensible ways, and they are used to analyze and interpret inflation-unemployment tradeoffs and postwar business cycles. In addition, the systematic component of inflation, which is equivalent to a NAIRU gap, is shown to predict changes in inflation reasonably well over a one-year horizon.

1. Introduction

There is wide agreement that the dynamics of inflation and unemployment are influenced by supply and demand shocks, such as oil price and monetary policy surprises, and by systematic factors such as overlapping contracts. However, there is less agreement about the precise nature of supply and demand shocks and about the relative importance of the various determinants of inflation and unemployment. This paper uses a structural vector autoregression approach to construct a model of the dynamics of inflation and unemployment. The model is consistent with a natural rate of unemployment corresponding to long-run equilibrium and decomposes each of the two variables into three orthogonal components representing, respectively, systematic or predictable changes, supply shocks, and demand shocks.

This model differs from earlier treatments in several respects. First, a structural VAR form is used to construct aggregate supply and demand schedules whose slopes are required to have the natural signs. Second, the model is parameterized in terms of the ratio of the variances of supply and demand shocks. This specification subsumes any controversial assumptions into a single parameter, and we examine the implications of values of this parameter that span its admissible range. Third, a preferred specification is selected by imposing a long-run restriction which is in the spirit of Blanchard and Quah (1989), but which is expressed in terms that were unavailable in the context of that paper.

The orthogonality of the major components of the model facilitates the detailed analysis of each component individually. For example, the supply and demand shocks are shown to be correlated with the innovations in observable variables in sensible ways. In the context of the model, we can make precise sense of -- and test -- the assertions that variables such as oil prices, medical costs and import prices are associated with supply shocks. In addition, the model is used to analyze and interpret postwar business cycles. For instance, most post-war U.S. recessions are seen to be driven by a relatively balanced mix of supply and demand shocks. The exceptions are the 1973-75 recession, which was dominated by supply influences, and the 1980-1981 double-dip recessions, which were dominated by demand factors.

Finally, the systematic component of inflation, which is seen to be equivalent to a short-run NAIRU gap, is shown to predict changes in inflation reasonably well over a one-year horizon.

The following section describes the structural VAR model that underlies the empirical analysis and discusses how the model may be fully identified. Section 3 presents empirical results for various values of the key identifying parameter q , the ratio of the variance of supply and demand shocks, including the value that corresponds to the fully-identified model. Sections 4 to 7 consider various applications of the model. Section 4 examines long and short run tradeoffs between inflation and unemployment. Section 5 looks at possible connections between the shock components of the model and observable variables, and section 6 uses the model's shock decomposition to analyze post-war U.S. business cycles. Section 7 shows how the predictable component of inflation may be interpreted as a short-run NAIRU gap, and section 8 offers some concluding remarks.

2. The model

2.1 Basic equations

The basic model of this paper is a bivariate structural VAR containing the monthly level of unemployment and the monthly change in the annualized percentage rate of monthly inflation.

Thus, defining

$$y_t = \begin{bmatrix} u_t \\ \Delta\pi_t \end{bmatrix}$$

the VAR may be expressed as

$$y_t = b + B(L)y_{t-1} + x_t$$

where the coefficients are contained in

$$b = \begin{bmatrix} b_{10} \\ b_{20} \end{bmatrix} \quad B(L) = \begin{bmatrix} B_{11}(L) & B_{12}(L) \\ B_{21}(L) & B_{22}(L) \end{bmatrix}$$

and the innovations of the two equations are given by

$$x = \begin{bmatrix} U \\ \Pi \end{bmatrix}.$$

The structural identification of the shocks is accomplished by writing appropriately signed supply and demand equations in the innovations, which are of the form

$$\text{Supply} \quad U = -m_1 \Pi - \epsilon_1 \quad (1)$$

$$\text{Demand} \quad U = m_2 \Pi - \epsilon_2 \quad (2)$$

where $m_1, m_2 \geq 0$, and ϵ_1 and ϵ_2 are orthogonal pure supply and pure demand shocks, respectively. The negative signs preceding the two shocks are arbitrary and not crucial to the analysis. They simply mean that both types of shocks are “good” in the sense that they lower unemployment.

By solving the demand and supply equations for U and Π , namely,

$$U = \frac{m_2}{m_1+m_2} (-\epsilon_1) + \frac{m_1}{m_1+m_2} (-\epsilon_2) \quad (3)$$

$$\Pi = \frac{1}{m_1+m_2} (-\epsilon_1) + \frac{1}{m_1+m_2} \epsilon_2 \quad (4)$$

we can verify that good supply shocks lower both unemployment and inflation and that good demand shocks lower unemployment but raise inflation. The precise mix of these effects on unemployment is determined by the relative magnitude of the two coefficients. The sign restrictions on these coefficients correspond to the selection of one of two solutions to a quadratic identifying equation, as seen below.

The decision to enter unemployment in levels and inflation in first differences is motivated primarily by theory. Only this specification seems fully consistent with a natural rate model such as Friedman (1968). Suppose that in equilibrium $u_t = \bar{u}$ and $\Delta\pi_t = 0$. Then

$$\bar{u} = b_{10} + B_{11}(1)\bar{u}$$

and

$$0 = b_{20} + B_{21}(1)\bar{u}$$

The two expressions for the equilibrium value of u must be equal, implying the nonlinear cross-equation restriction

$$\bar{u} = \frac{b_{10}}{1-B_{11}(1)} = \frac{-b_{20}}{B_{21}(1)} \quad (5)$$

If this restriction is imposed, the VAR may be rewritten as

$$\tilde{y}_t = \begin{bmatrix} u_t - \bar{u} \\ \Delta\pi_t \end{bmatrix} \quad (6)$$

$$\tilde{y}_t = B(L)\tilde{y}_{t-1} + x_t$$

where $B(L)$ and x_t are as defined before and \bar{u} is given by expression (5).

The foregoing specification seems to be the only one that makes the dynamics of the model plausible. When there is a one-time set of shocks, unemployment returns in the long run to the equilibrium level \bar{u} , while inflation settles at some level that in general differs from the starting level and is determined by the coefficients of the model. If, on the contrary, both inflation and unemployment were entered in levels (in the vector y), both would revert to predetermined equilibrium levels, which is implausible in the case of inflation. A third alternative is to enter both inflation and unemployment in changes. In that case, both variables lack an anchor in the long run, which seems implausible for unemployment.¹

¹If the restriction $b=0$ is imposed in this case, the results of a single shock need not be explosive. However, unemployment could in principle end up at any level, including values outside the range from zero to one.

There is also some empirical justification for choosing the level-versus-change specification of unemployment and inflation. Analysis of these variables, for example, in King and Watson (1994) and King, Stock and Watson (1995) shows that there is evidence in post-war U.S. data of a unit root in both variables. However, the evidence in the case of unemployment is not altogether strong and consistent, providing some “Bayesian” justification for the assumption of stationarity, especially since it conforms more closely with the natural rate prior.

