MONETARY AND NON-MONETARY SOURCES OF INFLATION: AN ERROR CORRECTION ANALYSIS

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The economic events of the past two decades have done a great deal to discredit the old monetarist dictum, that inflation is "always and everywhere a monetary phenomenon." First, the oil shocks of 1973 and 1979 reminded economists that major shifts in relative prices can be associated with large, if transitory, inflation shocks. Second, in spite of the rapid growth of many monetary aggregates, the early 1980s saw an abrupt reduction in the rate of inflation in conjunction with the deepest recession since the 1930s.

These episodes have underscored the importance of three distinct, if interrelated, sources of inflation: first, the monetary effect; second, the demand side effect represented by the Phillips Curve; and third, the price level adjustment resulting from exogenous supply shocks, or shifts in the terms of trade.

This is not to say that the three mechanisms operate independently of one another, however. A given increase in the stock of money may raise the price level directly (for example, in the context of a rational expectations model in which agents directly observe the money supply), and indirectly through a Phillips Curve mechanism, as in textbook IS-LM models, or a rational expectations model with a Lucas supply curve. Furthermore, while these mechanisms may be conceptually distinct, in practice it may be difficult to identify their *structural* coefficients, owing to contemporaneous feedback into the monetary aggregates through money supply rules.[1]

An additional important relationship is the interaction between real output and the money supply implicit in the Quantity Equation, $MV = PX$, where P is the price level, X real output, M the money supply, and V the velocity of circulation. On one hand, the Phillips Curve relation implies that an increase in real output above the full employment level is inflationary. On the other hand, an increase in real output, *ceteris paribus*, is deflationary from a monetary perspective; with M and V held constant, an increase in X implies a lower P.

In fact, if this deflationary effect exactly equals the inflationary effect implied by the Phillips Curve, then the net effect of that change in real output will be zero; the level of output will be irrelevant to the determination of inflation and the price level. The money stock becomes the sole determinant (apart from any supply shocks) of the price level.

It is this idea which motivated the recent paper by Jeffrey Hallman, Richard Porter and David Small (1989).[2] Their paper (referred to subsequently as the HPS study) proposes and estimates an error-correction model of inflation in which the inflationary and deflationary effects of output changes exactly cancel, leaving a variable labelled p^* as the sole determinant of inflation. Because p^* depends only on M2 and potential GNP (adjusted by the mean velocity of M2), this specification reasserts the purely monetary nature of inflation.

This paper uses a comparable error-correction framework to conduct a more thorough analysis of the dynamics of monetary-based inflation, comparing them with those stemming from Phillips Curve effects. In particular, it scrutinizes both the empirical and theoretical basis for the p^* specification in the HPS study.

Our main empirical finding is to reject the p^* specification in favor of a similar, but less restrictive, error correction model, embodying distinct dynamic responses to money supply and real output changes. By allowing the real and monetary responses to differ, the alternative model does not allow the two inflationary sources to be combined into a single variable, as they were under the p^* restrictions. The practical significance of this finding is to uphold the importance of real GNP (or its deviation from its potential) as an important short-run determinant of inflation.

Specifying an error correction inflation model

The attractiveness of the error correction models advanced by Davidson *et al.* (1978) is their ability to integrate a certain amount of theoretical content with a flexible dynamic adjustment process, which can be freely estimated. Suppose theory suggests that two variables, y and y^*, obey an equilibrium relationship $y = y^*$. If an error correction mechansim exists, then the deviation of y from its equilibrium y^* will predict subsequent movements in y. Such a mechanism can be written as:

$$\Delta^k y_t = A(L)(y^*_{t-1} - y_{t-1}),$$

where L is the lag operator, Δ is the difference operator $(1 - L)$, and $A(L)$ is a polynomial in the lag operator representing the adjustment dynamics.

The case of money and the price level is an obvious candidate for such a long-run equilibrium relationship. No economist would argue with the proposition that over a sufficiently long horizon, the price level will be proportional to some appropriately measured monetary aggregate. (The debate instead tends to focus on the direction of causality between money and nominal income, or the "measurability" and stability of the appropriate money supply concept in the presence of financial system innovation.)

This observation suggests that an error correction mechanism may be operating between either between money and nominal income, or between money and the price level, or both.[3] The obvious starting point is the logarithmic form of the Quantity Equation, where lower case letters denote logarithms:

$$p_t + x_t = m_t + v_t.$$

Unlike the other monetary aggregates, the M2 velocity has (since 1955, at least) tended to revert to its historical mean, $\bar{v}$.[4] This fact suggests using M2 to construct an "equilibrium" price level, $\bar{p}$, implied by a given stock of M2 and real output, corresponding to the steady-state velocity of M2, $\bar{v}$:

$$\bar{p}_t \equiv m_t - x_t + \bar{v}.$$

If p indeed tends to return to $\bar{p}$ over time, then an appropriate error correction specification would be in terms of the deviation of p from $\bar{p}$. Thus, a plausible error correction model of price adjustment would be:

$$\Delta^k p_t = A(L)(\bar{p}_{t-1} - p_{t-1}).$$

While this addresses the monetary side of the story, one might also want to include other factors contributing to inflation. One obvious additional factor is the effect of demand pressure on prices, falling under the Phillips Curve rubric. The natural specification for this demand pressure is in terms of the gap between the unemployment rate and the "natural" rate of unemployment. Alternatively, because most measures of potential output rely on some form of Okun's Law, one can recast the unemployment gap in terms of the difference between (the log of) actual output, x, and potential output, $\bar{x}$.

As the employment or output gap is not a function of the price level, it would be considered exogenous in the context of this single equation model. With its inclusion, the error correction specification becomes:

$$(1) \qquad \Delta^k p_t = A(L)(\bar{p}_{t-1} - p_{t-1}) + B(L)(x_{t-1} - \bar{x}_{t-1})$$

where $B(L)$ is another polynomial in the lag operator, reflecting the adjustment dynamics specific to the exogenous output gap term.

With the general form of an error correction equation in hand, one part of the search for an appropriate inflation model requires finding the right k, the degree of differencing of p, which determines the model's steady state properties and its potential for oscillatory behavior. These issues will be discussed later in the paper; the next section is concerned with the search for the appropriate lag polynomials $A(L)$ and $B(L)$.

Deriving the p^* specification

Before considering the properties of general error correction model in Equation 1, we turn to a discussion of the restrictions required to deliver the p^* model.

One starts by noting that because $\bar{p}$ is a function of real output, x implicitly appears in the error correction term, $(\bar{p}_{t-1} - p_{t-1})$, as well as the output gap term $(x_{t-1} - \bar{x}_{t-1})$. This means that the model, as it stands, is not closed; in order to forecast future inflation, one must also know the trajectory of x. Alternatively, from the monetary authority's point of view, controlling m is not sufficient to achieve a given target price level, or target rate of inflation.

