Expectations and the Core Rate of Inflation

by Richard H. Jefferis, Jr.

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Introduction

Policymakers seeking to control inflation are confronted by a bewildering array of price statistics that often provide conflicting signals about the current inflation rate. The disparity among different measures of inflation is illustrated by figure 1, which depicts quarterly inflation rates implied by movements in several well-known price series between 1954 and 1987, and by table 1, which displays the correlation among inflation rates associated with a broader group of indices over the same period.[1] Although the CPI, the PCE deflator, and the PPI trend together, there is a wide variation in the movements of these price indices over periods as long as a quarter.

The discrepancy among inflation rates associated with different price indices has important implications for the conduct of monetary policy linked to inflation targets. If long-term increases in the price level are masked by statistical noise that is a consequence of changing circumstances in individual markets, then monetary policy linked to *any* index of current inflation will be affected by transient shocks as well as by the secular trend in prices. Although shocks to the price of individual commodities or groups of commodities do affect the cost of living, they do not necessarily reflect the impact of money growth on the price level. Nor is the appropriate policy response to these two types of inflation necessarily the same. Overall, both the source of noise and the amount of noise in individual price indices make them a poor choice for inflation targets.

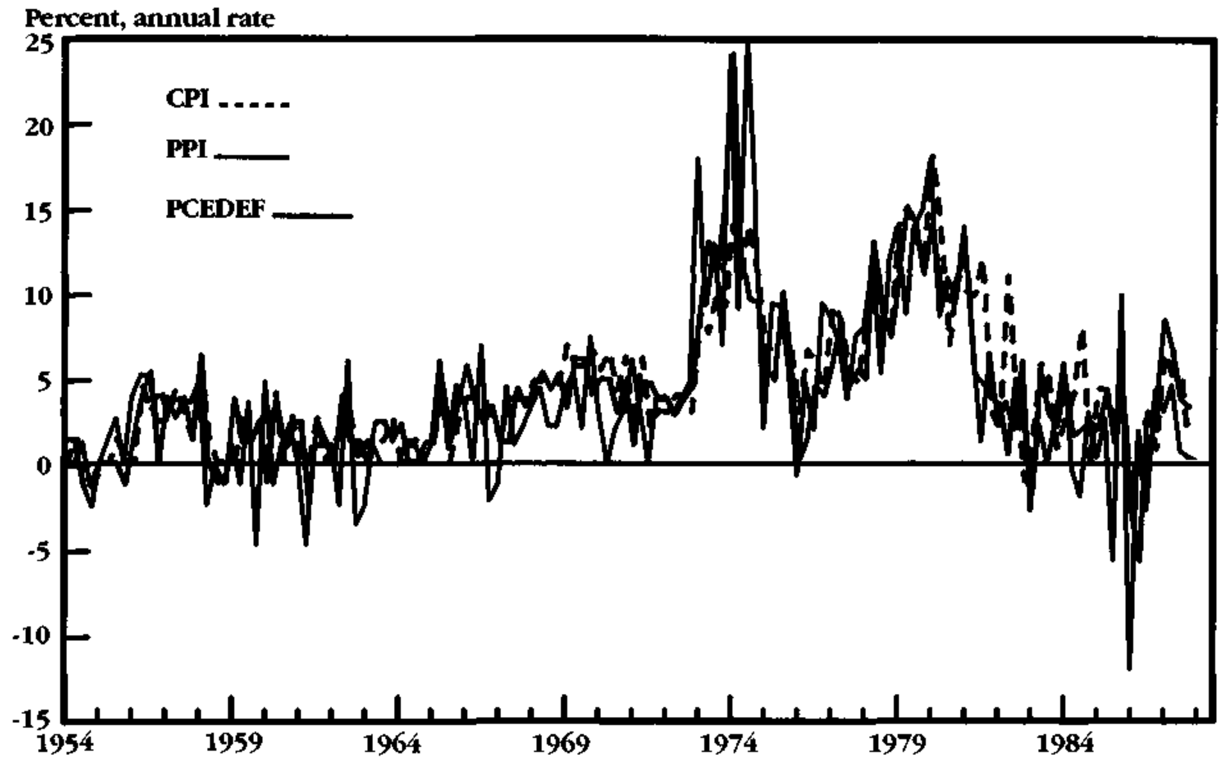
A related problem associated with using realized inflation as a guide for monetary policy is the timing of inflation signals. The inflation rate of last quarter or even last month is a poor guide for policy that seeks to influence the future course of the economy, yet this is the type of information provided by direct examination of any historical record. Forward-looking policies linked to a measure of current inflation should be based on what the past can tell us about the present and the future. To make the historical record useful, we need to extract from it information about current inflation and expected future inflation.