2.2 Identifying assumptions

Let the variance matrices of the VAR innovations and the supply and demand shocks be given by

$$Vx = \Omega$$

and

$$V\epsilon = \Sigma \text{ (diagonal)}$$

Then the structural equations (1) and (2) imply that

$$A \Omega A' = \Sigma$$

where

$$A = \begin{bmatrix} 1 & m_1 \\ 1 & -m_2 \end{bmatrix}$$

That is,

$$\begin{bmatrix} \omega_{11} + 2\omega_{12}m_1 + \omega_{22}m_1^2 & \omega_{11} + \omega_{12}(m_1 - m_2) - \omega_{22}m_1m_2 \\ \omega_{11} + \omega_{12}(m_1 - m_2) - \omega_{22}m_1m_2 & \omega_{11} - 2\omega_{12}m_2 + \omega_{22}m_2^2 \end{bmatrix} = \begin{bmatrix} \sigma_{11} & 0 \\ 0 & \sigma_{22} \end{bmatrix} \quad (7)$$

From the observable values of the VAR residual covariances ω_{11} , ω_{12} , ω_{22} , we must estimate m_1 , m_2 , σ_{11} , σ_{22} . Thus, one additional restriction is required. We consider two alternatives.

First, we assume that we know the ratio of the variances of the supply and demand shocks, $q = \sigma_{11}/\sigma_{22}$. This seems like an overly optimistic assumption, but examination of the consequences of the whole range of possible identifications provides valuable information for evaluating the plausibility of particular admissible cases. It also allows an easy, intuitive mapping into models such as the Keynesian, real business cycle and rational expectations specifications of King and Watson (1994).

In the second alternative identification, we identify q by imposing the additional restriction that the long run cumulative effect of a supply shock on the level of inflation is zero. The rationale for this restriction is that, in the long run, inflation is strictly a monetary phenomenon. Since the effects of monetary surprises in the model are subsumed in the demand shocks, supply shocks should have no effect on the level of inflation in the long run. This assumption is consistent with empirical results in Gali (1992, pp. 735-736), which attribute persistent changes in the level of inflation to various demand shocks, but not to supply shocks.

The long run assumption is also in the spirit of the Blanchard-Quah (1989) model, although that model did not contain nominal variables and such a restriction was not feasible there, and it is formally similar to the long run restriction used by Bayoumi and Eichengreen (1994). In a model with real GDP growth and inflation, Bayoumi and Eichengreen assume that demand shocks have no long run effect on the level of real GDP. In a sense, an analogous restriction is already included in the reduced form VAR of this paper, since unemployment converges to \bar{u} in the long run.

2.3 Solution

To write down the solution to the identified model, it is convenient to assume that $\omega_{12} < 0$, that is, that the unemployment and inflation innovations are negatively correlated. This covariance is, of course, determined by the data and cannot be subject to an identification restriction. However, knowing the sign of this covariance is helpful in applying the sign

restrictions to the coefficients of the identified model. Furthermore, the assumption is by no means empirically controversial. Lucas (1972) comments that

It is an observed fact that, in U.S. time series, inflation rates and unemployment are negatively correlated. This remains true (with the obvious sign change) if unemployment is replaced with de-trended real output, if price inflation is replaced by money wage inflation, and so forth. It follows that this short-run (whatever this ambiguous qualification means) trade off will be exhibited in any econometric model estimated from these time series, regardless of its complexity, lag structure, or theoretical motivation.

Lucas' assertion holds just as robustly with more recent data as it did in 1972.

With the foregoing assumption, the covariance restriction from the preceding subsection implies that $\partial m_1/\partial m_2 < 0$, that $m_1 = -\omega_{11}/\omega_{12} > 0$ when $m_2 = 0$, and that $m_1 = -\omega_{12}/\omega_{22} > 0$ when $m_2 \rightarrow \infty$. Thus, although m_2 can assume any nonnegative value, m_1 is subject to both lower and upper bounds if the sign restrictions are to hold. The ratio of the lower bound to the upper bound is ρ^2 , where

$$\rho \equiv \omega_{12} / \sqrt{\omega_{11} \omega_{22}}$$

is the correlation between the two VAR innovations.

Similarly, assume that $q = \sigma_{11}/\sigma_{22}$ is known. Then equation (7) implies that $\partial q/\partial m_2 < 0$, that $q = (1 - \rho^2)/\rho^2$ when $m_2 = 0$, and that $q = 0$ when $m_2 \rightarrow \infty$. The unique solution to the structural model (as a function of q) is given by

$$m_1 = \sqrt{\frac{\omega_{11}}{\omega_{22}}} \left(\sqrt{q(1-\rho^2)} - \rho \right)$$

$$m_2 = \sqrt{\frac{\omega_{11}}{\omega_{22}}} \left(\sqrt{\frac{1-\rho^2}{q}} + \rho \right)$$

$$\sigma_{11} = \omega_{11} (1+q) (1-\rho^2)$$

$$\sigma_{22} = \omega_{11} \frac{1+q}{q} (1-\rho^2)$$

To obtain the second specification in which q is identified from a long run restriction, define

$$v_t = \Sigma^{-\frac{1}{2}} \epsilon_t$$

as the vector of orthogonal standardized unit shocks to supply and demand ($Vv_t = I$). The VAR may then be written in vector moving average form as

$$\begin{aligned} y_t &= (I-B(L))^{-1} x_t \\ &= -(I-B(L))^{-1} A^{-1} \Sigma^{\frac{1}{2}} v_t \end{aligned}$$

Thus, if we define

$$C(q) = -(I-B(1))^{-1} A^{-1} \Sigma^{\frac{1}{2}}$$

(both A and Σ depend on q), the requirement that the long run effect of a supply shock on inflation equals zero is satisfied by choosing $q=q_0$ such that $C_{21}(q_0)=0$.² Given that $\omega_{12}<0$ and given the form of the structural model, there is a unique explicit solution:

²When $q=0$, the variance of the demand shocks is infinite ($\sigma_{22} \rightarrow \infty$). Nevertheless, both the vector moving average specification and $C(q)$ are well defined in that case, since $A^{-1} \Sigma^{1/2}$ has a finite limit as $q \rightarrow 0$.

$$q_0 = \frac{B_{21}(1)^2(1-\rho^2)}{\left(B_{21}(1)\rho + (1-B_{11}(1)) \sqrt{\frac{\omega_{22}}{\omega_{11}}} \right)^2}$$

In the following section, empirical results based both on key interpretable values of q and on q_0 will be examined.

3. Empirical results

3.1 Results assuming q in known

The basic VAR results for the model are presented in table 1.³ The estimates reported for the reduced form VAR coefficients impose the cross-equation restriction of equation (5), which insures that inflation stops drifting in the long run as a result of a shock. However, we may note that the likelihood ratio test of this restriction has a p value of .732 and, thus, imposing the restriction does not materially alter the estimates.

The first panel of table 1 shows that there is strong evidence of Granger causality running from unemployment to inflation, but not vice versa. The second panel, which looks at the sums of lag coefficients in the VAR (the matrix $B(1)$), exhibits a similar pattern. Only one sum is not significant, corresponding to lags of the change in inflation in the unemployment equation. These results are consistent with a real business cycle view in which the dynamics of unemployment are autonomous with regard to nominal variables. However, the result by itself is not conclusive, since the contemporaneous structural relationship is not fixed by the data, but is subject to the choice of structural specification as discussed in section 2.

As shown at the bottom of table 1, the long run equilibrium level of unemployment is estimated to be 6%. This value is in line with estimates of a constant NAIRU, for example in Gordon (1997) and King, Stock and Watson (1995), and is relatively stable in subsamples of the estimation period. The correlation between the residuals of the VAR equations is -.06. Although

³The variables are defined as the level of unemployment in percent and the monthly log change in the CPI multiplied by 1200.

this value is low in absolute terms and not very significant, it is negative, as the Lucas (1972) remarks quoted earlier would suggest.