But what if it were true that $A(L)$ and $B(L)$ were equal, implying identical price level responses to both $(\bar{p}_{t-1} - p_{t-1})$ and $(x_{t-1} - \bar{x}_{t-1})$? If so, then the two terms could be combined into one:

$$\Delta^k p_t = A(L)[(\bar{p}_{t-1} - p_{t-1}) + (x_{t-1} - \bar{x}_{t-1})].$$

Recalling that $\bar{p}_t \equiv m_t - x_t + \bar{v}$, the output terms cancel, leaving:

$$\Delta^k p_t = A(L)[m_{t-1} - \bar{x}_{t-1} + \bar{v} - p_{t-1}], \text{ or}$$
$$= A(L)(p^*_{t-1} - p_{t-1}),$$

where $p^*_t \equiv m_t - \bar{x}_t + \bar{v}$. Thus, M2 per unit of *potential* GNP becomes the sole anchor for the price level. Because of this cancellation, actual GNP (or its divergence from potential GNP) is completely irrelevant to inflation.

Imposing $A(L) = B(L)$ is only the first step towards the p^* specification; the second is to choose $k = 2$,

$$\Delta^2 p_t = A(L)(p^*_{t-1} - p_{t-1}),$$

so that the *change* in inflation is a function of the gap between p and p^*. The motivation for choosing $k = 2$ comes from the familiar inflation-augmented Phillips Curve story,

$$\Delta p_t = \theta(x_{t-1} - \bar{x}_{t-1}) + (\Delta p_t)^e,$$

where $(\Delta p_t)^e$ is the expected rate of inflation, and θ is a positive constant. A naïve, but tractable, version of this equation can be obtained by assuming $(\Delta p_t)^e = \Delta p_{t-1}$; that is, setting tomorrow's expected inflation equal to today's rate of inflation. Consistent with elementary textbooks' discussion of the "Non Inflation Accelerating Rate of Unemployment," this yields the change in the rate of inflation as a function of the output gap.

Unlike the Phillips Curve effect, in which the expectations term motivates the second difference specification, no theoretical reason exists for assuming that the *change* in inflation depends on the gap between $\bar{p}$ and p. Although the *a priori* specification of second differences is arbitrary, there is also no theoretical reason to rule it out. Here, economic theory provides no guide for specifying the degree of differencing — that remains an issue for empirical testing.

The third and final step in deriving the p^* model is to add dummy variables to capture the effects of petroleum price shocks and the Nixon Administration's wage-price controls. Combining these dummies into a single column vector, d_t produces the final form of the p^* model:

$$C(L)\Delta^2 p_t = \alpha\,(p^*_{t-1} - p_{t-1}) + d_t'\gamma, \tag{2}$$

where γ is the column vector of coefficients on those dummy variables.

Testing the p^* restrictions

Thus, the two key assumptions underlying the p^* model are: first, identical dynamics on $(\bar{p}_{t-1} - p_{t-1})$ and $(x_{t-1} - \bar{x}_{t-1})$; and second, the second-differenced specification. This section subjects those restrictions to a variety of tests to determine to what extent they are supported by the data.

We begin with a transformed version of Equation 1, which includes a white noise error term, ε_t, and the set of dummy variables introduced above, d_t:

$$\begin{aligned} C(L)\Delta^2 p_t =\, &\alpha_1(\bar{p}_{t-1} - p_{t-1}) + \alpha_2(\bar{p}_{t-2} - p_{t-2}) + \\ &\beta_1(x_{t-1} - \bar{x}_{t-1}) + \beta_2(x_{t-2} - \bar{x}_{t-2}) + d_t'\gamma + \varepsilon_t. \end{aligned} \tag{3}$$

This equation is therefore equivalent to the original error correction model of Equation 1, in which $A(L)$ and $B(L)$ are rational transfer functions of the form $(\alpha_1 + \alpha_2 L)C^{-1}(L)$ and $(\beta_1 + \beta_2 L)C^{-1}(L)$, respectively.

The expanded equation generalizes the specification in HPS by including an additional lag of $(\bar{p}-p)$ and $(x-\bar{x})$. Including $(\bar{p}_{t-2} - p_{t-2})$ and $(x_{t-2} - \bar{x}_{t-2})$ as additional regressors makes possible a more general test of the various restrictions imposed by the p^* specification. Specifically, that specification requires that:

$$\alpha_2 = \beta_2 = 0 \text{ and } \alpha_1 = \beta_1,$$

which reduces Equation 3 to the p^* model in Equation 2.

In contrast, the narrower HPS test of the p^* model entails simply including in the regression an additional lagged inflation term:

$$C(L)\Delta^2 p_t = \alpha\,(\bar{p}_{t-1} - p_{t-1}) + \beta(x_{t-1} - \bar{x}_{t-1}) + d_t'\gamma + \zeta\Delta p_{t-1} + \varepsilon_t.$$

Performing a test of the joint hypothesis that $\zeta = 0$ and $\alpha = \beta$, the failure to reject is interpreted as support for the p^* specification.

The important thing to note is that the HPS test is performed under the maintained assumption that the lag structures on the $(\bar{p}-p)$ and $(x-\bar{x})$ terms are identical, and therefore tests only the degree of differencing, k. In the context of Equation 3, this corresponds to imposing $\alpha_2 = \beta_2 = 0$. The results which follow demonstrate the misleading consequences of this arbitrary assumption.

Table 1 displays the OLS estimates of Equation 3 (and variations on it) from 1955:1 through 1988:1. Because this first set of regressions is designed to facilitate comparison with the original HPS results, it follows their procedure by including four lags of $\Delta^2 p_t$ as regressors, and by using the same measure of potential GNP.[5] Also following HPS, these regressions use the implicit GNP deflator price series, and the oil shock and price control dummy variables, ΔOS_1 and $(PC_1 - PC_2)$.

The t-statistics associated with the coefficients on $(\bar{p}_{t-2} - p_{t-2})$ and $(x_{t-2} - \bar{x}_{t-2})$ lend weak support to their exclusion from the equation, with the additional lags significant at the 12% and 7% levels, respectively. More informative are the relative sizes of the point estimates of the coefficients on $(\bar{p}_{t-1} - p_{t-1})$ and $(\bar{p}_{t-2} - p_{t-2})$; equal to 0.101 and -0.091 respectively, they are nearly equal in size and opposite in sign.

This observation suggests the specification in Column (b) of Table 1. This regression is identical to the regression in Column (a), but reparameterized in terms of $\Delta(\bar{p}_{t-1} - p_{t-1})$, $(\bar{p}_{t-1} - p_{t-1})$, $\Delta(x_{t-1} - \bar{x}_{t-1})$ and $(x_{t-1} - \bar{x}_{t-1})$. There, although the t-statistic on $\Delta(\bar{p}_{t-1} - p_{t-1})$ remains a marginal 1.6, the t-statistic associated with $(\bar{p}_{t-1} - p_{t-1})$ falls to only 0.8. Once $\Delta(\bar{p}_{t-1} - p_{t-1})$ is included in the regression, therefore, the effect of $(\bar{p}_{t-1} - p_{t-1})$ in levels becomes insignificant.

For comparison purposes, the third column in Table 1 imposes the p^* restrictions discussed above, and embodied in Equation 2. As this regression uses the same data, sample, and specification, the results are identical to those reported in the HPS study.

