Long-Run Relationship and Structural Change between Inflation and Unemployment †

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Abstract

This paper explores whether the characteristics of the long-run relationship between inflation and unemployment have changed since Paul Volcker's appointment as Chairman of the Fed. Analyses of VAR forecast errors at long horizons are used to obtain information on the long-run relationship. The results provide evidence of a positive long-run relationship for the period of rising inflation, the 1960s and 1970s, but no long-run relationship for the subsequent two decades of falling inflation. This suggests that the great inflation of the earlier period is a consequence of the combined effects of discretionary policymaking and increases in the natural rate of unemployment. However, the driving force of the fall in inflation in the latter period was attributed to the Fed's credible monetary policy.

Keywords: Inflation; Unemployment; Monetary Policy; Long-Run Relationship; Structural Change

JEL Classification: E31; E52; E61

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1. Introduction

The long-run dynamics of U.S. inflation over the last four decades are dramatic. Inflation rose considerably from the late 1960s through the 1970s, and was the number one macroeconomic concern in the late 1970s. However, since then, inflation has fallen and appears to be under control. Understanding the driving forces of the observed changes is of enormous importance to policymakers concerned about the return of high inflation.

The model of monetary policy, proposed by Kydland and Prescott (1977) and Barro and Gordon (1983), provides a widely-accepted explanation. A key ingredient of the model is that policymakers lack the ability to commit to a policy rule, in an effort to exploit an expectational Phillips curve. This leads to the discretionary equilibrium, in which inflation is proportional to the natural rate of unemployment. Hence, coupled with discretionary policymaking, increases (decreases) in the natural rate of unemployment resulted in the great (low) inflation of the 1960s and 1970s (in the 1980s and 1990s). Parkin (1993) lends support to this explanation by pointing out that demographic shifts associated with the baby-boom generation resulted in changes in the natural rate of unemployment, and coincided with the low-frequency movement of inflation. This explanation has recently received the first empirical support from Ireland (1999), focusing on the implication that equilibrium inflation and unemployment are positively related in the long-run. In particular, evidence was found of a cointegrating relationship between inflation and unemployment, a special case of the long-run relationship, under the assumption that the natural rate has a unit root.

This paper explores whether the long-run relationship between inflation and unemployment has undergone structural change since Volcker's appointment as Chairman of the Board of Governors of the Federal Reserve System. A structural change in the long-run relationship is suggested by the degree of inflation persistence in the post-Volcker period. A substantial body of research has shown that inflation persistence has fallen since the early 1980s (see Emery 1994, Anderton 1997, Levin and Piger 2003, and Cecchetti and Debelle 2005). This decline is in sharp contrast to discretionary policymaking in two aspects. First, the discretionary equilibrium predicts a high degree of persistence in inflation, due to the linkage between inflation and the natural rate perceived as being highly persistent. Second, as documented by Sargent (1999), the decline in inflation persistence suggests that the Fed conducted monetary policy in a credible manner. By the end of the 1970s, the Fed recognized that the disinflation policy was effective only when credible, as argued by Sargent and Wallace (1975). The Fed's response to expected inflation was much more rigorous during the Volcker-Greenspan era than the pre-Volcker period (Clarida et al. 2000, Kim and Nelson 2005, and Judd and Rudebusch 1998). Even the Fed's policy over the last two decades is viewed as inflation targeting that has been implemented gradually and implicitly (Goodfriend 2003).

To obtain information regarding the long-run relationship, this study estimates a vector autoregression (VAR) model and analyzes the correlations of VAR forecast errors of inflation and unemployment at long horizons. This method proposed by den Hann (2000) has an advantage over cointegration tests conducted by Ireland (1999). The unit root assumption for the natural rate is required for deriving the cointegrating relationship. However, the order of integration in the unobservable natural rate is unable to be pre-determined, and the original Barro and Gordon model allows for stationarity in the natural rate, suggesting that the cointegrating relationship is too restrictive. In contrast, the procedure adopted in this paper can be applied to stationary as well as integrated processes of any order and, thus, allows measurement of a more general form of the long-run relationship.

This paper is organized as follows. Section 2 discusses the Barro and Gordon model and its testable implications. The empirical methodology is presented in Section 3. Section 4 discusses empirical results. Concluding remarks are given in Section 5.

2. A Theoretical Background on the Long-Run Relationship between Inflation and Unemployment: Barro and Gordon (1983) Revisited

This section briefly discusses Barro and Gordon's (1983) model to stress the potential in explaining the inflation behavior, and its testable implications. In the model, the unemployment rate U_t equals the natural rate U_t^n, plus deviations of the actual inflation rate π_t from the expected rate π_t^e, in the spirit of the expectation-augmented Phillips curve

$$U_t = U_t^n - \alpha(\pi_t - \pi_t^e), \quad \alpha > 0. \tag{1}$$

The natural rate is assumed to follow an autoregressive process driven by real supply-side shocks ξ_t

$$U_t^n = \lambda U_{t-1}^n + (1-\lambda)\bar{U}^n + \xi_t, \tag{2}$$

where $\bar{U}^n$ indicates the long-run mean of the natural unemployment rate.

The policymaker is penalized for the departure of the unemployment and inflation rates from their target values of kU_t^n and zero, and wishes to push the actual unemployment rate below the natural rate. Thus, has the objective to minimize

$$Z_t = a(U_t - kU_t^n)^2 + b(\pi_t)^2, \quad a,\ b > 0, \quad 0 < k < 1. \tag{3}$$

If the policymaker could commit to a policy rule, then optimal policy would be to have zero inflation for all future periods, which is referred to as the rules-type equilibrium by Barro and Gordon.