Table 2 contains the estimates of the structural coefficients obtained using the two alternatives for identification discussed in section 2.2. The first alternative assumes that we know the value of q , the ratio of variances of pure supply and demand shocks. Although a priori knowledge of q may seem implausible, it provides the most direct means of examining the implications of the whole range of admissible identifications.

Extreme values of q correspond to extreme values of the slope coefficients of the supply and demand equations (1) and (2). When q is set at its maximum possible value (287), $m_2=0$ and equation (2) (or (3)) indicates that the unemployment innovation is driven exclusively by demand shocks. King and Watson (1994) call an analogous model "Traditional Keynesian", although it is doubtful that anyone, including Keynes himself, would find the specification acceptable.⁴ At the other extreme, when $q=0$, m_1 takes its minimum possible value and m_2 is infinite. As seen from equation (3), these conditions imply that the unemployment innovation is supply determined. Coupled with the Granger causality results in table 1, this specification may be viewed as a real business cycle model.⁵

Table 2 presents estimates of the structural parameters corresponding to these two extreme cases, as well as to a case in which supply and demand shocks are equally variable ($q=1$). This last case seems reasonable in the absence of any other identification information, since it allows both demand and supply shocks to play a role in the determination of unemployment and inflation. In fact, in the case of inflation, equation (4) shows that the magnitude of the influence in the case of inflation would be exactly equal. As it turns out, this specification is very close to the

⁴See, for instance, the discussion of aggregate supply and demand in Keynes (1964 (1936)), chapter 3, section II).

⁵In King and Watson (1994), the real business cycle specification corresponds to $m_1=0$. Equation (1) shows that in that case unemployment is determined by supply shocks, as in the real business cycle variant in this paper. However, $m_1=0$ implies that m_2 is negative ($= -1.56$ with the King-Watson data), which means that the demand equation has the wrong slope and is inconsistent with the identification assumptions of this paper.

“rational expectations monetarist” formulation in King and Watson (1994), which is their preferred model.⁶

All three cases in the upper panel of table 2, however different from each other, are consistent with the data, and preference among them is undecidable in the absence of further information. Some evidence that argues against the extreme cases may be obtained by considering the values of q that are necessary to obtain them. As table 3 indicates, when $q=0$ the variance of the unemployment innovation is driven almost entirely by supply shocks. However, $q=0$ means that the variance of those supply shocks is infinitely less than the variance of demand shocks, which seems to be at odds with a real business cycle approach. When $q=287$, the variance of the unemployment innovation is determined exclusively by demand shocks. However, the value of q implies that the variance of these demand shocks is negligible compared to the variance of supply shocks, which seems inconsistent with the extreme Keynesian position described above.

Thus, it is questionable whether potential advocates of either of the two extreme cases would be comfortable with all the implications of the respective models. The case with $q=1$ is much more plausible, but the arguments against the extremes leave us with an infinity of other intermediate solutions. One way of resolving this issue is to introduce another identifying assumption, as was argued in section 2.2.

3.2 Results with long run identifying assumption

The bottom panel contains the results of assuming that the long run cumulative effect of a supply shock on inflation is zero. The estimate of $q=1.686$ and the standard error of .256 lead to a rejection of the hypothesis that $q=1$. Nevertheless, the results are qualitatively similar to those obtained with $q=1$ in that the slopes of the supply and demand equations are not too disparate and that both variables, unemployment and inflation, are very much jointly determined by supply and demand effects.

⁶Computations based on the results reported by King and Watson (1994) indicate that for their “REM” case, $q=.91$ and $m_1=m_2=.07$. These figures are very close to the $q=1$ case in table 2.

Further support for the long run restriction is provided in table 4. Intuitively, the effects of a supply shock on unemployment and inflation should have the same sign. This is true by construction one period ahead in the general model of this paper, given that the supply and demand equations are required to have the right signs. However, there is no guarantee that the signs of these effects will not change more than one period ahead. The right hand section of table 4 shows that, whereas the long run effect of a supply shock on unemployment is always positive, the long run effect on inflation may be substantially negative, even for $q=1$.

Moreover, examination of impulse responses shows that this transition to negative effects occurs quite soon after the shock. Figure 1, for example, presents 60-month impulse responses to standardized unit supply and demand shocks for $q=0$. This extreme case shows that the effects of a supply shock very quickly turn into a pattern that more closely resembles the expected effects of a demand shock -- inflation and unemployment move in opposite directions. As q increases, this pattern of supply shock effects becomes less pronounced and with $q=q_0$, as shown in figure 2, the results become more intuitive.

3.3 Variance decompositions

To put the foregoing results in context, it is helpful to examine how much of the variance of the two dependent variables is determined by the three orthogonal factors of the modeling approach: the predictable or systematic component, the pure supply shock, and the pure demand shock. Table 5 presents a look at these results in the base model with $q=q_0$.

The first row of the portion of the table corresponding to each dependent variable provides the one-month ahead variance decomposition for the variables as they appear in the VAR. In the case of unemployment, it is clear that the systematic component dominates the shocks, which account for only 1.5% of the variance. However, the predictability of unemployment drops dramatically at the one-year horizon, as indicated by the next two rows of the table. For the twelve-month change in unemployment, the shock is about four times the predictable component.⁷

⁷In principle, the results for the 12-month dependent variables may be derived formally from the results of the VAR. The results presented in the table are based on simpler regressions

The pattern for inflation is somewhat different. Although the predictable component captures much less of the one month ahead variation (43%) than that of unemployment, there is almost no deterioration in the contribution of this component when moving to the 12 month change. This predictable component is examined further in section 7.

Turning to the decomposition of the shocks, demand shocks tend to dominate in the case of unemployment. One month ahead, the variance of these shocks is about twice as large as the variance of supply shocks. Twelve months ahead, they are about 1½ times more variable than supply shocks. For inflation, the relative magnitude of the shocks switches. One month ahead, supply shocks are almost twice as variable as demand shocks. However, the lag structure of the VAR is such that, on average over a twelve-month horizon, demand shocks are more than three times as variable as supply shocks.

4. Demand shocks and inflation-unemployment tradeoffs

A classic question in macroeconomics is whether monetary policy can exploit a tradeoff between inflation and unemployment both in the short run and in the long run. Using a methodology similar to that of King and Watson (1994), table 6 examines the ratio of the effects of a demand shock on inflation and unemployment, and the relative magnitude of these effects. The underlying assumption is that a monetary policy surprise is essentially a pure demand shock. In this application, we look at the one-month effects of a demand shock, as well as at the long run cumulative response of unemployment (cumulative sum of deviations of u from the equilibrium level \bar{u}) and of inflation (cumulative sum of changes in inflation or the total change in inflation). The long run approach differs from some earlier computations of the “sacrifice ratio”, Ball (1994) for example, in that the horizon is infinite rather than of some arbitrary finite length.⁸

of the dependent variable (e.g., the 12 month change in unemployment) directly on the VAR regressors. Because the VAR may not have the “true” lag length, these two approaches may produce different results in finite samples. Experimentation with the present data showed that this problem was not significant.

⁸Cecchetti (1994) discusses various ways of measuring a sacrifice ratio, including the use of infinite horizons. In the context of a ratio based on output, he suggests discounting deviations from potential output. It is less clear that discounting is appropriate in the case of unemployment.