Inflationary expectations address both of these problems. Expectations are, by their nature, linked to long-term trends in the price level rather than to transient movements. They are forward-looking. Moreover, there is a remarkable degree of correlation among the inflation forecasts

■ 1 The price indices are the Consumer Price Index (CPI), the service component of the CPI (CPIS), the Producer Price Index (PPI), the PPI without food and energy (PPIWF), and the Personal Consumption Expenditure (PCE) deflator. Only the CPI, PPI, and PCE deflator appear in the figure.

FIGURE 1

Different Measures of Inflation, 1954-1987



SOURCES: U.S. Department of Commerce, Bureau of Economic Analysis, and U.S. Department of Labor, Bureau of Labor Statistics.

generated by different price indices and forecast methodologies. Realistic models of inflation discount current innovations in the inflation rate, which are largely noise, and focus instead on movements that tend to persist over time. As a result, different models of expected inflation agree on what is likely to occur in the immediate future, even when individual price series give conflicting signals about the current inflation rate. The common trend in the different series is an indicator of the pervasive price growth, or core inflation, that is of interest to policymakers.

I. Expected Inflation

We usually think of expected inflation as the expected rate of change in a particular price index, and judge different models of expectations by their ability to project movements in that index. The two criteria most commonly used to judge model performance are the mean squared error and bias of the inflation forecast. Both statistics are informative, since an unbiased forecast that fails to identify large, predictable movements in inflation will have a larger mean squared error than a forecast that is, on average, less accurate but better able to predict significant changes in the inflation rate.

Two types of statistical models used to forecast inflation have, in the past, performed equally well in terms of both bias and mean squared error.[2] Time series models identify temporal patterns in the inflation rate and use those patterns, combined with information about the recent history of inflation, to predict future inflation. These models are capable of identifying very complex relationships among inflation rates at different points in time, but tend to ignore other contemporaneous information that might be useful in forecasting.

Econometric models that incorporate information about interest rates or money growth attempt to remedy this shortcoming. Although the history of money growth is correlated with inflation, interest rates often take the place of money in forecasting models. The motivation for this choice is the notion that, in an efficient capital market, the

■ 2 Fama and Gibbons (1984) compare pure time-series models and interest-rate models, and find that the interest-rate models yield a smaller root mean squared error in out-of-sample forecasts. The differences in forecast performance increase with the forecast horizon.

TABLE 1

The Correlation among Quarterly Inflation Rates Based on Different Price Indices between 1954 and 1987

	CPI	CPIS	PPI	PPIWF	PCEDEF
CPI	1.00	0.83	0.74	0.72	0.82
CPIS	0.83	1.00	0.48	0.56	0.56
PPI	0.74	0.48	1.00	0.79	0.76
PPIWF	0.72	0.56	0.79	1.00	0.78
PCEDEF	0.82	0.56	0.76	0.78	1.00

SOURCE: Author's calculations.

inflation premium in nominal interest rates is a sufficient statistic for expected inflation.