However, the rules-type equilibrium is not time-consistent when private agents expect the policymaker to follow the rule. Given zero expected inflation of private agents, the policymaker is tempted to deviate from the rule each period because doing so can reduce social costs. The discretionary policymaker, therefore, minimizes the loss function given in Eq. (3) conditional on information available at the beginning of each period. The resulting policy choice denoted as $\hat{\pi}_t$ satisfies the first order condition for π_t:

$$\pi_t = \frac{a\alpha}{b}[-\alpha(\pi_t - \pi_t^e) + (1-k)E_{t-1}U_t^n], \tag{4}$$

where E_{t-1} is the conditional expectation, given information available at the beginning of period t.

Meanwhile, private agents with rational expectations understand that $\hat{\pi}_t$ satisfies Eq. (4) and, at the same time, equals π_t^e for consistency. This entails the discretionary equilibrium

$$\hat{\pi}_t = \frac{a\alpha}{b}(1-k)E_{t-1}U_t^n = \pi_t^e. \tag{5}$$

Eq. (5) states that equilibrium inflation is proportional to the natural rate, providing an insight on the initial rise and subsequent fall of inflation. It is clearly noted that actual inflation is driven by the natural rate of unemployment if the expectation error is random. Furthermore, it is apparent that real shocks underlie the movement of the natural rate. Thus, a negative (positive) shock raises (lowers) the natural rate and, in turn, inflation. If a series of adverse (favorable) shocks hit the economy over a long horizon, inflation continues to increase (decrease), as in the 1960s and 1970s (the 1980s and 1990s).

The equilibrium equation (5) has two important implications for inflation dynamics. First, in combination with Eq. (1), Eq. (5) implies that inflation and unemployment move together in the long-run, since both series are driven by the natural rate. Depending on the order of integration in the natural rate, the long-run relationship takes two alternative types. As detailed by Ireland (1999), if the natural rate has a unit root, i.e., $\lambda = 1$, both inflation and unemployment contain a unit root, and the linear combination of both variables becomes stationary, indicating the existence of a long-run cointegrating relationship. On the other hand, when λ lies within the stationary region, a simple positive correlation in the long-run exists between the two series. Second Eq. (5) implies that expected and actual inflation persists over time since the natural rate is perceived as being highly persistent.

This paper examines the first implication of the discretionary equilibrium, taking into account a breakdown in the long-run relationship suggested by evidence of the decline in inflation persistence since the early 1980s. To measure the long-run relationship, the methodology of den Hann (2000) is employed. The next section details this methodology.

3. Econometric Methodology

Consider a reduced form VAR of lag order p, that describes the dynamics of y_t=[π_t, $u_t, r_t]'$ where π_t is the inflation rate, u_t is the unemployment rate, and r_t is the real interest rate:

$$y_t = \delta + \Phi_1 y_{t-1} + \cdots + \Phi_p y_{t-p} + \epsilon_t, \quad \epsilon_t \sim (0, \Omega), \tag{6}$$

where Φ_i is a 3×3 matrix of regression coefficients of y_{t-i}, and the elements of ϵ_t are assumed to be serially uncorrelated, but may be correlated with each other. [1]

This study uses the VAR coefficients and the variance-covariance matrix of ϵ_t to construct correlations of forecast errors at different horizons. [2] Den Hann (2000) documents that this strategy has three advantages in examining the comovement of the variables of interest. First, y_t can contain stationary as well as integrated processes of any order. Second, the statistics capture important information of the dynamics of the system that

[1] For variables such as output and prices that exhibit a persistent upward trend, the model can be extended to include deterministic trends, as in the original work of den Hann (2000).

[2] An alternative way of obtaining forecast errors is to subtract forecasts from realizations. This method, however, suffers from the shortcoming of losing increasing information as the forecast horizon increases. For example, for a 10-year forecast horizon, no forecast errors are available for the first 10 years of the sample.

would be lost if one only focused on the unconditional correlation coefficient. Finally, this strategy does not require identifying assumptions for impulse response analysis, an alternative way of obtaining complete information about the comovement of variables in the context of VAR.

To illustrate the approach of estimating correlations of forecast errors at different horizons, Eq. (6) can be rewritten as a first-order vector difference equation for $\tilde{Y}_t = [y_t, \cdots, y_{t-p+1}]$:

$$\tilde{Y}_t = \mu + F\tilde{Y}_{t-1} + v_t, v_t \sim (0, \Sigma), \tag{7}$$

where

$$\mu = \begin{pmatrix} \delta \\ 0 \\ 0 \\ \vdots \\ 0 \end{pmatrix}, F = \begin{pmatrix} \Phi_1 & \Phi_2 & \cdots & \Phi_p \\ 1 & 0 & \cdots & 0 \\ 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \cdots & \vdots \\ 0 & 0 & \cdots & 0 \end{pmatrix}, v_t = \begin{pmatrix} \epsilon_t \\ 0 \\ 0 \\ \vdots \\ 0 \end{pmatrix}, \Sigma = \begin{pmatrix} \Omega & 0 & \cdots & 0 \\ 0 & 0 & \cdots & 0 \\ 0 & 0 & \cdots & 0 \\ \vdots & \vdots & \cdots & \vdots \\ 0 & 0 & \cdots & 0 \end{pmatrix}.$$