The fourth column of Table 1 presents the estimates of an alternative model,

$$(4) \qquad C(L)\Delta^2 p_t = \alpha\,\Delta(\bar{p}_{t-1} - p_{t-1}) + \beta_1(x_{t-1} - \bar{x}_{t-1}) + \beta_2(x_{t-2} - \bar{x}_{t-2}) + d_t'\gamma + \varepsilon_t,$$

inspired by the observation that the data favored a model in which $(\bar{p}_{t-1} - p_{t-1})$ entered only in first differences. Of course, because this model embodies distinct lag structures on $(\bar{p}_{t-1} - p_{t-1})$ and $(x_{t-1} - \bar{x}_{t-1})$, it is not possible to combine the two into the single p^* as it was under the HPS restrictions.

Table 2 contains results of formal F tests of the p^* restrictions in the context of Equation 3. The F tests of the first two exclusion restrictions are equivalent to t tests based on the information in Table 1. The third test is for the joint exclusion

Table 1

Estimates of a Generalized Error-Correction Mechanism

Regressor		Unrestricted (a)	Unrestricted (b)	Restricted p^* Model	Restricted Alternative
1	$(\bar{p}_{t-1} - p_{t-1})$	0.1011 (2.0)	0.0104 (0.8)	...	...
2	$(\bar{p}_{t-2} - p_{t-2})$	-0.0907 (1.6)	...	...	...
3	$\Delta(\bar{p}_{t-1} - p_{t-1})$	...	0.0907 (1.6)	...	0.1171 (2.6)
4	$(p^*_{t-1} - p_{t-1})$	...	...	0.0312 (4.2)	...
5	$(x_{t-1} - \bar{x}_{t-1})$	0.1453 (2.4)	0.0411 (3.5)	...	0.1733 (3.7)
6	$(x_{t-2} - \bar{x}_{t-2})$	-0.1042 (1.8)	...	...	-0.1305 (2.9)
7	$\Delta(x_{t-1} - \bar{x}_{t-1})$	...	0.1042 (1.8)	...	...
8	$\Delta^2 p_{t-1}$	-0.6308 (6.5)		-0.7002 (8.4)	-0.6052 (6.6)
9	$\Delta^2 p_{t-2}$	-0.4489 (4.2)		-0.5083 (5.5)	-0.4264 (4.1)
10	$\Delta^2 p_{t-3}$	-0.3140 (3.1)		-0.3563 (3.9)	-0.2987 (3.0)
11	$\Delta^2 p_{t-4}$	-0.1131 (1.4)		-0.1380 (1.8)	-0.1046 (1.3)
12	ΔOS_1	0.0060 (2.2)		0.0059 (2.2)	0.0061 (2.3)
13	$(PC_1 - PC_2)$	-0.0038 (3.5)		-0.0032 (3.1)	-0.0039 (3.6)
	$\bar{R}^2$	0.3825		0.3783	0.3846

Sample period is 1955:1 – 1988:1, quarterly data.

Absolute values of t-statistics appear in parentheses.

Table 2
F-Tests of the p^* Restrictions

	Restriction	DF	Statistic	P-Value
1	Excluding $\Delta(\bar{p}_{t-1} - p_{t-1})$	1	2.50	0.117
2	Excluding $\Delta(x_{t-1} - \bar{x}_{t-1})$	1	3.35	0.070
3	Restrictions (1) and (2) jointly	2	1.70	0.188
4	Equal coefficients on $(\bar{p}_{t-1} - p_{t-1})$ and $(x_{t-1} - \bar{x}_{t-1})$	1	2.44	0.121
5	Restrictions (1), (2) and (4) jointly	3	1.28	0.283

of $(\bar{p}_{t-2} - p_{t-2})$ and $(x_{t-2} - \bar{x}_{t-2})$. The fourth imposes an equality between the coefficient on $(\bar{p}_{t-1} - p_{t-1})$ and $(x_{t-1} - \bar{x}_{t-1})$, while the fifth combines these two sets of restrictions, yielding the p^* specification.

Using the GNP deflator series, the imprecision of the estimates of the lagged $(\bar{p}_t - p_t)$ coefficients makes it impossible to reject any of the joint hypotheses at traditional significance levels. (Results reported later in in the paper using other price indices do yield strong rejections of the p^* restrictions, however.) On the other hand, using the GNP deflator, it is also impossible to reject the restriction implied by the alternative model, with $(\bar{p}_{t-1} - p_{t-1})$ in differences. Nonetheless, a model selection process guided purely by the data and not by a set of priors favoring a particular model probably would have favored the alternative model over the p^* version.

This result creates a predicament common to a lot of empirical work in economics, in which the data lack sufficient power to formally reject on statistical grounds either of two (or more) competing models. One way out of this bind is to seek corroboration for one model or the other using other data — the CPI or PPI, for example. As reported later, doing so produces results unfavorable to the p^* specification.

If we insist on modelling the behavior of the GNP deflator, the dilemma persists. In some cases, this ambiguity may simply indicate that both models adequately describe the data, and differ little in their underlying structure and fundamental implications. The following section shows that this is not true in the case of the p^* and the alternative models — the two models' implications for inflationary dynamics differ considerably.

An analysis of error-correction dynamics

This section compares the properties of the p^* model with those of the alternative model, illustrating how seemingly small and innocuous changes in the specification can produce enormous differences in the medium- and long-run behavior of the models.

In analyzing the models, we consider two basic attributes. The first is the behavior of the steady-state error — the strength of the tendency for p_t to converge to its equilibrium level. The second property concerns the cyclicality, if any, of the adjustment to the new equilibrium — whether convergence is monotonic, or oscillatory.

Answers to both of these issues lie in the characteristics of the transfer functions relating the endogenous variable p_t to the exogenous forcing variables of the model. The next two subsections discuss how these properties can be divined from the model specification.

Steady-state properties

One very important feature of an error correction model is the "strength" — appropriately defined — of the mechanism bringing the endogenous variable back into equilibrium, and how that convergence depends on the characteristics of the equilibrium path. More concretely, the question is whether an error correction model implies a zero, constant, or diverging error in the face of a given pattern of growth of its equilibrium, or "target" level.

This issue was first introduced to the economics literature by Salmon (1982), who analyzed the steady-state properties of a class of error correction models in response to step function, linear growth, and quadratic growth patterns in the forcing variable. The discussion in this section parallels that in Salmon's paper, highlighting the results which are relevant for our analysis of the inflationary process.