In practice, money may have some incremental predictive power, because the decomposition of nominal rates into an expected real return and an inflation premium is not observable, but is imposed on the data by the econometrician. To the extent that this decomposition is imperfect, the econometric model will fail to uncover the market's inflation forecast, even if movements in the nominal interest rate are completely determined by changes in the expected real rate and expected inflation, as theory would suggest. The merits of econometric models that extract inflation forecasts from interest rates and the empirical relevance of monetary growth for predicting inflation are issues that may be resolved only by examining the data.

II. Time Series Models

Time series models express current inflation as a weighted sum of past inflation and past changes in the inflation rate. The manner in which this history is translated into forecasts depends on the properties of the inflation process. When movements in the inflation rate tend to be transient, current innovations play a marginal role in the formation of expectations, and the historical record receives more emphasis in the inflation forecast. If, on the other hand, increases in inflation tend to persist, the inflation forecast will be closely linked to the behavior of prices during the recent past.

A time series model of inflation that has been found to forecast well is

$$(1) \quad I(t) - I(t-1) = \varepsilon(t) - \theta\varepsilon(t-1).$$

In this model, $I(t)$ is the inflation rate at time t and $\varepsilon(t)$ is an impulse that affects that rate.[3] Conceptually, the impulse comes either from expansion of the money stock or from some change in market conditions, such as a drought or the threat of war in the Middle East. The current change in the inflation rate is determined by current and past impulses, where the weight assigned to the past is θ.

These models have an appealing interpretation in terms of expected and unexpected inflation.[4] From equation (1), we know that

$$(2) \quad \Delta I(t) = \varepsilon(t) - \theta\,\varepsilon(t-1).$$

This implies that

$$(3) \quad \hat{I}(t) = I(t-1) - \theta\,\varepsilon(t-1)$$

or that

$$(4) \quad \Delta I(t) = \Delta I(t-1) - \theta\,\Delta\varepsilon(t-1).$$

Using the definition of $\Delta I(t)$ from equation (2) and the fact that $\Delta[\theta\,\varepsilon(t-1)] = \theta[\varepsilon(t-1) - \varepsilon(t-2)]$, we obtain

$$(5) \quad \Delta\hat{I}(t) = (1-\theta)\,\varepsilon(t-1).$$

Expression (5) states that expected inflation follows a random walk, with an innovation variance that is $(1 - \theta)^2$ times the variance of $\varepsilon(t)$. Values of θ close to 1 imply that most of the variance in inflation is accounted for by transient shocks, so that current innovations are not reflected in expected future inflation, while values of θ close to 0 imply that most of the variance is accounted for by movements in inflation that are expected to persist.[5]

Estimation of equation (1) for the different series described in table 1 and figure 1 yields values of θ that range from 0.45 for the PCE deflator to 0.70 for the PPI.[6] The evidence from the econometric model is therefore in accord with the intuition suggested by the data: A modest fraction of the quarterly innovation in inflation is reflected

■ 3 The model described here is examined by Fama and Gibbons (1982).

■ 4 Jeffrey Hallman suggested this interpretation.

■ 5 Ansley (1980) provides an alternative interpretation that yields the same inference

■ 6 Maximum likelihood estimates are based on a sample of inflation rates from the first quarter of 1954 to the fourth quarter of 1987. The Breusch-Pagan Lagrange multiplier test for autoregressive conditional heteroscedasticity (ARCH) effects reveals that the data are conditionally heteroscedastic. All estimates involve an ARCH (2,0) model of the conditional variance, although this is found to have only a minimal impact on estimated parameter values and forecasts.