Recursive substitution yields

$$\tilde{Y}_{t+j} = \sum_{i=0}^{j-1} F^i \mu + F^j \tilde{Y}_t + \sum_{i=0}^{j-1} F^i v_{t+j-i}, \tag{8}$$

for which the j-period ahead forecast is given by

$$E_t[\tilde{Y}_{t+j}] = \sum_{i=0}^{j-1} F^i \mu + F^j \tilde{Y}_t, \tag{9}$$

where E_t is the expectation operator conditional on information up to time t, $\{y_{t-1}, \cdots, y_1\}$. It follows that the associated error $\tilde{\eta}_{t,j}$ is

$$\tilde{\eta}_{t,j} = Y_{t+j} - E_t[\tilde{Y}_{t+j}] = \sum_{i=0}^{j-1} F^i v_{t+j-i}, \tag{10}$$

the variance-covariance matrix of which can be computed as

$$COV_j = \sum_{i=0}^{j-1} F^i \Sigma F^{i\prime}, \tag{11}$$

since $v_t = [\epsilon_t, 0, \cdots, 0]'$ is uncorrelated over time by the structure of the model.

The correlation coefficient of the j-step ahead forecast errors of the inflation and unemployment rates can be calculated as

$$\rho_j = \frac{cov_{\pi u,j}}{\sqrt{var_{\pi,j}\ var_{u,j}}}, \tag{12}$$

where $var_{\pi,j}$ and $var_{u,j}$ are the variances of the j-step ahead forecast errors of the inflation and unemployment rates, which are (1,1) and (2,2) elements of COV_j, respectively, and $cov_{\pi u,j}$, (1,2) element of the matrix, is the covariance of the forecast errors.

To judge the validity of the methodology, the present study performs Monte Carlo experiments in which four sets of artificial inflation and unemployment are simulated 2,500 times, each containing 160 observations. The rules-type equilibrium is imposed on two of them, the first is nonstationary and the second is stationary. The discretionary equilibrium is imposed on the remaining two sets. Likewise, they differ in the order of integration of the natural rate. Figure 1 displays the results for each set of simulated data. The middle lines are the averages of correlation coefficient estimates of up to 40-period ahead forecast errors, and the dotted lines are the averages plus and minus two times their standard deviations. With the rules-type equilibrium imposed on the simulated data, no significant long-run correlations exist, as shown in Panel A. When the discretionary equilibrium is imposed on the simulated data, significant positive long-run correlations are found, regardless of the order of integration of the natural rate, as presented in Panel B.

4. Empirical Results

Both monthly and quarterly data are analyzed in this paper. The inflation rate is measured by period-by-period changes in the Consumer Price Index (CPI) for monthly data, and in the GDP implicit price deflator for quarterly data. The monthly unemployment rate is for all workers 16 years of age and over, and the quarterly rate is measured using the average of monthly values for each quarter. The monthly nominal interest rate is the yield on 90-day Treasury bills, and the observations for the first month of each quarter are used as quarterly series. The inflation rate is subtracted from the nominal interest rate to yield the ex post real interest rate. [3] Data on the CPI, GDP deflator, and unemployment rate are taken from the DRI Basic Database. [4] The Treasury bill yield is taken from the CRSP tape.

The VAR specification given in Eq. (6) includes an intercept, but a model without the intercept is also considered. If an intercept is included when the variables of interest have a unit root, then this may make it difficult to capture the long-run comovement, since the intercept can be interpreted as a drift or time-trend. The intercept-free specification is, thus, analogous to the sprit of Ireland (1999).

Eq. (11) shows that the F and Σ matrices are required for estimating the correlation coefficients of forecast errors. The F matrix is estimated using OLS regression of Eq. (7), and the resulting residuals are used to estimate the Σ matrix. The optimal lag order of a VAR is determined by the Akaike Information Criterion. Table 1 describes the characteristics of estimated VARs. [5] The calculated correlation coefficients are subject to sampling variation because they are based on the estimated VARs. Bootstrap methods are used to construct confidence intervals, following den Hann (2000). The number of

[3] The same set of variables are used by Cogley and Sargent (2001) to explain postwar U.S. inflation dynamics in a VAR context. Stock and Watson (2001) employ the inflation and unemployment rates, and the nominal interest rate to highlight the performance of VAR models in describing data and forecasting.

[4] The codes used in the database are PUNEW for the CPI, GDPD for the GDP deflator, and LHUR for the unemployment rate.

[5] den Hann (2000) documents that a necessary condition for consistent estimates of correlation coefficients is a stationary ϵ_t. As a diagnostic check, an Augmented Dickey-Fuller unit root test is carried out for the residuals from the OLS regression. For all circumstances considered, the null hypothesis of a unit root is rejected at the 1% significance level. For example, for monthly data for 1961–2000, the test statistic is -20.2776 while the 1% critical value is -2.5707.

replications is 2,500. [6]

4.1. Full Sample Results

For comparison with Ireland (1999), the period of 1961–2000 is first examined. As mentioned above, the intercept-free VAR specification is analogous to the assumption made by Ireland (1999) that the variables of interest have a unit root. Hence, the VAR model without an intercept is estimated.

Figure 2 displays the results. The middle lines are the estimates of correlation coefficients of up to 10-year ahead forecast errors of inflation and unemployment, and the upper and lower lines are the estimates' of 90% of bootstrap confidence intervals. For the monthly data, the confidence intervals for forecast horizons of 52 months and onward lie above zero, suggesting rejection of the null of $\rho_j = 0$ in favor of the alternative of $\rho_j > 0$ (panel A). For the quarterly data, the null hypothesis is rejected for $j \geq 14$ quarters (panel B). Hence, a long-run positive relationship appears to exist between inflation and unemployment, consistent with the finding of Ireland (1999). [7]

4.2. Subsample Results

A large body of research has found empirical findings that suggest little role of discretionary policymaking for the fall in inflation during the 1980s and 1990s. Hence, the possibility of structural change in the long-run relationship is investigated, using subsample analyses.