As table 6 shows, negative demand shocks tend to have a positive influence on unemployment and a negative influence on inflation, regardless of the value of q . The only exception is the long run effect on unemployment with $q=0$. Thus, the results are generally consistent with some tradeoff between inflation and unemployment both in the short and long run. In the short run with $q=0$, a demand shock has essentially no effect on unemployment; the full brunt of the shock is borne by inflation. At the other end with $q=287$, lowering inflation by one percentage point requires a rise in unemployment of 1.25 percentage points. In the preferred specification with $q=q_0$, the comparable required cost is only .1 of a percentage point of unemployment.

In the long run, the sacrifice in unemployment is generally substantial, especially considering that the half life of the unemployment deviations is just over two years (25.5 months). Of most interest is the case with $q=q_0$, in which the long run cumulative effect of lowering inflation by one percentage point is 13.8 percentage points of unemployment. This result is consistent with the analysis of Friedman (1968), which suggests that there is a ratcheting effect of monetary shocks on inflation. In the long run, the level of unemployment returns to the natural rate \bar{u} while inflation settles, in the case of a negative shock, at a lower level. However, in the transition to the long run, unemployment will have hovered above the natural rate by a cumulative total of almost 14 percentage points. The only case that fails to exhibit these kinds of relationships is the $q=0$ case, which has been shown earlier to be subject to various interpretational shortcomings.

5. Supply and demand shocks and observable variables

We now try to identify the sources of the supply and demand shocks of the base model ($q=q_0$) by correlating them with the contemporaneous components of observable variables. The strategy of this section is to run, for each of a series of variables (v_t) that may be thought to be related to supply and demand shocks, regressions of the form

$$\epsilon_{it} = \beta_0 + \beta_1 v_t + \beta_2 v_{t-1} + \beta_3(L)u_{t-1} + \beta_4(L)\Delta\pi_{t-1} + \xi_t$$

for $i=1,2$. This equation correlates the pure supply and demand shocks of the structural VAR with the innovation in each variable v , after adjusting for the effects of the VAR regressors and the first lag of the observable variable. The significance of the contemporaneous relationship between ϵ and v is represented in table 7 by the t statistic and the p value corresponding to β_1 in the above regression.

A leading candidate for representing supply shocks is oil prices, and the first line of table 7 confirms that this assumption is warranted. The correlation with a supply shock is very significant and the sign indicates that a positive supply shock is associated with a drop in oil prices. Other commodity prices do not fare as well as supply shock proxies. There is, however, evidence that raw commodity prices are positively related to demand shocks, and it is conceivable that causality runs from demand to prices.

Recently, it has been suggested by Meyer (1997) that medical costs and import prices are related to supply factors that are helping to keep inflation under control. The results in table 7 provide support for this view, particularly in the case of import prices. The medical costs variable (a component of the consumer price index) has undergone substantial revisions over the years and it is only since the 1980s that the expected relationship appears significant.

Capacity utilization is an interesting example in which the correlation with both supply and demand shocks is extremely strong and positive. It is not difficult to come up with reasons why this may be so. Increases in capacity utilization may be associated with outward shifts in the output-based supply curve, which corresponds to the way supply shocks are modeled in this paper. Alternatively, it is conceivable that demand shocks lead to increases in production and, hence, in capacity utilization.

The last six rows of the table examine monetary policy variables. No discernible patterns are found for M2. However, the results for the federal funds rate are consistent with a pattern based on a reaction function such as that of Taylor (1993). Over the full sample, there is evidence that the funds rate was reacting contemporaneously to both supply and demand shocks. Subperiod analysis, moreover, suggests that reactions to supply shocks were concentrated in the 1970s, whereas reactions to demand shocks were concentrated in the period since 1982.

Arguably, it is more appropriate for monetary policy to react to demand shocks, as in the last subsample. If monetary policy surprises are essentially demand shocks, they tend to move inflation and unemployment in opposite directions and would be most effective in counteracting the effects of other demand shocks. If used to offset supply shocks, a choice must be made as to whether the intention is to focus on unemployment or inflation, since the direction of one of the effects would be undesirable. Suppose there is a negative supply shock, which increases both unemployment and inflation. To offset the rise in unemployment, a positive monetary shock would bring a further increase in inflation (see table 6). To offset the rise in inflation, alternatively, a negative monetary shock would be accompanied by a further rise in unemployment. Thus, the apparent post-1982 reaction function seems the most desirable.

6. What drives recessions and expansions?

In this section, we consider the role of supply and demand shocks in U.S. postwar business cycles. Specifically, we use the structural VAR decomposition to look at the relative contribution of supply and demand shocks to changes in unemployment over the course of recessions and expansions. The results, especially for recessions, seem to accord well with conventional analysis and views.⁹

The first four columns of table 8 present the results for recessions. The first column contains the NBER-dated cyclical peak that marks the beginning of the recession. The next two columns indicate the length of each recession and the total rise in unemployment over the recession, providing some evidence of its severity. The fourth column shows the percentage of the total change in column three that is attributable to supply shocks. Of the seven episodes examined, there are three (August 1957, April 1960, December 1969) in which the proportion attributable to supply is about 40%. Not surprisingly, November 1973, which is associated with the first oil shock of the 1970s, is an outlier in that most of the rise in unemployment is attributable to supply. This result (52%) also suggests, however, that demand factors played an

⁹For example, Gali (1992) performs a similar experiment for recessions, using a structural VAR with four equations. He obtains qualitatively similar results with regard to the proportion of the change in unemployment attributable to supply shocks.

important role in this recession. A similar result is obtained for the July 1990 recession, in which unusual events such as the Gulf war and the “credit crunch” may have played a role.

The double-dip recessions of 1980-81 are outliers in the other direction; at least three quarters of the unemployment surprise is attributable to demand factors in each case. Again, this is not surprising given the important role played by monetary factors in these recessions.

The corresponding analysis of expansions in the last four columns is not as clean as for recessions. The periods tend to be substantially longer and the results are not as consistent, particularly when the total drop in the unemployment rate is not large. Nevertheless, some regularities emerge. For instance, supply shocks are more frequently dominant than in recessions. In three of the seven cases (April 1958, July 1980, March 1991), supply played a bigger role than demand in the expansion. In contrast, the small or negative contribution of supply shocks to the November 1970 and March 1975 expansions may be explained by the fact that each ended in a time of surging oil prices. Interestingly, although supply shocks were important in the “supply side period” of the 1980s, they were not dominant. They contributed 42% of the unemployment surprise in the November 1982 expansion.

7. A short run NAIRU

The model of this paper was constructed to have a long run equilibrium rate of unemployment -- a natural rate. The variance decompositions of the inflation equation in section 3 suggest, moreover, that the predictable component of inflation is significant even with a one-year horizon and that it may be possible to construct a short run NAIRU -- a rate that may be compared with current unemployment to predict inflation within the following year.