TABLE 2

The Correlation among Expected Quarterly Inflation Rates Generated by a One-Parameter Time Series Model. Inflation Is Assumed to Follow an IMA (1,1) Process

	CPI	CPIS	PPI	PPIWF	PCEDEF
CPI	1.00	0.92	0.93	0.90	0.90
CPIS	0.92	1.00	0.82	0.81	0.71
PPI	0.93	0.82	1.00	0.93	0.89
PPIWF	0.90	0.81	0.93	1.00	0.87
PCEDEF	0.90	0.71	0.89	0.87	1.00

SOURCE: Author's calculations.

in expected future inflation. In the case of the PCE deflator, a 1 percent increase in quarterly inflation is associated with a 0.55 percent increase in expected inflation. That fraction is 0.30 in the case of the PPI. An alternative perspective on the estimated value of θ is provided by examining the fraction of the variance of changes in quarterly inflation accounted for by changes in expected inflation. This number ranges from 10 percent in the case of the PPI to 30 percent in the case of the PCE deflator.

The effect of filtering the inflation-rate series with this model, and focusing on the expected inflation series implied by equation (3), is illustrated in table 2. The correlation among expected inflation rates inferred from the different price series is substantially greater than the correlation in realized inflation rates, even when expectations are generated by the parsimonious one-parameter time series model. For example, the correlation between the expected inflation rate inferred from the CPI and the expected inflation rate inferred from the PPI over 35 years of quarterly data is 0.93, while the correlation between the realized rates of inflation implied by these same indices is 0.74. Thus, the different price series yield highly correlated inflation forecasts, even though there is substantial disagreement about the current inflation rate among these series.

III. Econometric Models

Inflation forecasts based exclusively on the temporal pattern of past inflation ignore a great deal of potentially useful data. Information about money growth or interest rates will be without value only in the event that the history of inflation is a sufficient statistic for its expected future course. Both the tremendous amount of noise in the various inflation series and common sense suggest that this is unlikely.

Nominal interest rates are an especially appealing source of information, since the yield on fixed-rate debt instruments contains a premium that compensates the investor for expected depreciation in the purchasing power of money over the life of the instrument. The advantage of using interest rates to identify expected inflation, rather than modeling the link between money and prices directly, is that the inflation premium found in bond yields represents a consensus forecast of inflation over a fixed time interval known to the observer. In contrast, the history of money growth provides little information about when an increase in money will be reflected in prices, or even whether it will be reflected in prices rather than output. Focusing on bond yields rather than on money growth makes it unnecessary to consider the complex lag structures typical of macroeconomic models that attempt to characterize directly the link between money and prices.

Extracting inflationary expectations from bond yields is not a trivial exercise: Variations in nominal yields reflect changes in expected real returns as well as changes in expected inflation. (Yields may also contain a risk premium when inflation is uncertain, but this feature of returns is rarely modeled.) Neither component of nominal yields is observed directly, and models that exploit interest-rate data rely on auxiliary assumptions to separate expected real rates from expected inflation. The models discussed below are distinguished by the assumptions about the real rate process that are used to identify these components of the nominal interest rate.

One method of identifying the model is to assume that the expected real rate of return follows a random walk. This implies that

$$(6) \qquad \hat{R}(t) = \hat{R}(t-1) + \zeta(t).$$

Then, if the realized real return is equal to the expected real return plus a noise term $\eta(t)$, the first difference of the observed real return takes the form

$$(7) \qquad \Delta R(t) = \zeta(t) + \eta(t) - \eta(t-1).$$

TABLE 3

The Correlation among Expected Quarterly Inflation Rates when the Expected Real Rate Follows a Random Walk and the Nominal Yield Is the Sum of the Expected Real Rate and Expected Inflation

	CPI	CPIS	PPI	PPIWF	PCEDEF
CPI	1.00	0.95	0.96	0.93	0.92
CPIS	0.95	1.00	0.88	0.87	0.78
PPI	0.96	0.88	1.00	0.96	0.92
PPIWF	0.93	0.87	0.96	1.00	0.89
PCEDEF	0.92	0.78	0.92	0.89	1.00

SOURCE: Author's calculations.