For the period of rising inflation, 1961–1979, inflation and unemployment are positively related in the long-run, regardless of inclusion of an intercept and the data frequency; Figure 3 plots the results. When an intercept is in the VAR, the correlation

[6] The Gauss codes used in the present study were modified from the Matlab programs available at den Hann's website. I am thankful to den Hann for these programs.

[7] Similar results are found for the periods of 1961–1997 and 1970-1997 that Ireland (1999) examined.

estimates are greater than 0.5 at long horizons and are statistically significant at the 10% level, as shown in Panel A. For the monthly data, the correlation estimates are positive and marginally significant for horizons over 55 months. For the quarterly data, the estimates of correlation are significant for horizons over approximately 16 quarters. The results for the case of no intercept in the VAR, shown in Panel B, are similar. The correlation estimates are positive and significant for horizons over 72 months and for horizons over 22 quarters.

The long-run relationship between inflation and unemployment for 1980–2000, as shown in Figure 4, is strikingly different from that for 1961–1979. The correlation estimates at long horizons are close to zero and not statistically significant at the 10% significance level, regardless of inclusion of an intercept and the data frequency.

The results so far can be summarized as follows. For the period of 1961–2000, long-run correlations between forecast errors of inflation and unemployment are significantly positive when variables are implicitly assumed to have a unit root; this is consistent with Ireland (1999). For the period of 1961–1979, correlations at long-run horizons are significantly positive. However, for the period of 1980–2000, correlations are not significantly different from zero. These results suggest that structural change in the long-run relationship has occurred and that the result for Ireland's (1999) period is a consequence of heavy influence of the pre-1980 period.

4.3. A Potential Interpretation of Structural Break in the Long-Run Relationship

Here, a potential interpretation of structural change in the long-run relationship between inflation and unemployment is presented. For the period of 1961–1979, evidence of a positive long-run relationship is found between inflation and the natural rate. This relationship emanates from the linkage between inflation and the natural rate of unemployment implied by the discretionary equilibrium of Barro and Gordon's (1983) model.

Hence, this evidence indicates that the great inflation is a result of the combined effects of discretionary policymaking and increases the natural rate of unemployment, for example, baby-boomers entering work age.

In contrast, no evidence of a long-run relationship is found for the period of 1980–2000. What can be inferred from this counterevidence to the implication of the equilibrium? It is generally agreed that the natural rate declined in the 1980s and 1990s. If policymaking had been discretionary in those periods, such decline would have led to declining inflation, resulting in a positive long-run relationship. Hence, this evidence suggests that the fall in inflation during the 1980s and 1990s occurred mainly due to the Fed's credible conduct of monetary policy.

Then, a natural question arises: why did the Volcker-Greenspan Fed conduct monetary policy credibly in the most recent two decades? Taylor (1997) provides an answer to this question. At the end of the 1970s, economists revised the costs of inflation upwardly and those of disinflation downwardly. These revisions, coupled with the introduction of rational expectations in the Phillips curve, ultimately influenced the Fed to take a disinflation policy. Furthermore, the work of Sargent and Wallace (1975) helped the Fed recognize that the anti-inflation policy is effective only when credible.

4.4. Counterfactual Analysis

Eq. (11) suggests that a change in the long-run relationship between inflation and unemployment is caused by a change either in the variance-covariance matrix of forecast errors, Σ, or in the lag dynamics of the VAR, F. To investigate, counterfactual experiments were performed on the correlations, using the VAR estimates for the two subsamples. [8]

Given that the correlation is a function of Σ and F, it can be expressed as $\rho_j(F_m, \Sigma_m)$

[8] A similar experiment in the context of VAR can be found in the work of Boivin and Giannoni (2002) and Stock and Watson (2002).

where $m = 1, 2$ denotes the first and second subsample, respectively, and j indicates the forecast horizon. An evaluation of ρ_j for F and Σ from different subsamples allows computation of counterfactual correlation. For example, $\rho_j(F_2, \Sigma_1)$ is the correlation computed using F from the second subsample and Σ is the correlation computed from the first subsample.

Figure 5 displays two counterfactual correlations, $\rho_j(F_1, \Sigma_2)$ and $\rho_j(F_2, \Sigma_1)$, and two actual correlations, $\rho_j(F_1, \Sigma_1)$ and $\rho_j(F_2, \Sigma_2)$, with the case for an intercept in the VAR in Panel A and the case of no intercept in Panel B. When the F matrix from the pre-1980 period is replaced with that from the post-1980 period, holding Σ_1 unchanged, the resulting counterfactual correlation $\rho_j(F_2, \Sigma_1)$ is very close to the actual correlation for the post-1980 subsample. In contrast, when the Σ matrix changes from the pre-1980 to the post-1980 period, holding F_1 unchanged, the resulting counterfactual correlation $\rho_j(F_1, \Sigma_2)$ is not close to the actual correlation for the post-1980 period but similar to that for the pre-1980 period. The results are insensitive to inclusion of the intercept and the data frequency. These findings reveal that a change in the propagation of shocks associated with the F matrix played a very important role in the disappearance of the long-run correlation between inflation and unemployment for the 1980–2000 period.