The goal is to extract from the representation of the error correction mechanism the relevant measure of the strength of that mechanism. To that end, suppress the ε noise term, and rewrite the generic error correction model in Equation 1 as:

$$\begin{aligned} p_t &= \Delta^{-k} L A(L)(\bar{p}_t - p_t) + \Delta^{-k} L B(L)(x_t - \bar{x}_t) \\ &\equiv \Gamma(L)(\bar{p}_t - p_t) + \Theta(L)(x_t - \bar{x}_t), \end{aligned}$$

defining $\Gamma(L) \equiv \Delta^{-k} L A(L)$, and $\Theta(L) \equiv \Delta^{-k} L B(L)$, and solve for p_t:

$$p_t = \frac{\Gamma(L)}{1 + \Gamma(L)} \bar{p}_t + \frac{\Theta(L)}{1 + \Gamma(L)} (x_t - \bar{x}_t).$$

Table 3
Steady-State Error

Number of Unit Poles $(k-j)$	Type of Growth Path		
	Constant: $\bar{p}_t = \mu$	Linear: $\bar{p}_t = \mu t$	Quadratic: $\bar{p}_t = \mu t^2$
0	Constant	∞	∞
1	0	Constant	∞
2	0	0	Constant

Now, setting $(x_t - \bar{x}_t)$ equal to zero, the error can be written as a function of $\bar{p}_t$:[6]

$$e_t \equiv (\bar{p}_t - p_t) = \frac{1}{1+\Gamma(L)}\bar{p}_t.$$

The key to analyzing the steady-state behavior of the error lies in the transfer function $\Gamma(L)$, relating the level of the endogenous variable p_t to the error. In particular, the key is the number of unit roots, or poles, introduced into the denominator of the transfer function $\Gamma(z)$ by the differencing operation.

If the $A(L)$ polynomial contains no $(1-L)$ terms, then, as $\Gamma(z) = (1-z)^{-k}zA(z)$, the number of unit roots in the denominator of $\Gamma(z)$ simply equals k, the degree to which the endogenous variable is differenced on the left-hand-side of the error correction equation. However, the number of unit roots in Γ may be less than k if $A(L)$ also contains first difference terms, as in the "alternative" model advanced earlier. If $A(L)$ contains j (where $1 \leq j \leq k$) first difference terms, then $A(L) = (1-L)^j\tilde{A}(L)$. When multiplied by Δ^{-k}, j of those difference terms will cancel, leaving only $k-j$ unit poles in the denominator.

As demonstrated by Salmon, the number of unit poles, or *integral effects*, present in the error correction mechanism determines the relationship between the steady-state value of e_t and the path of $\bar{p}_t$. Specifically, invoking the Final Value Theorem of z-transforms,[7] one can find $\lim_{t\to\infty} e_t$ as a function of the number of unit poles and the type of growth of $\bar{p}$ (*i.e.*, step function, linear, quadratic, *etc.*).

Table 3, taken from Salmon (1982), summarizes the asymptotic properties of the steady-state error, according to the nature of the growth of $\bar{p}_t$ and the number of unit poles in Γ. Consider, for example, the conventional partial adjustment model

$$\Delta p_t = \phi(\bar{p}_{t-1} - p_{t-1}),$$

with a single unit pole in $\Gamma(z)$. According to the table, p will converge to $\bar{p}$, so long as $\bar{p}$ remains constant as $t \rightarrow \infty$. By contrast, if $\bar{p}$ is growing at a linear rate in the steady state, then the discrepancy between p and $\bar{p}$ will not vanish, but converge to a constant. To achieve convergence in *levels* with linear growth would require an additional integral effect, which would require specifying $\Delta^2 p_t$ as a function of $(\bar{p}_{t-1} - p_{t-1})$.

Cyclical properties

A second important consideration in the evaluation of dynamic models, like the error correction models discussed here, is their frequency domain properties. In particular, are the models characterized by instabilities which generate cyclical or pseudo-cyclical behavior? Or do the models imply a smooth, monotonic convergence of the endogenous variable to their steady-state values?

To address this question, consider a simplified version of the error correction model in Equation 3:

$$C(L)\Delta^k p_t = \phi(\bar{p}_{t-1} - p_{t-1}), \text{ or}$$

$$C(L)\Delta^k p_t + \phi p_{t-1} = \phi \bar{p}_{t-1},$$

where ϕ is a positive constant. The cyclical properties of this model are determined by the roots of the characteristic polynomial corresponding to the autoregressive terms in p_t, namely, the solutions to:

$$C(z)(1-z)^k + \phi z = 0.$$

Complex roots to this polynomial generally indicate pseudo-cyclical behavior.[8]

For well-behaved C(L) lag structures, an error correction mechanism in first differences (*i.e.*, $k = 1$) produces no oscillation. However, specifying the mechanism in *second* differences introduces the possibility of pseudo-cyclical behavior. A simple example will illustrate the effect of second differencing. Setting $k = 2$ and assuming $C(L) = 1$, the simplified version of Equation 3 reduces to:

$$\Delta^2 p_t = \phi(\bar{p}_{t-1} - p_{t-1}).$$

The roots of the characteristic equation $z^2 - (2-\phi)z + 1 = 0$ are:

$$\frac{2 - \phi \pm \sqrt{\phi(\phi - 4)}}{2},$$

which are complex for all ϕ implying convergence (between 0 and 4). By contrast, if $k = 1$, the single root is always real, equal to $(1-\phi)^{-1}$.

Evaluating the cyclical behavior of models with non-trivial lag structures $C(L)$ is considerably more complicated, however; as all of the models analyzed here take $C(L)$ to be a fourth-order polynomial, the relevant characteristic equations are sixth-order polynomials. Nonetheless, it is still possible to characterize the cyclical behavior of the models in the frequency domain by computing the models' frequency response functions. This will be the approach in the next two sections, which examine the models' cyclical behavior and steady-state properties.

Properties of the p^* model

As discussed above, the p^* model,

$$C(L)\Delta^2 p_t = \alpha(p^*_{t-1} - p_{t-1}) + d_t'\gamma,$$

restricts the general model in Equation 1 by imposing identical lag structures on the monetary and output gap terms, ruling out the possibility that the $(\bar{p}_{t-1} - p_{t-1})$ term may enter in differences, while the $(x_{t-1} - \bar{x}_{t-1})$ term enters in levels.

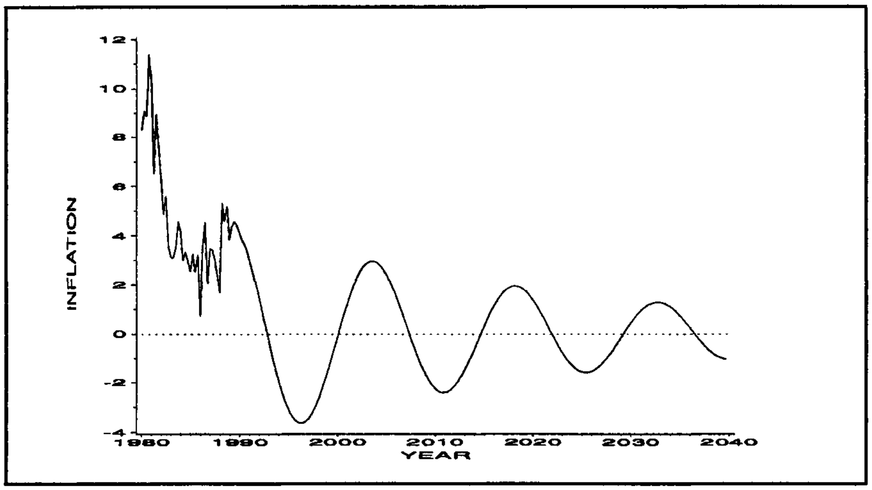
The combination of this restriction with the second-difference specification yields a model with two unit poles in the denominator of $\Gamma(z)$. This means that the model specification enforces the convergence of to p^* in the steady state when p^* follows a linear growth path, as is plausible in reality.