Consider a model that predicts A_t , the increase or acceleration in inflation from the last twelve months to the next twelve months. By time aggregation, the VAR of equation (6) implies an equation of the form

$$A_t = \tilde{b}_{20} + \tilde{B}_{21}(L)u_t + \tilde{B}_{22}(L)\Delta\pi_t + \eta_t \quad (8)$$

where

$$A_t = \bar{\pi}_{t+12} - \bar{\pi}_t, \quad \bar{\pi}_t = \frac{1}{12} \sum_{i=0}^{11} \pi_{t+i}$$

Equation (8) may be rewritten as

$$A_t = \theta (u_t - n_t) + \eta_t \tag{9}$$

where $\theta = \tilde{B}_{21}(0)$ and n_t is defined by the expression

$$n_t = (\tilde{b}_{20} + (\tilde{B}_{21}(L) - \tilde{B}_{21}(0))u_t + \tilde{B}_{22}(L)\Delta\pi_t) / \tilde{B}_{21}(0)$$

Thus, n_t is a time-varying short-run (one-year) NAIRU and, since only simple algebraic manipulation has been applied, the explanatory power of the associated unemployment gap is exactly the same as in the general equation (8). This definition of the NAIRU differs from approaches such as Gordon (1982, 1997) and Staiger, Stock and Watson (1997a,b) in that the NAIRU gap enters only contemporaneously rather than in a distributed lag. This is accomplished by subsuming all the explanatory power of the equation, other than that in u_t , into the NAIRU itself.

It is clear from this construction that the NAIRU and the NAIRU gap as defined here are predetermined. Thus, they function only as information variables and are not potential targets of monetary policy. Furthermore, the resulting NAIRU may be quite variable, since it consists of a linear combination of several lags of unemployment and inflation. However, an accurate estimate of n_t is available contemporaneously without the need for auxiliary predictions. Uncertainty about n_t at time t arises only because of uncertainty about the coefficients, since the right hand side variables are predetermined as of time t . If those coefficients are tightly estimated, so will n_t .

We have seen in table 5 that the R^2 of the equation is 40%, indicating that there is substantial predictive content in the approach. The principal advantage of the reformulation of the equation in terms of the short run NAIRU is that the informational content of the equation can be summarized by a single variable: the difference between NAIRU and the actual current level of unemployment.

Estimation of equations (8)-(9) results in an estimate of $\theta = -2.23$ with a standard error of .35. The short run NAIRU since 1954 is plotted in figure 3 together with current unemployment and the NAIRU gap. The next two figures provide visual confirmation of the accuracy of the gap in forecasting inflation acceleration. Figure 4 is a scatter plot of actual inflation acceleration (monthly observations between January 1954 and April 1997) against the NAIRU gap. The fitted regression line is also plotted. The figure confirms that the relationship is fairly tight, and that the direction of acceleration is predicted especially well when the absolute gap is relatively large (say above .5).

Figure 5 supports a similar conclusion by focusing on the likelihood of an acceleration in inflation as a function of the gap. The ordered pairs (gap, acceleration) are sorted by the value of the gap and collected in (overlapping) subsets containing one tenth of the observations. For each such moving decile, the proportion of observations in which inflation increased -- acceleration was positive -- is plotted against the mean value of the gap.¹⁰ The figure confirms the reliability of large values of the gap, indicating that inflation increases at least three quarters of the time when the gap is less than -.5, whereas it declines at least three quarters of the time when the gap is above .5.

8. Conclusions

The model of this paper introduces some new means of identifying a VAR with inflation and unemployment, in particular some natural coefficient sign restrictions and a long run condition on the effect of supply shocks on inflation. More generally, the model allows the examination of the full range of admissible specifications. We conclude that extreme specifications have some implausible implications and that the base case model, with the imposition of the long run condition, produces satisfactory results.

The results of the base case model are employed in several applications. First, the estimated effects of demand shocks suggest that there are short and long run tradeoffs between inflation and unemployment. Second, pure supply shocks are significantly correlated with some

¹⁰This technique is similar to one employed in Council of Economic Advisers (1997, page 46).

observable variables that have been used in the past as supply shock proxies, particularly oil prices, import prices and medical costs. There is also a plausible connection between supply and demand shocks and the federal funds rate, suggesting the existence of a policy reaction function. Third, the behavior of unemployment during recessions and expansions is suggestively explained by decomposition of unemployment innovations into supply and demand shocks.

Finally, the systematic component of the model contains a long-run natural rate and a short-run NAIRU, both of which play an important role in the determination of inflation. The condition that sets the natural rate also ensures that the effects of shocks on inflation are not explosive in the long run. Furthermore, the systematic or predictable component of inflation is large and robust, even when the prediction horizon is extended to one year. This observation leads to an examination of that component in terms of a short run NAIRU, which is shown to have substantial explanatory power for inflation changes over a one-year horizon.

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Table 1. VAR Estimation Results

Sample: Monthly from January 1954 to April 1997
 Lags in VAR: 12 months
 (standard errors in parentheses)

Granger causality (p values of joint F tests)

Dependent variable	Lags of u	Lags of $\Delta\pi$
u	.0000	.0852
$\Delta\pi$.0000	.0000

B(1) matrix: sums of lag coefficients

Dependent variable	Lags of u	Lags of $\Delta\pi$
u	.9875 (.0062)	.0372 (.0421)
$\Delta\pi$	-.2390 (.0843)	-4.391 (.5708)

Ω matrix (covariance of VAR residuals)

	U	Π
U	.0332	-.0266
Π	-.0266	6.119

$$\bar{u} = 6.037$$

(.3608)

$$\rho = -.0589$$

(.0437)

$$(1-\rho^2)/\rho^2 = 287$$

Table 2. Estimates of the structural parameters
Standard errors in parentheses*

2a. Structural parameter estimates for some fixed values of q

q	m_1	m_2	σ_{11}	σ_{22}
0	.0043 (.0032)	∞ (∞)	.0331 (.0021)	∞ (∞)
1	.0779 (.0046)	.0692 (.0046)	.0662 (.0041)	.0662 (.0041)
287	1.251 (.0548)	0 (.0032)	9.545 (.5920)	.0332 (.0021)

2b. Structural parameter estimates (including q) with long run restriction**

q	m_1	m_2	σ_{11}	σ_{22}
1.686 (.2564)	.0999 (.0090)	.0523 (.0014)	.0890 (.0119)	.0528 (.0034)

*Standard errors are computed using the asymptotic distribution of $\hat{\Omega}$ and the fact that the structural parameters are functions of $\hat{\Omega}$. See, for example, Hamilton (1994, sections 11.1 and 11.7). Calculations based on simulations produced similar results.

**The restriction requires that the cumulative long run effect of a supply shock on inflation is zero.

Table 3. Proportion of Variance Attributable to Pure Demand ShocksProportion of variance of VAR innovations (U and Π) attributable to pure demand shocks.

q	Variance of U	Variance of Π
0	.003	1
1	.559	.500
1.686	.684	.372
287	1	.003

Table 4. Effect of Negative Supply Shock

q	One month response		Long run cumulative response	
	of u	of π	of u	of π
0	.182	0	12.86	-.570
1	.121	1.75	9.41	-.093
1.686	.103	1.96	8.20	0
287	0	2.47	1.20	.405

Table 5. Variance Decomposition of Unemployment and Inflation
 Percent of Total Variance of Dependent Variable

Dependent variable	Shock decomposition			
	Systematic	Shocks	Supply	Demand
Unemployment				
1 month ahead level	98.5	1.5	.5	1
12 month change	21	79	32	47
12 month ahead level	55	45	18	27
Inflation				
1 month change	43	57	36	21
12 month change	40	60	13	47
12 month ahead level	76	24	5	19

Table 6. Effect of Negative Demand Shock and Tradeoff Ratios

q	One month response			Long run cumulative response		
	of u	of π	ratio	of u	of π	ratio
0	.011	-2.47	-.004	-.447	-.439	1.02
1	.136	-1.75	-.078	8.78	-.714	-12.3
1.686	.151	-1.51	-.100	9.92	-.720	-13.8
287	.182	-.146	-1.25	12.8	-.595	-21.5

Table 7. Supply and Demand Shocks and Observable VariablesSignificance of contemporaneous observable variable v (coefficient β_1) in regression of the form

$$\epsilon_{it} = \beta_0 + \beta_1 v_t + \beta_2 v_{t-1} + \beta_3(L)u_{t-1} + \beta_4(L)\Delta\pi_{t-1} + \xi_t$$

for $i=1,2$, where ϵ_1 and ϵ_2 are pure supply and demand shocks, respectively.
 Model includes long-run restriction ($q=q_0$).