5. Summary and Conclusion

This paper is concerned with testing the ability of the model of discretionary policy of Kydland and Prescott (1979) and Barro and Gordon (1983) to account for the low frequency movement of inflation over the last four decades. For this, the implication of the model that the long-run relationship between inflation and unemployment is positive, is examined. To obtain information about the long-run relationship, the procedure of den Hann (2000) is employed, which has the advantage that it requires no assumptions about the order of integration in the variables of interest. The procedure estimates a vector autoregression (VAR) model and analyzes the correlations of VAR forecast errors of inflation and unemployment at long horizons.

The main empirical finding is that long-run correlations are significantly positive for the 1960s and 1970s but are not significantly different from zero for the 1980s and 1990s. This finding has a few important implications. First, only the result for the earlier period is consistent with the implication of the discretionary policy model. Hence, the finding of Ireland (1999) that the model is valid for the entire period may be a consequence of heavy influence on that of the earlier period. Second, while the great inflation of the earlier period was caused by the combined effects of discretionary policymaking and increases in the natural rate of unemployment, the fall in inflation for the latter period occurred due to the Fed's credible monetary policy.

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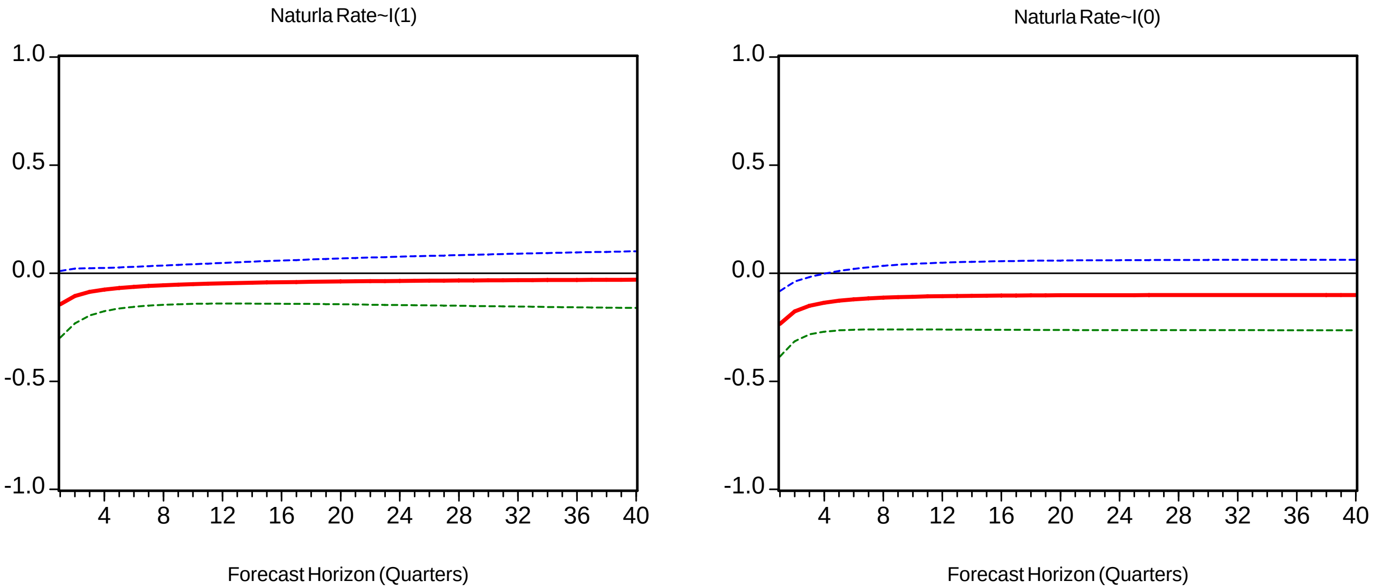
Table 1. Characteristics of the Estimated VARs

Sample period	Intercept included	Lag order	AIC
		Monthly Data	
1961–2000	Yes	9	–3.702
	No	9	-3.678
1961–1979	Yes	7	-4.219
	No	7	-4.126
1980–2000	Yes	9	-4.125
	No	9	-4.099
1952-1958	Yes	3	-4.234
	No	3	-4.189
		Quarterly Data	
1961–2000	Yes	6	-3.010
	No	6	-2.928
1961–1979	Yes	2	-3.156
	No	6	-3.113
1980–2000	Yes	3	-4.991
	No	6	-4.407