This powerful convergence property might be termed "strong-form" monetarism. It goes beyond asserting that *inflation* is always a monetary phenomenon, insisting that the price level itself is also determined solely by the money stock. Alternatively, it states that for non-accelerating price growth, there is no path dependence, or hysteresis, in the price level; the steady-state error will converge to zero, regardless of the path followed by potential GNP and the money stock. This property sqares with classical models of price level determination, in which the money stock uniquely determines the level of prices.

The cyclical properties of the p^* model are also rather distinctive. Figure 1 displays the simulated time paths of inflation generated by the p^* inflation model in response to a reduction in the rate of growth of M2 to a rate consistent with zero inflation (*i.e.*, equal to the assumed growth rate of potential real GNP of 2.5% per annum). The p^* model produces wide oscillations, with inflation fluctuating between -4% and 3%. Only slightly damped, these oscillations continue to display a sizeable magnitude for over a century.[9]

The reason for this cyclical behavior can be traced directly to the second-difference specification employed by the p^* model. Assuming that the *change* in the rate of inflation depends on $(p^*_{t-1} - p_{t-1})$ builds in an "accelerationist" dynamic — inflation does not abate when a balance is reached between p and p^*. Instead, it continues even after p reaches p^*, causing p to overshoot its target. Only once p exceeds p^* does inflation start to slow down. Although the specification that produced this behavior is not rejected (using GNP deflator data), it does conflict with most

Figure 1
Simulated Inflation Path — p* Model



economists' understanding of the inflation process — one simply doesn't observe the kinds of large swings in the inflation rate implied by the model.

This oscillatory pattern can be examined more precisely in Figure 2, which plots (in the frequency domain) the *gain* of the p^* model as a function of the period (in quarters) of an arbitrary input. The estimated values of α and the elements of the $C(L)$ lag polynomial are used for the computation.

The gain function shows a large peak corresponding to a period of approximately 60 quarters, implying that any input at that frequency is amplified tremendously, yielding an inflation rate with five-year cycles. No evidence of this kind of oscillation is found in spectrum of the GNP deflator inflation rate, shown in Figure 3.[10]

Properties of the alternative model

In contrast, the alternative model,

$$C(L)\Delta^2 p_t = \alpha\,\Delta(\bar{p}_{t-1} - p_{t-1}) + \beta_1(x_{t-1} - \bar{x}_{t-1}) + \beta_2(x_{t-2} - \bar{x}_{t-2}) + d_t'\gamma,$$

displays no such pseudo-cyclical properties. Figure 4 displays its simulated response to the same experiment depicted in Figure 1, in which M2 growth is set to a rate consistent with zero inflation in the steady state.[11] Again, the actual parameter estimates are used. In contrast to the p^* model, here the rate of inflation converges smoothly to its steady-state level of zero.

Figure 2
Amplitude Response of p* Model

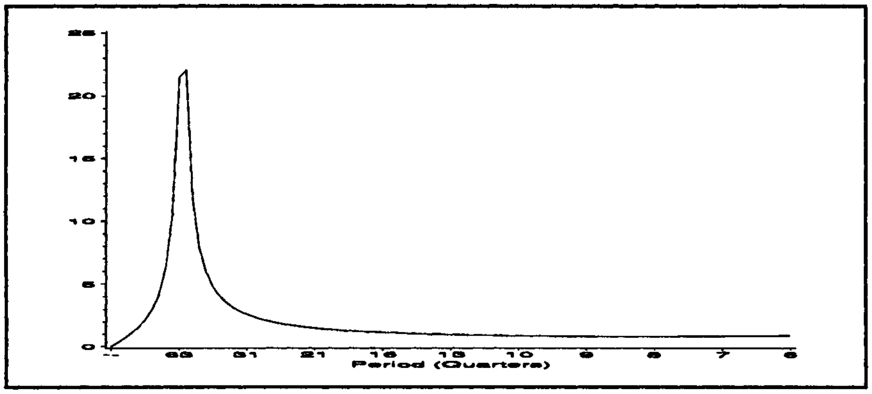
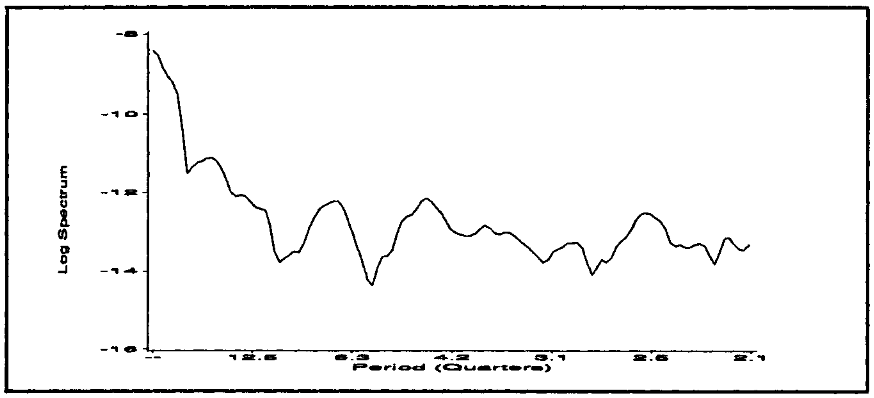


Figure 3
Log Spectrum of GNP Deflator Inflation



Again, examining the frequency domain properties of this model provides an alternative way of discerning the cyclical properties. As indicated by the plot of its gain function, shown in Figure 5, the alternative model displays no cyclical tendencies at all.

The steady-state properties of the alternative model also differ substantially from those of the p^* model. Because the $(\bar{p}_{t-1} - p_{t-1})$ term enters the alternative model in first differences, one finds only a single unit pole in the denominator of the transfer function Γ, compared with the two unit poles in the p^* model. This difference is