TABLE 4

The Correlation among Expected Quarterly Inflation Rates Generated by a Regression-Based Model. The First Difference in Inflation Is Projected onto the First Difference in the 90-Day Treasury Yield

	CPI	CPIS	PPI	PPIWF	PCEDEF
CPI	1.00	0.95	0.94	0.93	0.91
CPIS	0.95	1.00	0.85	0.88	0.78
PPI	0.94	0.85	1.00	0.95	0.90
PPIWF	0.93	0.88	0.95	1.00	0.88
PCEDEF	0.91	0.78	0.90	0.88	1.00

SOURCE: Author's calculations.

This has a first-order moving average representation identical to that of equation (1). Estimation of this model yields an expected real return series.[7] Quarterly inflation forecasts are then constructed by subtracting the expected real return series corresponding to a particular price index from the yield on 90-day Treasury bills. The correlation among the inflation forecasts created in this manner is described in table 3.

The more sophisticated model of expectations yields inflation forecasts that are both more accurate and more highly correlated with each other than those from the time series model, even when the dynamics of the expected real interest rate are extremely simple.[8] The increased correlation is especially noticeable in situations where the correlation between the time series forecasts is lowest; for example, in the service component of the CPI and PPI. The high correlation among the fitted values from the interest-rate-based models suggests that all of the forecasts are tracking some underlying trend. The natural interpretation of that trend is the core rate of inflation.

This interpretation is reinforced by estimates from a closely related model. If expected real rates are constant or nearly constant between adjacent quarters, the main source of variation in Treasury yields is the inflation premium. This suggests a regression-based model of the form

$$(8) \qquad \Delta\pi(t) = \beta_0 + \Delta i(t)\beta_1 + \varepsilon(t),$$

where $\Delta\pi(t)$ is the change in inflation from one quarter to the next and $\Delta i(t)$ is the change in Treasury yields from the beginning of quarter $t-1$ to the beginning of quarter t. Estimation of this model indicates a statistically significant relationship between the change in Treasury yields and the change in inflation.[9]

The correlation among fitted values obtained by estimating equation (8) is documented in table 4. The strong resemblance between these results and those presented in table 3 suggests that whether interest rates are included in the model is a more important consideration than the manner in which they are incorporated. As before, the expected inflation forecasts track each other quite closely.

Adding lagged values of either the growth rate of money or the change in the growth rate of money to the regression equation has almost no impact on the fitted values for expected inflation, even though the regression coefficients associated with these variables are statistically

■ 7 Application of the Breusch-Pagan test to the residuals from maximum likelihood estimates reveals ARCH effects. The figures in table 3 are based on fitted values from a maximum likelihood model where the conditional variance is ARCH (2,0). It is also worthwhile noting that the magnitude of the moving-average parameter is considerably less than in the results reported by Fama and Gibbons for monthly data. In other words, monthly data contain even more noise.

■ 8 Fama and Gibbons (1984) document the superiority of this model relative to the time series model, using monthly data.

■ 9 The model is estimated by maximum likelihood with an MA(1) error structure and an ARCH correction for conditional heteroscedasticity. The regresssion coefficient β_1 is statistically significant at 1 percent for all of the inflation series when the parameter covariance matrix is estimated from the information matrix, with or without the Newey-West correction for heteroscedasticity.

TABLE 5

The Correlation among Actual and Predicted Series for the CPI

	Actual	IMA (1,1)	Real rate is a random walk	Regression w/int. rates	Same w/int. rates and money
Actual	1.00	0.76	0.81	0.80	0.82
IMA (1,1)	0.76	1.00	0.96	0.97	0.95
Real rate is a random walk	0.81	0.96	1.00	0.99	0.98
Regression with interest rates	0.80	0.97	0.99	1.00	0.98
Same with interest rates and money	0.82	0.95	0.98	0.98	1.00

SOURCE: Author's calculations.

significant in all of the models. Indeed, the correlation among fitted values cannot be distinguished from the results presented in table 4. This is consistent with results reported by Fama (1982), who finds that interest rates contain most of the information about expected inflation that may be extracted from the history of money and output.