Figure 1. Correlation Coefficients of Forecast Errors for Simulated Data

Panel A. Rules-Type Equilibrium Imposed



Panel B. Discretionary Equilibrium Imposed

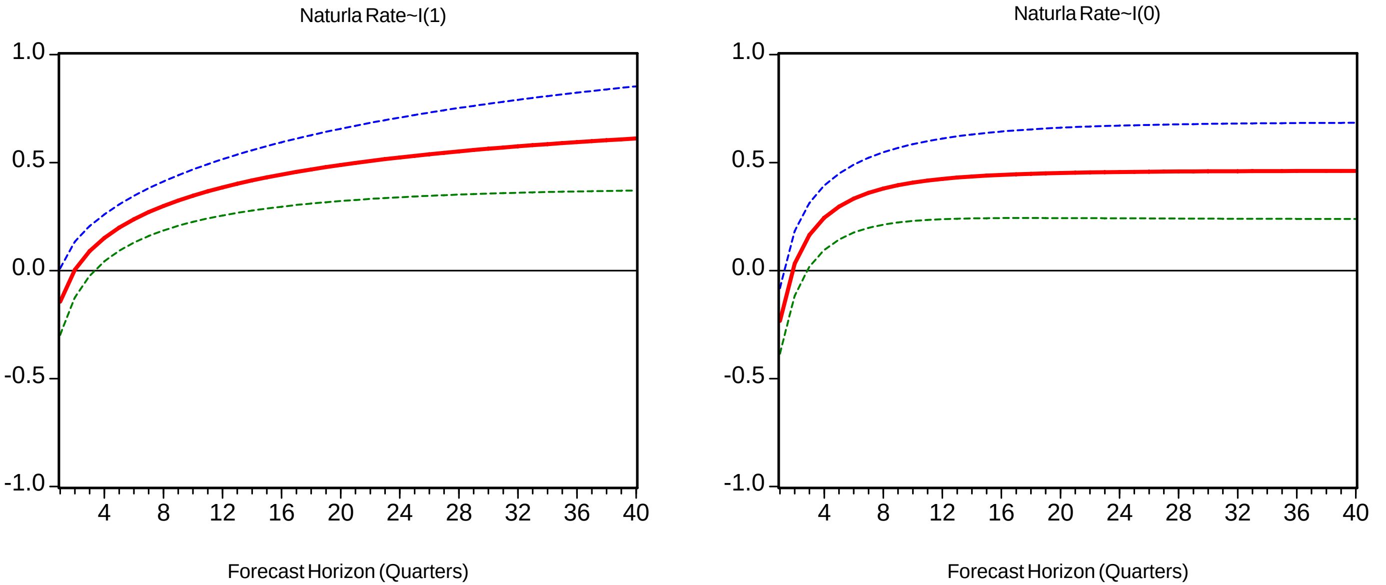


Figure 2. Correlation Coefficients of VAR Forecast Errors and 90% Confidence Intervals [1961-2000]

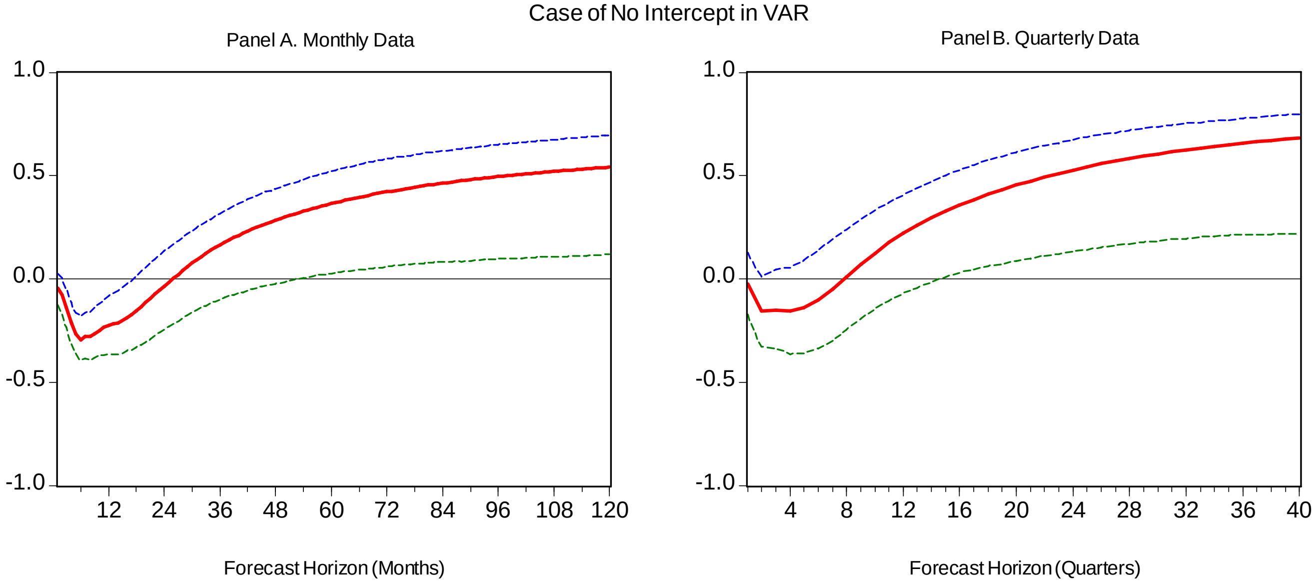


Figure 3. Correlation Coefficients of VAR Forecast Errors and 90% Confidence Intervals [1961-1979]