Observable variable	Shock: ϵ_1 (supply)		ϵ_2 (demand)		Sample
	t stat	p value	t stat	p value	
Oil prices	-4.18	.000	1.94	.052	54:1-97:4
Commodity prices--all	-0.04	.971	4.47	.000	67:3-97:4
Commodity prices--raw	1.33	.183	2.83	.005	54:1-97:4
Commodity prices--food	0.24	.808	1.41	.162	81:8-97:4
Medical costs	-0.03	.976	0.56	.576	54:1-97:4
Medical costs (subsample)	-2.12	.035	1.09	.279	82:6-97:4
Import prices	-3.83	.000	0.47	.642	89:2-97:4
Capacity utilization	4.27	.000	9.44	.000	54:1-97:4
M2	1.65	.099	0.56	.573	59:3-97:4
M2 (subsample)	1.72	.087	-0.77	.442	59:3-79:9
Fed funds - 10 year rate	1.64	.102	1.13	.259	55:2-97:4
Fed funds	2.87	.004	3.53	.000	55:3-97:4
Fed funds (subsample)	3.97	.000	0.18	.854	70:1-79:9
Fed funds (subsample)	0.91	.363	2.41	.017	82:7-97:4

Note: All observable variables are entered in monthly growth rates, except for interest rates and capacity utilization. The spread between the fed funds rate and the 10 year rate is in levels, and both the fed funds rate and capacity utilization are in first differences.

Table 8. Role of supply and demand shocks in business cycles

Peak (recession starting)	Months	Total unemployment change in recession (%)	Proportion supply (%)	Trough (expansion starting)	Months	Total unemployment change in expansion (%)	Proportio supply (%)
57:08	8	3.3	41	58:04	24	-2.2	66
60:04	10	1.7	43	61:02	106	-3.4	46
69:12	11	2.4	39	70:11	36	-1.1	-83
73:11	16	3.8	52	75:03	58	-2.3	13
80:01	6	1.5	25	80:07	12	-0.6	192
81:07	16	3.6	18	82:11	92	-5.3	42
90:07	8	1.3	53	91:03	73	-1.9	70

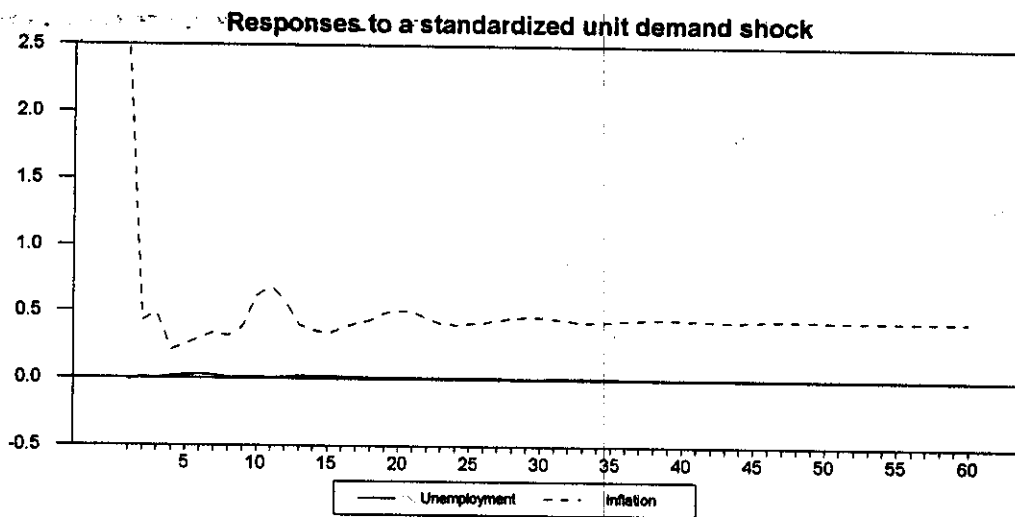
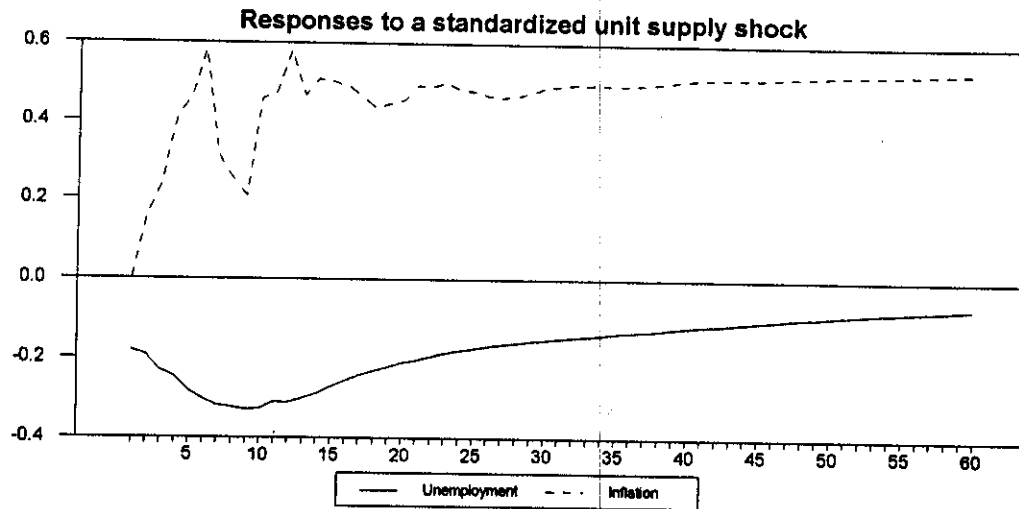