IV. Correlation among Forecasts from Different Methodologies

The results discussed above concern the correlation among the predicted values of different inflation series obtained with a specific econometric methodology. Inspection of the predicted values for a given series and different methodologies suggests that three observations are in order. First, the inflation forecasts from the different models are highly correlated; they appear to be tracking a common element. Second, the forecasts track each other more closely than they track actual inflation, consistent with my interpretation of the inflation series as signal plus noise. Third, the forecasts that incorporate interest-rate data are both more accurate than the forecasts generated by the time series model and more highly correlated with each other than with the time series model. Although table 5 describes the correlation among forecasts only for the CPI, similar results obtain for the other price series.

V. Hamilton's Model

A potential shortcoming of the econometric methodologies that I have considered is the extremely simple dynamics that are imposed on expected real interest rates and expected inflation in order to identify these components of the nominal rate process. Hamilton (1985) has proposed and estimated a model that permits richer dynamics in both components, and formalizes the intuition that the observed rate is equal to a signal (expected inflation) plus noise. The model, which contains the random-walk formulation (6) as a special case, assumes that the following relations among inflation, expected inflation, and real interest rates are stable over time:

$$(9)\quad \hat{r}(t) = k_r + \Phi(L)\,\hat{r}(t) + \Psi(L)\,\hat{\pi}(t) + \xi(L)\,\pi(t) + \varepsilon_r(t),$$

$$(10)\quad \hat{\pi}(t) = k_\pi + \alpha(L)\,\hat{r}(t) + \beta(L)\,\hat{\pi}(t) + \gamma(L)\,\pi(t) + \varepsilon_\pi(t),$$

$$(11)\quad \pi(t) = \hat{\pi}(t) + e(t).$$

Expected real rates and expected inflation are described by linear projections of these variables on their own past values and on the past values of actual inflation. The difference between expected inflation and actual inflation is a noise term, as in the simpler models discussed above. These assumptions, along with the assumption that the nominal rate is equal to the real rate plus the expected inflation rate, are sufficient to identify expected real rates and expected inflation. Note that equations (9) and (10), like equations (7) and (8), are statistical models of the relationships among these variables; there is no presumption that the lag polynomials $\Phi(L)$, $\psi(L)$, $\xi(L)$, $\alpha(L)$, $\beta(L)$, and $\gamma(L)$ represent the decision rules that agents use to form expectations about real rates and inflation.

Hamilton's model enjoys a second advantage relative to the simple models in addition to encompassing a wider variety of time series behavior. In equations (9), (10), and (11), the distinction between errors in expectations and errors that result from the econometrician's inability to observe expected real rates or expected inflation is modeled explicitly. The error terms ε_r and ε_π represent innovations in the expected real rate and expected inflation rate that are not captured by the linear projections of equations (9) and (10). These innovations arise because

TABLE 6

The Correlation among Expected Quarterly Inflation Rates Generated by Hamilton's Kalman Filter Model of Expected Inflation and Interest Rates

	CPI	CPIS	PPI	PPIWF	PCEDEF
CPI	1.00	0.57	0.40	0.57	0.60
CPIS	0.57	1.00	0.51	0.69	0.69
PPI	0.40	0.51	1.00	0.65	0.62
PPIWF	0.57	0.69	0.65	1.00	0.85
PCEDEF	0.60	0.69	0.62	0.85	1.00

SOURCE: Author's calculations.

we are unable to observe expectations. The error term $e(t)$ represents the difference between what agents thought would occur and what did in fact occur. Estimation of these parameters allows us to evaluate explicitly the contribution of these different sources of noise to the difference between expected inflation and actual inflation, making it unnecessary to assign an economic interpretation to the moving-average parameter in a time series model.