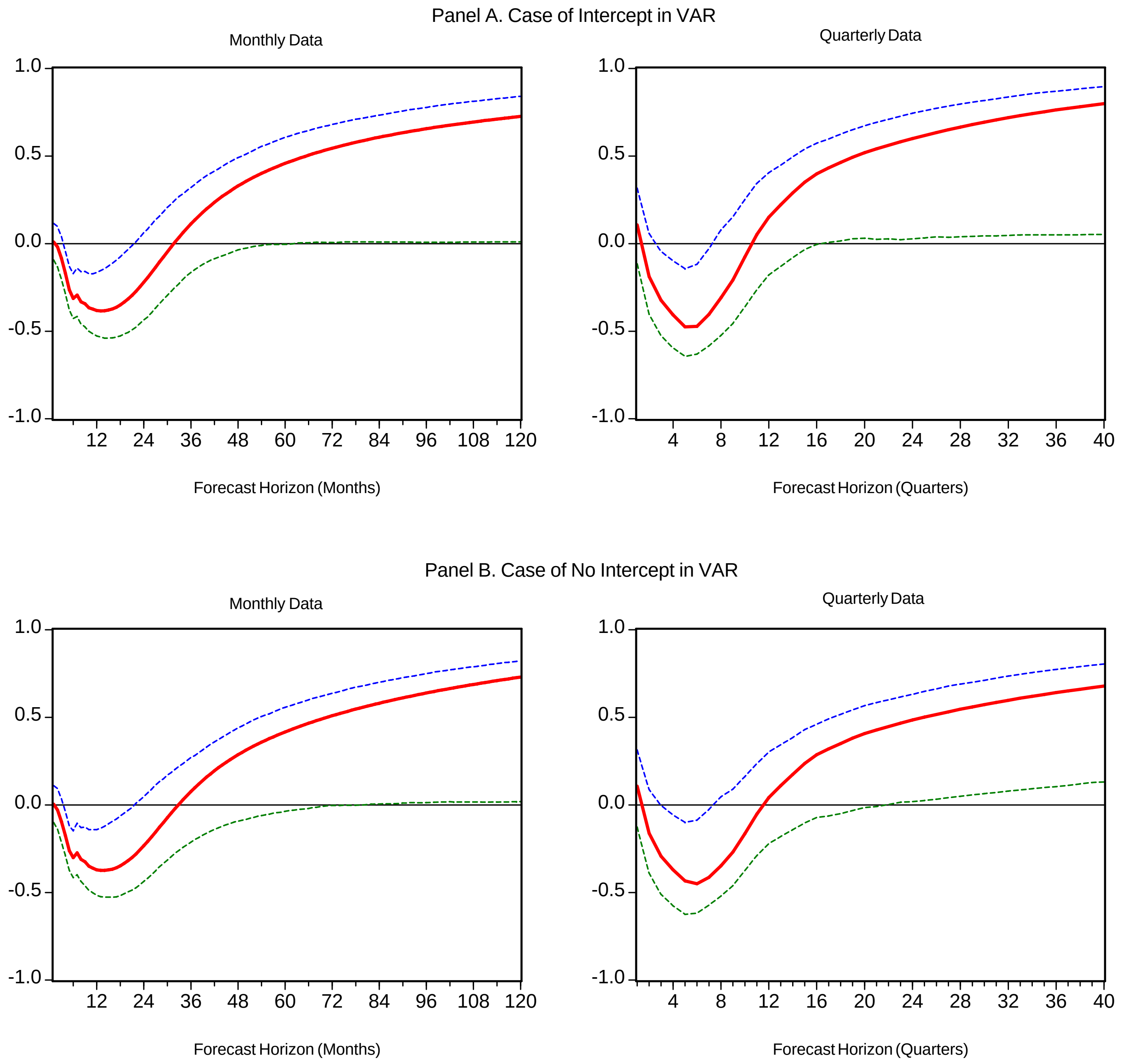
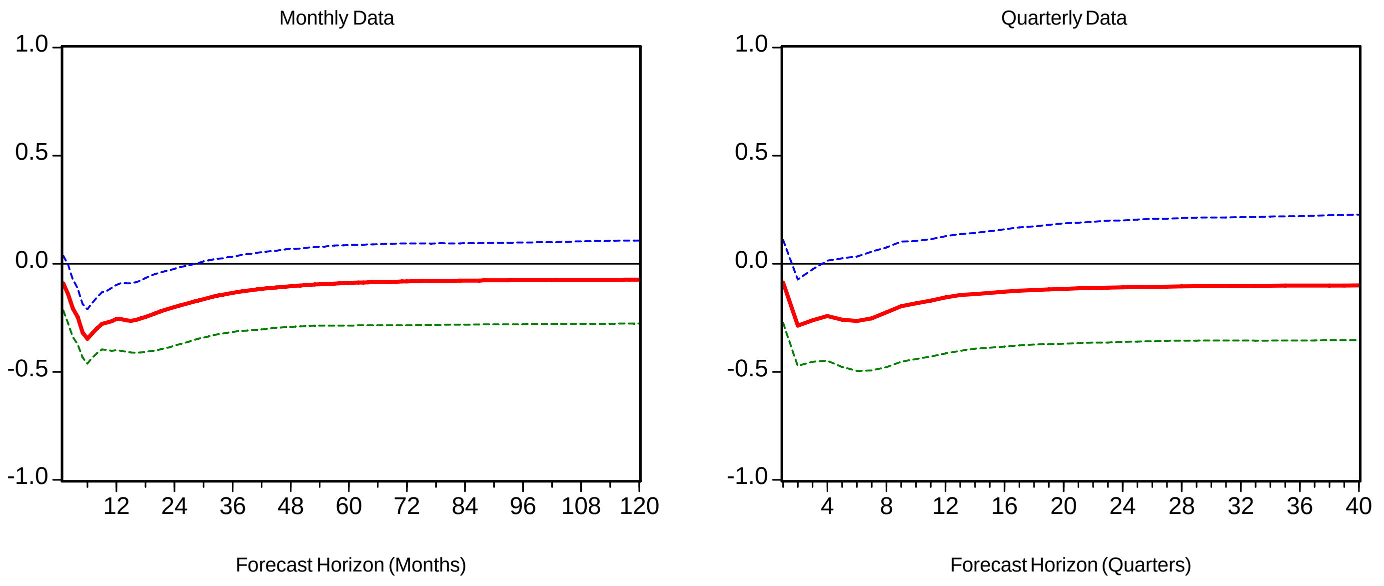