Figure 1. Impulse responses with $q=0$

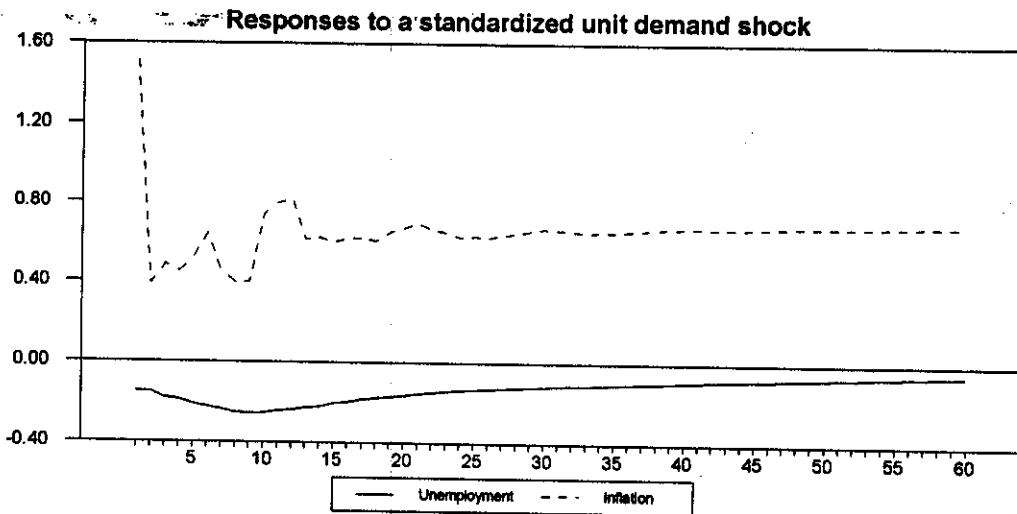
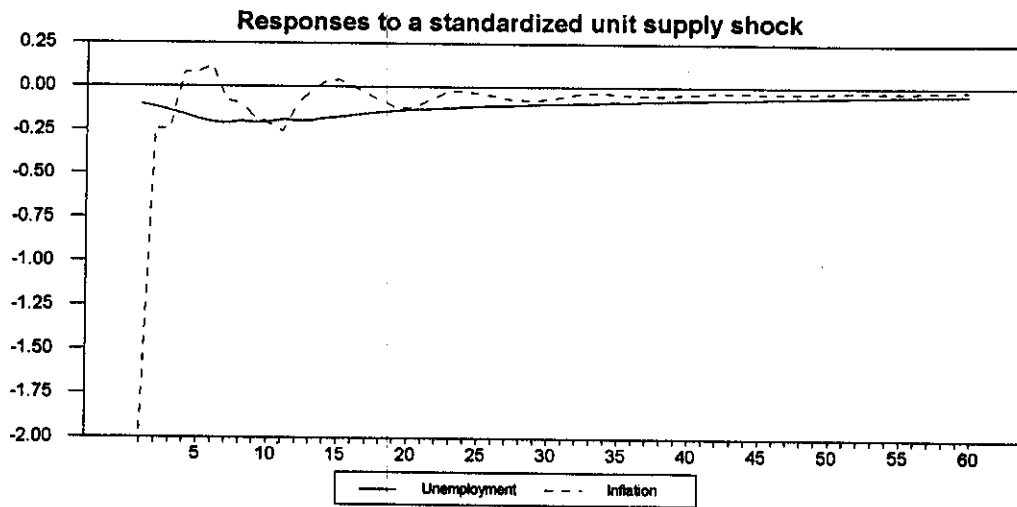