Figure 4

Simulated Inflation Path — Alternative Model

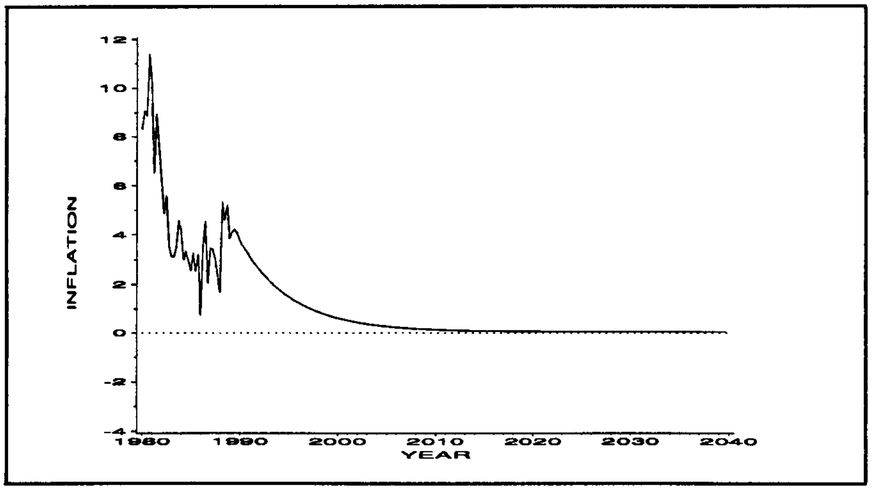
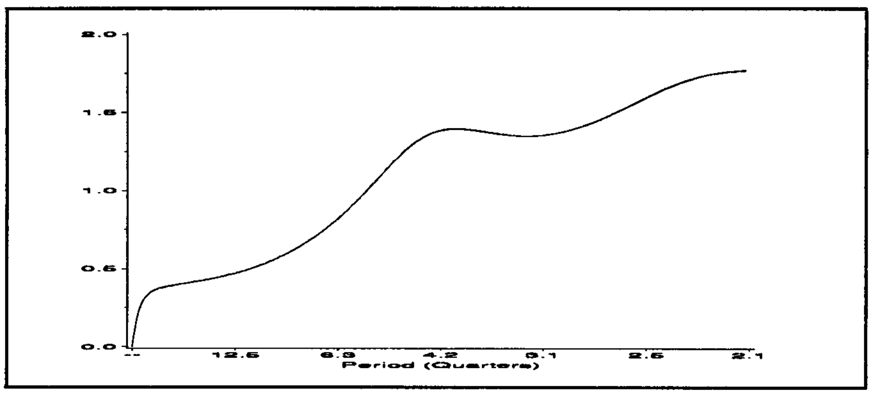


Figure 5

Amplitude Response of Alternative Model



what produces the contrasting steady-state behavior of p_t. Specifically, it implies that in the presence of a linearly growing $\bar{p}$, the error $(\bar{p} - p)$ will *not* converge to zero in the steady state. Instead, the error will converge to a constant which depends on the growth rate of $\bar{p}$ (which depends, in turn, on the growth rate of M2) and the speed of adjustment, α.

Another interpretation of the alternative model is as an error correction model between inflation and the growth rate of M2. A linear growth path of p implies a constant rate of inflation, so the alternative model does have the inflation rate converging in the steady-state to the growth rate of money.

This does not, however, imply that the price level p converges to the unique price level implicit in a given money stock and mean velocity. Because it takes some time for inflation to catch up to a change in the rate of money growth, a non-zero discrepancy between p and $\bar{p}$ may persist over time. In the quantity equation, this (constant) divergence would appear as a shift in the velocity of circulation. Therefore, it may be only coincidental that the M2 velocity has returned to its historical average over the past 33 years, owing to a fortuitous balancing of increases and decreases in the rate of M2 growth.

A model that displays this kind of price-level hysteresis in response to changes in the rate of money growth might be labelled "weak-form" monetarist. Here, inflation is indeed a monetary phenomenon in the long run, as it converges to the rate of money growth. But in the short run, there is considerable slack between the monetary aggregate and the price *level*. In fact, the precise value of the price level in the steady state will exhibit path dependence, and vary with the growth path followed by the money stock on the way to the steady state.

While it is impossible to formally dismiss either model on the basis of its steady-state properties or its cyclical dynamics, a consideration of these properties illuminates the radical differences implied by the subtle changes in their specification. Evaluating these properties in the light of theory, or independent pieces of evidence, can, therefore help to choose between statistically indistinguishable models.

In particular, one might be reluctant to insist on the p^* specification when it implies such large, underdamped oscillations in the inflation rate. On the other hand, the conflicting implications for the convergence of the price level to its equilibrium target should be borne in mind, and judged according to their congruence to formal theories of price level determination.

Oil shocks, price controls, and alternative price indices

This section analyzes the p^* and the alternative models using two additional price indices: the Consumer Price Index (CPI), and the final goods component of the Producer Price Index (PPI). Because the GNP deflator is a by-product of the construction of the real GNP figures, it reflects not only price changes, but also changes in the composition of GNP. The Bureau of Economic Analysis, recognizing its flaws, states that "its use as a measure of price change should be avoided."[12] This undesirable aspect of the GNP deflator suggests using the alternative price measures to check on the robustness of the original results.

Before beginning this comparison, one additional feature of the original p^* specification deserves closer scrutiny: the use of dummy variables to capture the effects of oil shocks and price controls. The following two sections are a short detour through this issue.

Dummy variables and oil price shocks

Using dummy variables to capture a shock present in a single time period introduces a danger of spurious correlation, or overfitting. Often, such dummy variables end up fitting a specific historical episode in a way that has no plausible economic interpretation.

A strong case can be made that the HPS oil shock dummies, OS_1 and OS_2, are guilty of this charge. The OS_1 variable is defined to equal unity in 1973:4, and zero elsewhere, and is supposed to capture the impact of the first oil shock. Likewise, the OS_2 variable, representing the second oil shock, is set equal to unity in 1979:4, and zero elsewhere. By including them in first differences, they would imply a once-and-for-all jump in inflation in the relevant quarter, and a once-and-for-all decline in the following quarter.

Stated in this way, it apparent that such a specification might fail to capture accurately the effects of the oil price shocks. First, most of the shocks' impact on the various price indices did not really appear until the following quarters. Second, such a one-time-only effect might not realistically reflect the dynamics through which oil price increases feed through to the prices of other goods. These reservations suggest that the oil shock dummies' significance may be spurious. One way to investigate this possibility is to estimate the oil shock effects using alternative price indices, such as the CPI and PPI.

Table 4 displays the results of estimating the p^* and the alternative models on the three alternative price indices: the GNP deflator (as in the original results), the CPI, and the PPI. The models include both ΔOS_1 and ΔOS_2, even though ΔOS_2 was deemed insignificant using the GNP deflator. For the sake of brevity, the table omits the estimates of the coefficients on lagged $\Delta^2 p_t$.

The results show that there is indeed good reason to suspect the validity of the oil shock dummies. While ΔOS_1 is statistically significant with the correct (positive) sign using the GNP deflator, it is statistically significant and *negative* when using the PPI, paradoxically indicating a deflationary effect. Similarly, ΔOS_2 is large and negative, and nearly statistically significant at the 10% level when using the CPI in the alternative model.[13]

Based on these results, we eliminate the oil shock dummies altogether in the regressions which follow. In place of the dummies, we include a direct measure of the price of crude petroleum.

Table 4

The Robustness of Oil Shock Dummies

	Regressor	p^* Model GNP	CPI	PPI	Alternative Model GNP	CPI	PPI
1	$(p^*_{t-1} - p_{t-1})$	0.0312 (4.2)	0.0231 (4.1)	0.0191 (3.0)	...	...	...
2	$(x_{t-1} - \bar{x}_{t-1})$	...	...	...	0.1758 (3.7)	0.2133 (5.3)	0.3237 (5.0)
3	$(x_{t-2} - \bar{x}_{t-2})$	...	...	...	-0.1329 (2.9)	-0.1703 (4.3)	-0.2603 (4.1)
4	$\Delta(\bar{p}_{t-1} - p_{t-1})$	...	...	...	0.1190 (2.6)	0.1429 (3.7)	0.1990 (3.7)
9	$(PC_1 - PC_2)$	-0.0032 (3.1)	-0.0025 (2.3)	-0.0048 (2.6)	-0.0039 (3.6)	-0.0036 (3.4)	-0.0072 (3.9)
10	ΔOS_1	0.0059 (2.2)	0.0003 (0.1)	-0.0209 (4.3)	0.0061 (2.3)	0.0002 (0.1)	-0.0202 (4.4)
11	ΔOS_2	-0.0005 (0.2)	-0.0029 (1.1)	0.0006 (0.1)	-0.0013 (0.5)	-0.0040 (1.6)	-0.0014 (0.3)
	$\bar{R}^2$	0.3735	0.2605	0.3308	0.3807	0.3407	0.4175

Absolute values of the *t*-statistics appear in parentheses.