Figure 4. Correlation Coefficients of VAR Forecast Errors and 90% Confidence Intervals [1980-2000]

Panel A. Case of Intercept in VAR



Panel B. Case of No Intercept in VAR

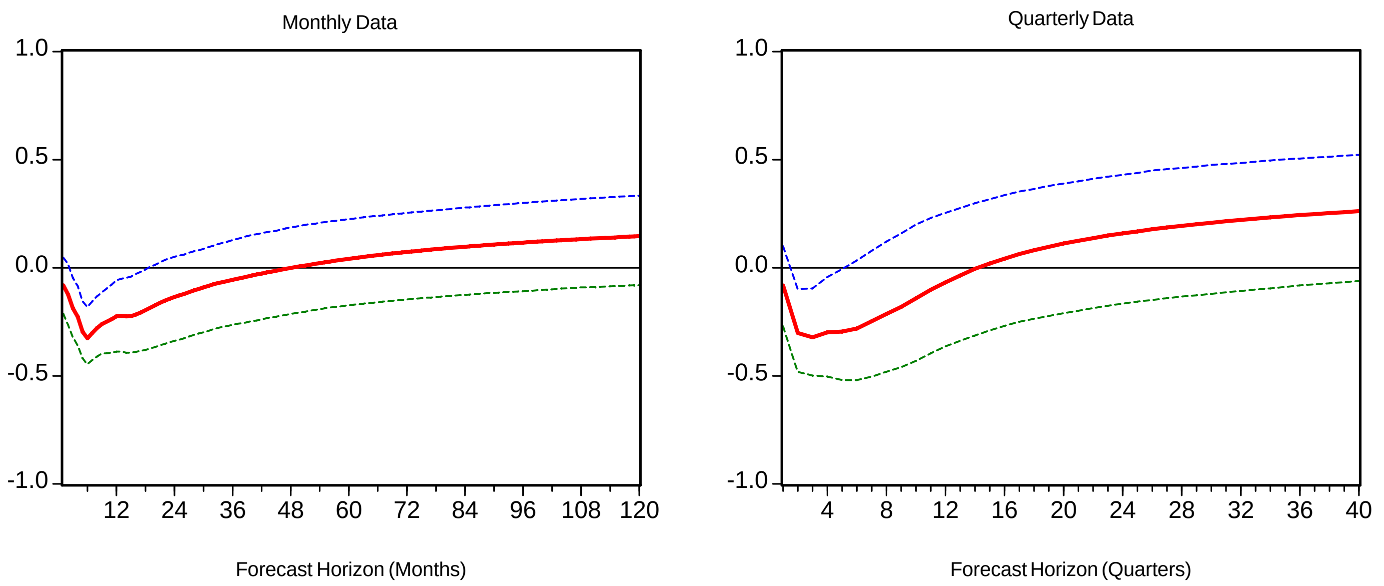
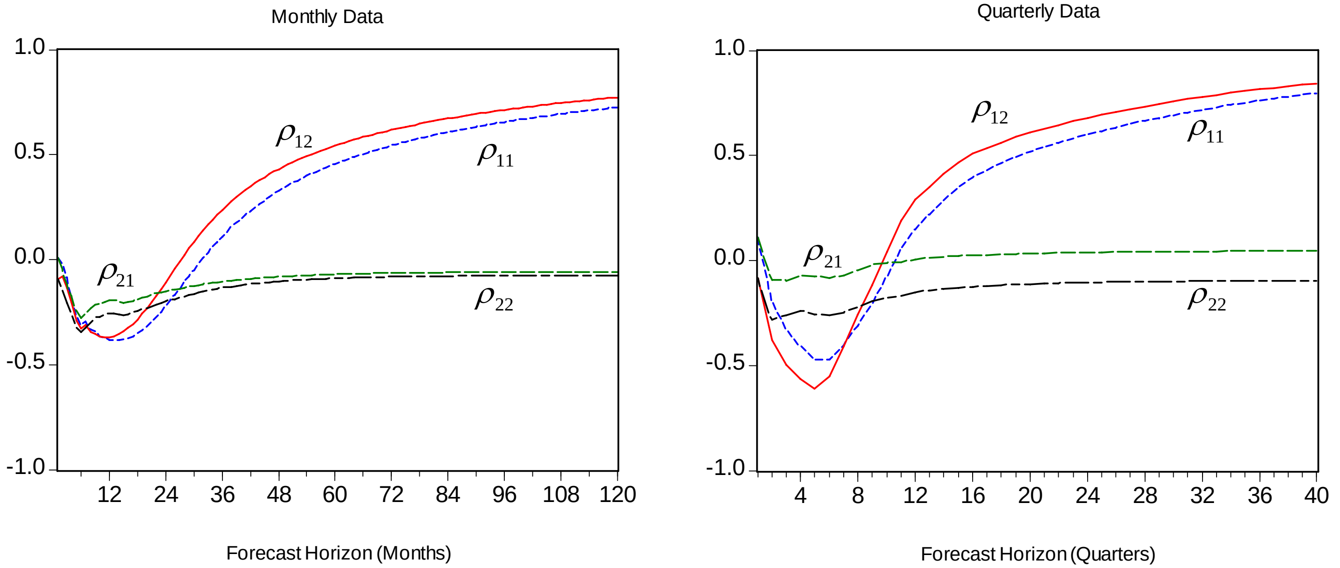


Figure 5. Counterfactual Correlation Coefficients of VAR Forecast Errors

Panel A. Case of Intercept in VAR



Panel B. Case of No Intercept in VAR