Figure 2. Impulse responses with $q=q_0$

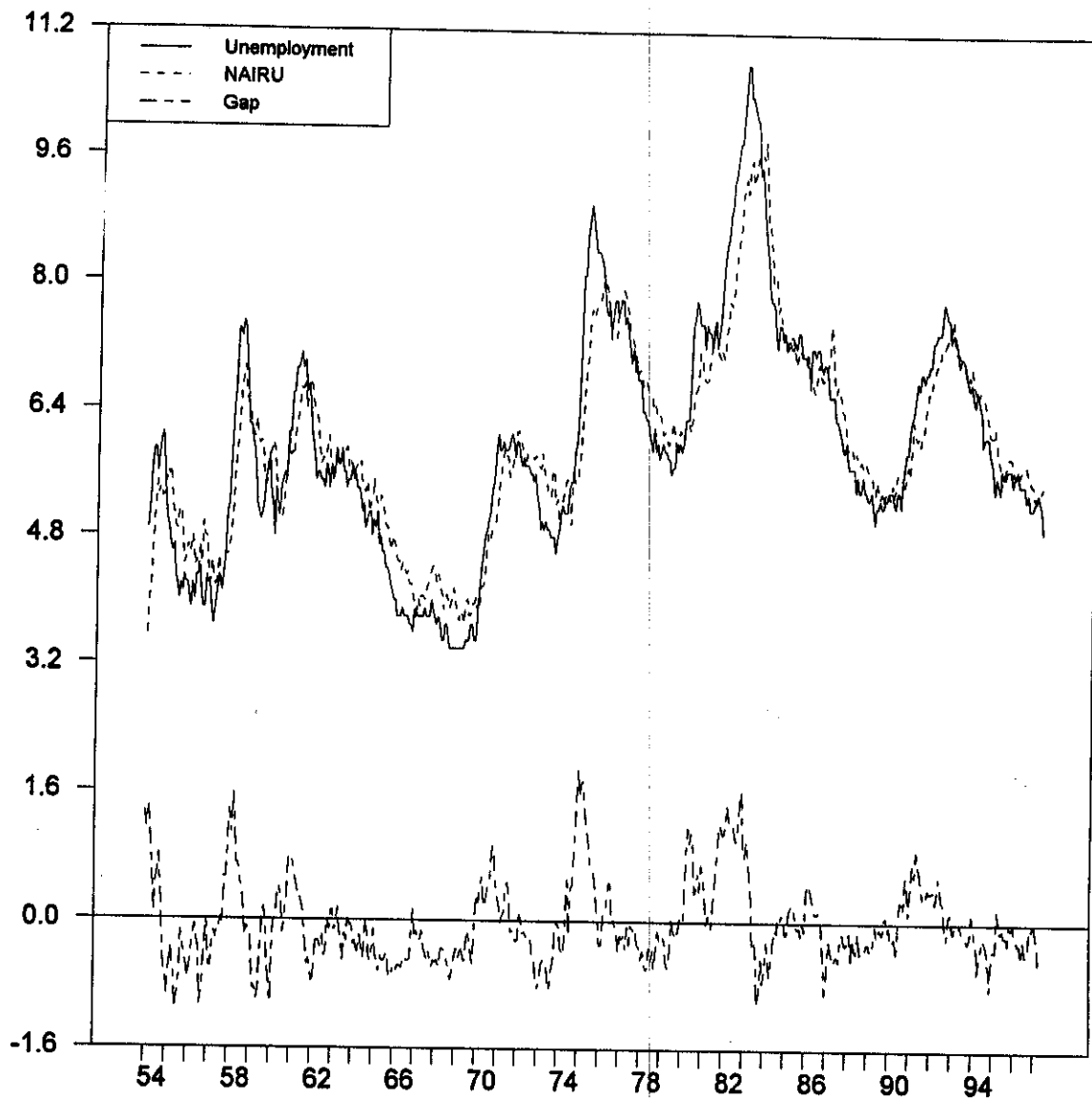


Figure 3. Unemployment, short run NAIRU, and the unemployment gap

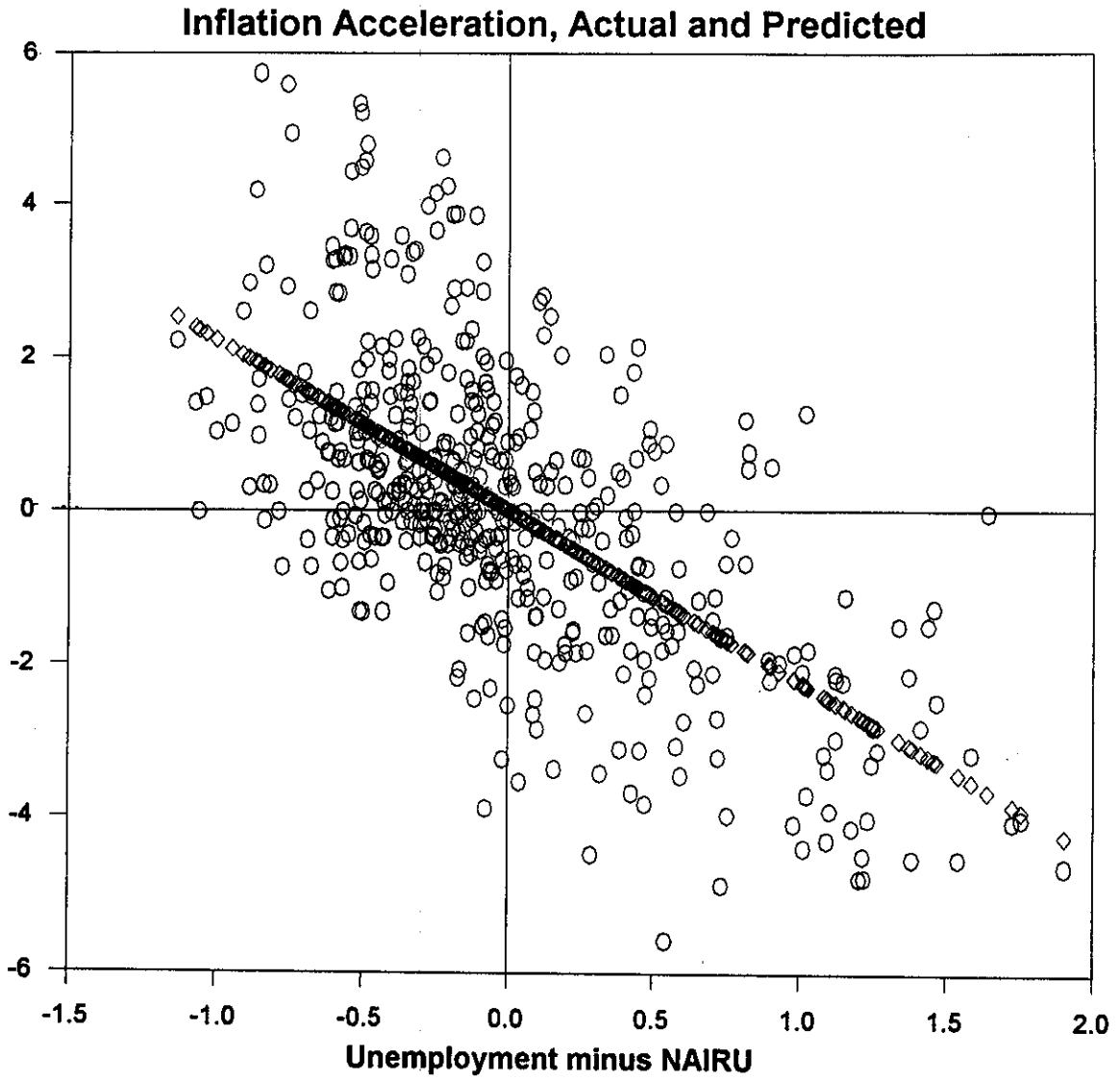


Figure 4. Unemployment gap and inflation acceleration (actual and predicted by equation (10))

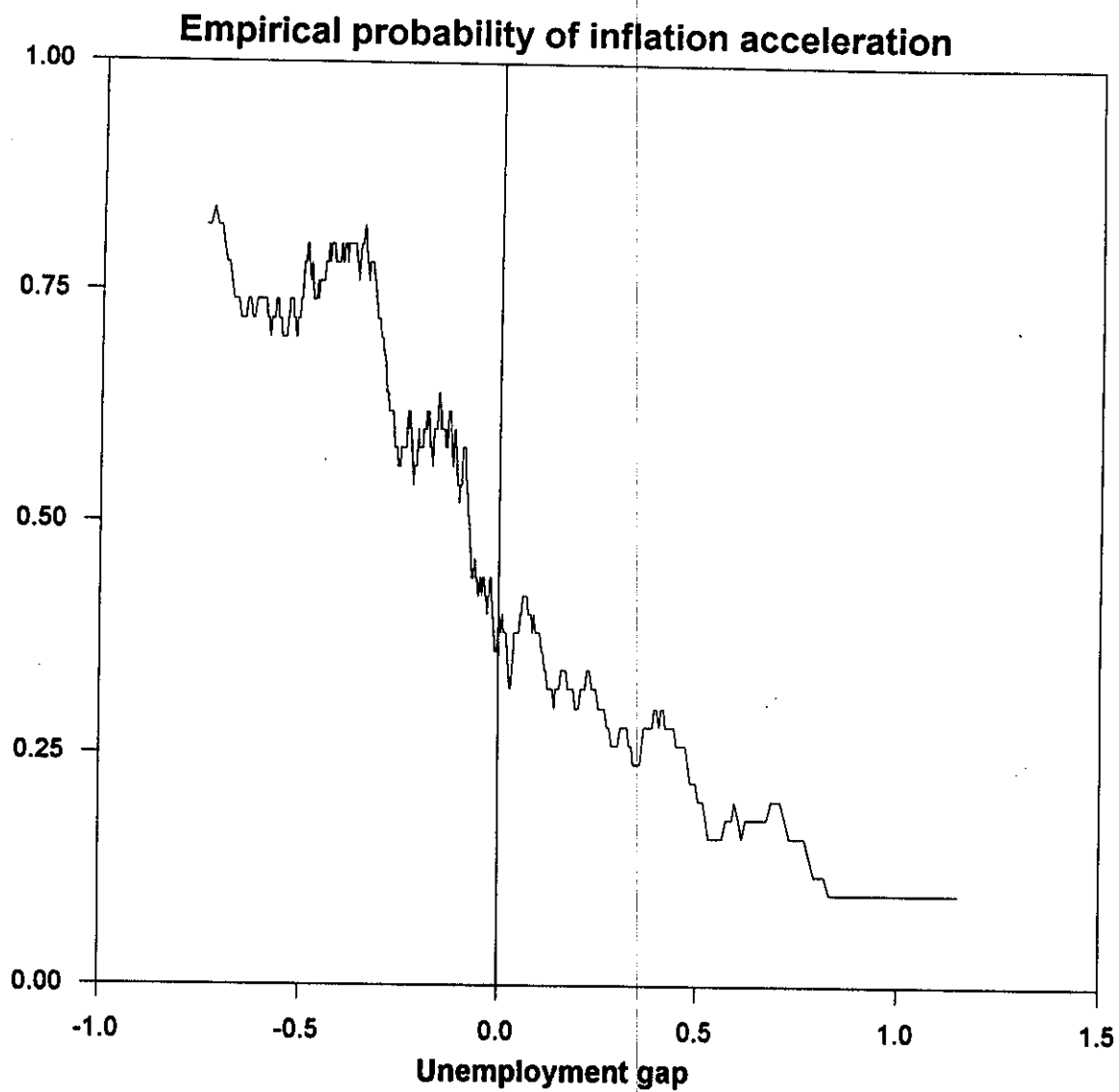


Figure 5. Empirical probability of inflation acceleration. Unemployment gap is the mean over moving deciles.

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