The estimated series are consistent with those produced by the other econometric models, in that innovations in the inflation rates appear to contain a substantial noise component.[10] One indicator of this phenomenon is the set of coefficients that represents the projection of expected inflation onto past values of inflation and expected inflation. In general, the sum of the coefficients for the four lagged values of expected inflation tends to be near one, while the sum of the coefficients for the four lagged values of actual inflation tends to be near zero. At the first two lags, the effect is even stronger; estimated parameter values imply that inflationary expectations tend to persist, while inflationary shocks tend to be reversed. This pattern, which is consistent with the time series properties of the errors in the simpler econometric models, is characteristic of all of the series except for the PCE deflator.[11] It suggests that expectations of inflation tend to persist, even in the face of significant changes in the current inflation rate.

A second indicator of the noise in the series for realized inflation is the fraction of the variation in the inflation rate accounted for by the expectation error series $e(t)$. This ranges from 20 percent in the case of the PCE deflator to 60 percent in the case of the PPI.

The expected inflation series from Hamilton's model differ from the estimates produced by the simpler econometric models in one important respect: The substantial increase in the number of explanatory variables yields a significant improvement in fit. As a result, the predicted values bear a stronger resemblance to the actual values and a weaker resemblance to each other. This fact is evidenced by the correlation among predicted values described in table 6.

VI. A Multiple Indicator Model

A multiple indicator model based on Hamilton's methodology incorporates the flexible dynamics of that model, but focuses on the common component of the different series rather than on the expected component of a particular series. Interest rates and a set of realized inflation series are driven by a single expected inflation series. This series is distinguished from the expected inflation series generated by Hamilton's model in that it provides information about pervasive price growth rather than about the behavior of a particular index.

I estimate the model by projecting expected inflation and the expected real interest rate onto their own past values and onto past values of the PPI. The realized values of the PCE deflator and the CPI both serve as indicators of the core rate. The realized value of inflation for each index is presumed to be equal to expected inflation plus a noise term.

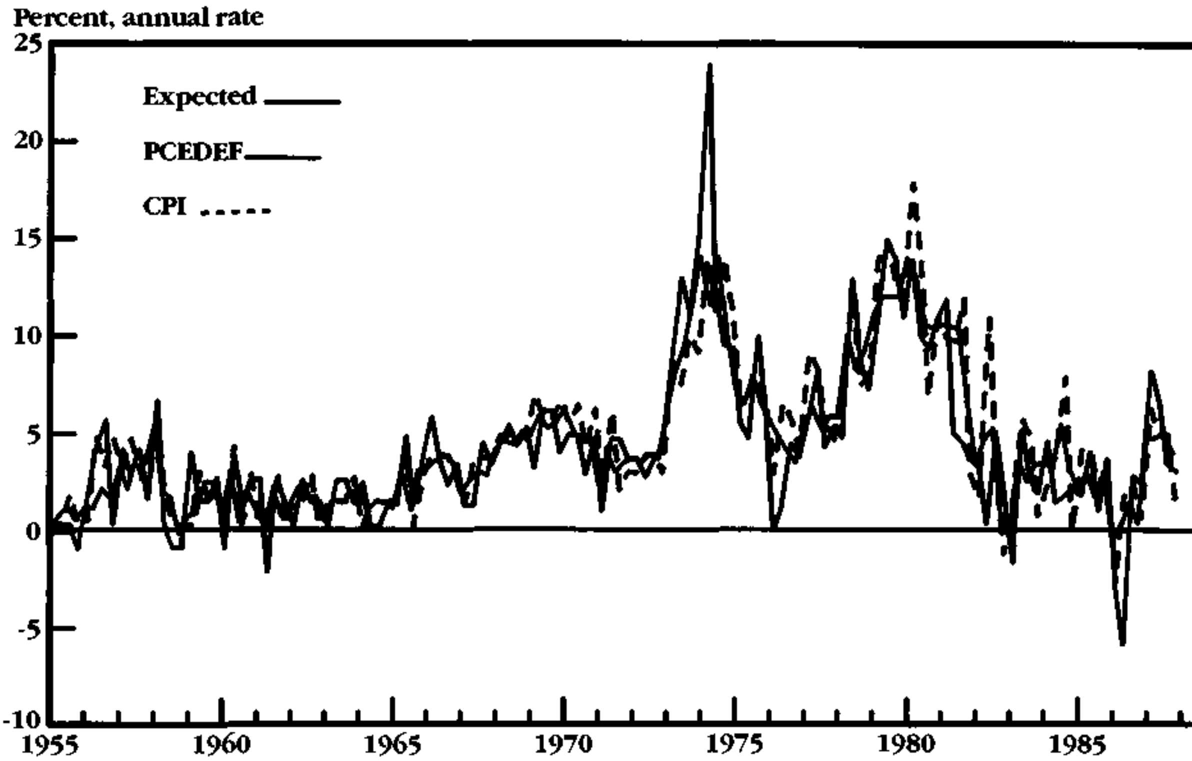
The expected inflation series for this model is presented in figure 2, along with the actual series for the CPI and the PCE deflator. Expected inflation exhibits the same time-series properties as do the individual series described above. Innovations in realized inflation are reflected only weakly in current expected inflation, which nonetheless displays a great deal of persistence.