What did price controls really accomplish?

The HPS price control dummies, PC_1 and PC_2, are subject to criticism on similar grounds. The PC_1 variable represents Phase I of the Nixon Adminstration's price control program, and equals unity from 1971:3 through 1972:4. Phase II is represented by the variable PC_2, and equals unity from 1973:1 through 1974:4.

Estimation using the GNP deflator produces a negative, statistically significant coefficient on $(PC_1 - PC_2)$, contrary to the widespread perception of the inefficacy of the controls. Combined with the second-difference specification, this result implies a *falling* (not just lower) rate of inflation under Phase I, and a *rising* (not just higher) rate of inflation under Phase II; inflation then falls back to the "normal" level (*i.e.*, driven entirely by lagged inflation changes and $(p^*_{t-1} - p_{t-1})$) at the end of Phase II. While attempting to model the impact of the Nixon Administration's

Table 5
The Robustness of Price Control Dummies

	Variables Significant at the 10% Level		
	GNP	CPI	PPI
p^* Model	$(PC_1 - PC_2)$	ΔPC_2	ΔPC_2
Alternative Model	PC_1 PC_2 ΔPC_2	PC_2	PC_2 ΔPC_2
Unrestricted Model	$(PC_1 - PC_2)$	PC_2	PC_2 ΔPC_2

wage-price control policies is certainly a worthwhile endeavor, the very odd estimated response to the controls suggests that the price control dummies may be capturing some other phenomenon.

As with the oil shock dummies, one possible check on the robustness of the results is to compare the results for alternative price indices. (If anything, due to the nature of the controls, the dummies should have an even stronger effect on the CPI inflation.) Table 5 displays a check on the robustness of the price control dummy variables. Versions of the p^* model, the alternative model, and the unrestricted model of Equation 3 were estimated on each of the three price indices. The table indicates which price control variables were individually statistically significant at the 10% level. The table shows no consistent pattern at all with regard to which price control dummies ought to be included in the regression. It is only with the GNP deflator that the PC_1 variable ever enters significantly. Yet, if PC_1 has an insignificant effect on inflation, it is not clear what role PC_2 has in the regression; one would imagine the Phase II relaxation to be inflationary only in relation to the Phase I controls.

Results with alternative price indices

Finally, after the foregoing examination of the performance of the oil shock and price control dummy variables, we are in a position to test the p^* model against the alternative using the CPI and PPI price series. These results differ substantially from those which used the GNP deflator; specifically, the p^* specification fails in the statistical tests which use the CPI and PPI.

In constructing a revised framework for estimating and testing the competing models, we draw on the results of the previous sections, which cast doubt on the oil shock and price control dummy variables as originally used. For lack of a satisfactory alternative to the price control dummies, we drop them from the regression. In lieu of the oil shock dummies, we model the inflationary impact of the oil shocks directly by including the change in oil price inflation, $\Delta^2 p^o_{t-s}$, as an additional exogenous variable:

$$C(L)\Delta^2 p_t = \psi_1(\bar{p}_{t-1} - p_{t-1}) + \psi_2\Delta(\bar{p}_{t-1} - p_{t-1}) + \beta_1(x_{t-1} - \bar{x}_{t-1}) + \beta_2(x_{t-2} - \bar{x}_{t-2}) + \sum_{s}^{S} \delta_s \Delta p^o_{t-s} + \varepsilon_t. \tag{5}$$

The oil price used is the crude petroleum component of the Producer Price Index.

One question about this specification is whether this second-differenced oil price ought to be considered contemporaneously exogenous, *i.e.*, uncorrelated with the noise term ε_t in the error correction model. If so, then current values of $\Delta^2 p^o$ can be included on the right-hand-side of Equation 5, and the index s runs from 0. If not, the appropriate procedure is to include only lagged (predetermined) oil prices, and s starts at 1.

To remain agnostic on this exogeniety issue, we estimate three versions of Equation 5: one with both current and lagged oil prices, the second with only lagged oil prices, and the third with no oil prices at all. The results of the F tests based on these regressions appear in Table 6. Starting from Equation 5, the p^* model and our alternative model can be represented by simple linear coefficient restrictions: $\psi_2 = \beta_2 = 0$ and $\psi_1 = \beta_1$. By contrast, the alternative model involves only a single restriction: $\psi_1 = 0$.

As shown on line 4 of the table, the joint p^* restrictions always fail at the 2% level (and usually at the 1% level) with the CPI and the PPI. Lines 1 through 3 show the results of the tests of the exclusion restrictions, $\psi_2 = 0$ and $\beta_2 = 0$, both individually and jointly. The form in which the oil price appears seems largely irrelevant to the test results. Only the GNP deflator results fail to reject the p^* restrictions; the GNP deflator data are unable to reject either hypothesis at the usual significance levels. In contrast, the statistics on line 5 are all too small to reject the alternative model's restriction, $\psi_1 = 0$, at the usual levels. The smallest P-value is 0.22.

Thus, the statistical tests of the p^* restrictions are highly sensitive to the choice of price index, passing with the GNP deflator, and failing with the CPI and PPI. Given the well-known peculiarities of the GNP deflator, a specification based on the GNP deflator results seems untenable.

Table 6

F-Tests of Alternative Inflation Models

Restriction	DF	No Oil Prices GNP	No Oil Prices CPI	No Oil Prices PPI	Lagged Oil GNP	Lagged Oil CPI	Lagged Oil PPI	Current & Lagged Oil GNP	Current & Lagged Oil CPI	Current & Lagged Oil PPI
1 Excluding	1	0.48	4.80	2.40	1.06	4.45	2.34	0.69	3.06	0.83
$\Delta(\bar{p}_{t-1} - p_{t-1})$		(0.49)	(0.03)	(0.12)	(0.31)	(0.04)	(0.13)	(0.41)	(0.08)	(0.36)
2 Excluding	1	0.72	8.01	7.02	1.12	7.29	6.20	0.87	6.50	5.68
$(x_{t-2} - \bar{x}_{t-2})$		(0.40)	(0.01)	(0.01)	(0.29)	(0.01)	(0.01)	(0.35)	(0.01)	(0.02)
3 Restrictions	2	0.36	4.10	3.53	0.62	3.78	3.19	0.45	3.26	2.88
1 and 2		(0.70)	(0.02)	(0.03)	(0.54)	(0.03)	(0.04)	(0.64)	(0.04)	(0.06)
4 p^* Model	3	0.42	3.50	4.05	0.52	3.65	4.08	0.46	3.80	4.23
		(0.74)	(0.02)	(0.01)	(0.67)	(0.01)	(0.01)	(0.71)	(0.01)	(0.01)
5 Alternative	1	1.54	0.83	0.90	1.12	0.58	0.81	1.19	0.35	0.62
Model		(0.22)	(0.36)	(0.34)	(0.29)	(0.45)	(0.37)	(0.28)	(0.55)	(0.43)

P-values appear in parentheses.

Table 7 presents the parameter estimates of what is, in light of the tests in Table 6, the preferred specification: the alternative model earlier, with $(\bar{p}_{t-1} - p_{t-1})$ in first differences. Taking a conservative approach to the exogeniety of the petroleum price, these regressions include only lagged oil prices.

The choice of price index seems to make very little difference in terms of the point estimates of interest; each index yields an estimate of the coefficient on $\Delta(\bar{p}_{t-1} - p_{t-1})$ very close to 0.1, with a slightly stronger effect found using the CPI. One striking aspect of these estimates is that although the alternative model in some sense embodies a weaker link between money and prices than the p^* model, the large coefficient on $\Delta(\bar{p}_{t-1} - p_{t-1})$ indicates a higher speed of adjustment to changes in the M2 growth rate. This more rapid adjustment is also reflected in the simulated inflation paths in Figures 1 and 4.

As with the earlier GNP deflator results, additional lags of $(x_t - \bar{x}_t)$ enter significantly in the regression. Comparing the magnitudes of the coefficients on $(x_t - \bar{x}_t)$, the strength of the Phillips Curve effect appears considerably stronger using the final goods PPI than with the other indices.

While the alternative model represents an improvement over the p^* specification, it is only a first step towards a satisfactory inflation model. One important check on it will be an analysis of its out-of-sample forecasting performance. In addition,

Table 7
Estimates of the Preferred Specification

Regressor		Price Index GNP	CPI	PPI
1	$\Delta(\bar{p}_{t-1} - p_{t-1})$	0.0953 (2.1)	0.1034 (2.7)	0.1087 (1.9)
2	$(x_{t-1} - \bar{x}_{t-1})$	0.1374 (2.9)	0.1699 (4.3)	0.2711 (3.9)
3	$(x_{t-2} - \bar{x}_{t-2})$	-0.0969 (2.1)	-0.1287 (3.2)	-0.2077 (3.1)
4	$\Delta^2 p_{t-1}$	-0.5200 (5.3)	-0.2838 (3.0)	-0.5264 (5.0)
5	$\Delta^2 p_{t-2}$	-0.3171 (2.9)	-0.3416 (3.3)	-0.3138 (2.8)
6	$\Delta^2 p_{t-3}$	-0.2816 (2.7)	-0.1542 (1.7)	-0.0544 (0.5)
7	$\Delta^2 p_{t-4}$	-0.0624 (0.8)	-0.0231 (0.3)	-0.0632 (0.7)
8	$\Delta^2 p^o_{t-1}$	-0.0101 (2.1)	0.0081 (1.8)	0.0184 (2.0)
9	$\Delta^2 p^o_{t-2}$	0.0073 (1.5)	0.0151 (3.2)	0.0073 (0.8)
	$\bar{R}^2$	0.3357	0.3336	0.2744

Sample period is 1955:1 – 1988:1, quarterly data.
Absolute values of the t-statistics appear in parentheses.

it retains certain unsatisfactory *ad hoc* aspects which deserve more thoughtful consideration.

One of these is the naïve modelling of inflationary expectations in the Phillips Curve portion of the model. Another is the crude way of introducing the effects of exogenous supply shocks. Through an aggregate cost or price function, it may be possible to motivate another error correction term incorporating the oil supply price as one of the inputs. Furthermore, by re-introducing real GNP as a determinant of inflation, the alternative model is not closed, but requires an additional equation relating real output to a set of exogenous variables, including money. Clearly, more work remains.

Conclusions

There is little doubt that some monetary aggregate — appropriately measured — is an important long-run determinant of inflation and the price level. Inspired by the apparent stability of the M2 velocity for the past 33 years, Hallman, Porter and Small propose and estimate an error correction model whose sole exogenous variable is p^*, a function of only M2 and potential GNP.

The first section of this paper showed how the p^* restrictions are equivalent to requiring that the output gaps and money supply changes affect prices in exactly the same way. The main finding of this paper is that these p^* restrictions are suspect on two grounds. As shown earlier, they produce implausible, underdamped oscillations in the price level and inflation. Second, they can be rejected outright in direct statistical tests of a generalized specification, when the Consumer Price Index or the Producer Price Index is used as the price variable. These results appeared in the second main section of the paper.

The acceptance of the p^* specification, therefore, depends both on the use of the GNP deflator, and on a specific set of maintained assumptions within which the HPS model selection process proceeded. A careful analysis of the error correction mechanism between the price level and M2 shows that the inflationary effects of an increase in the money stock differ qualitatively from those resulting from an output gap. It therefore seems inappropriate to combine the two in a way that makes p^* (and implicitly M2) the *only* determinant of inflation.

Despite the sharp differences between the p^* model and the alternative, their policy implications are not fundamentally dissimilar. Assuming that the observed empirical relationship between M2 and prices continues to endure, both establish a link between long-run inflation and the growth rate of the money stock. What distinguishes the alternative model is its separate inclusion of the output gap as an additional, distinct source of inflation. Because of this additional factor, it suggests that controlling M2 is a necessary, but insufficient, condition for controlling inflation.

Footnotes

1. See Cooley and LeRoy (1985).

2. "M2 per Unit of Potential GNP as an Anchor for the Price Level," Board of Governors of the Federal Reserve System Staff Study #157.

3. More specifically, if money and income are integrated random variables while velocity is stationary, an error correction mechanism can be shown to exist. See Engle and Granger (1987).

4. Friedman and Kuttner (1989) examine the behavior of the aggregates' velocities, finding that the recent deterioration of the M2 velocity has been mild compared with that of the other aggregates.

5. The relevant measure is the series constructed by staff members of the Board of Governors, from the work of Peter K. Clark, in "Okun's Law and Potential GNP," Board of Governors of the Federal Reserve System, October 1982.

6. In the context of error correction models, the term "error" refers to the gap between the endogenous variable and its equilibrium level, and should not be confused with the stochastic noise term appended to the estimating equation.

7. See Gabel and Roberts (1980).

8. Sargent (1979) and Harvey (1981) are useful introductions to the properties of second-order stochastic difference equations.

9. Similar simulations appear in the HPS study (pp. 21-23).

10. See also Sargent (1979, p. 217).

11. Because x, real output, does not fall out of this specification, it is also necessary to assume something about its time path. For the purposes of this simulation, x is simply set to $\bar{x}$.

12. Bureau of Economic Analysis, "GNP Report and Tables."

13. Similar results can be found in the HPS study itself. In their Table 1, the estimate of the coefficient on ΔOS_1 using the fixed-weight GNP deflator is also negative and statistically significant.

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