10 I estimate the state space version of the model described in Burmeister, Wall, and Hamilton (1986). By doing so, I avoid dealing with the moving-average error terms that characterize the earlier formulation.

11 My estimates for the deflator series are qualitatively similar to those reported by Hamilton (1985) and Burmeister, Wall, and Hamilton (1986).

FIGURE 2

Expected and Realized Inflation, 1955 - 1987



SOURCES: U.S. Department of Commerce, Bureau of Economic Analysis, and U.S. Department of Labor, Bureau of Labor Statistics.

VII. Conclusion

Inflation targets may contribute significantly to the credibility of a monetary policy that is oriented toward controlling inflation. A potential problem with inflation targets is that inflexible rules would couple money growth to random shocks in the price level; the substantial noise in individual inflation series suggests that this concern is more than academic. Building flexibility into policy rules is one means of dealing with this problem, but flexibility tends to undermine the credibility of the commitment to control inflation. An inflation target that filters out these transient shocks, combined with a tight feedback rule from the filtered inflation rate to money growth, is an alternative that maintains credibility while mitigating the problems associated with noise in the policy targets.

Expected inflation is an indicator of the pervasive price growth, or core inflation, that interests the architects of monetary policy. The correlation among expected inflation rates from different price series and forecast methodologies suggests that these series are tracking the core rate. Signal extraction models formalize this intuition. Policy rules linked to the expected inflation series from any of the econometric models examined here are both forward-looking and reasonably insulated from index-specific shocks. Moreover, such broadly based targets would be difficult to manipulate. All of these properties suggest that expected inflation may serve as an effective guide to monetary policy.

References

Ansley, Craig F. "Signal Extraction in Finite Series and the Estimation of Stochastic Regression Coefficients," Washington, D.C.: American Statistical Association, Proceedings of the Business and Economic Statistics Section, 1980.

Burmeister, Edwin K., Kent D. Wall, and James D. Hamilton. "Estimation of Unobserved Expected Monthly Inflation Using Kalman Filtering," *Journal of Business and Economic Statistics*, vol. 4, no. 2 (April 1986), pp. 147–60.

Fama, Eugene F. "Inflation, Output, and Money," *Journal of Business*, vol. 55, no. 2 (April 1982), pp. 201–31.

________, and Michael R. Gibbons. "A Comparison of Inflation Forecasts," *Journal of Monetary Economics*, vol. 13, no. 3 (May 1984), pp. 327–48.

________, and ________. "Inflation, Real Returns, and Capital Investment," *Journal of Monetary Economics*, vol. 9, no. 2 (May 1982), pp. 297–323.

Hamilton, James D. "Uncovering Financial Market Expectations of Inflation," *Journal of Political Economy*, vol. 93, no. 6 (December 1985), pp. 1224–41.