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INFLATION, FLEXIBLE EXCHANGE RATES, AND THE NATURAL RATE OF UNEMPLOYMENT

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ABSTRACT

The most important conclusion of this paper is that the growth rate of the money supply influences the U.S. inflation rate more strongly and promptly than in most previous studies, because the flexible exchange rate system has introduced an additional channel of monetary impact, over and above the traditional channel operating through labor-market tightness. Lagged changes in the effective exchange rate of the dollar, through their influence on the prices of exports and import substitutes, help to explain why U.S. inflation was so low in 1976 and why it accelerated so rapidly in 1978. Granger causality tests indicate that lagged exchange rate changes influence inflation, but lagged inflation does not cause exchange rate changes. A policy of monetary restriction in the 1980s is shown to cut the inflation rate by five percentage points at about half the cost in lost output as compared with the consensus view from previous studies.

The paper defines the "no shock natural rate of unemployment" as the unemployment rate consistent with a constant rate of inflation in a hypothetical state having no supply shocks and a constant exchange rate. A new estimate of this natural rate concept displays an increase from 5.1 percent in 1954 to 5.9 percent in 1980 that is entirely due to the much-discussed demographic shift in labor-force shares and relative unemployment rates. Other higher estimates of the natural unemployment rate, close to 7 percent in 1980, result from the use of a naive Phillips curve that relates inflation only to labor-market tightness and inertia variables.

The paper contains extensive sensitivity tests that examine the behavior of the basic inflation equation over alternative sample periods; that enter the growth rate of money directly and track the behavior of a money-augmented equation in dynamic simulation experiments; and that test and reject the view that wage-setting behavior is dominated by "wage-wage inertia", that is, the dependence of wage changes mainly on their own past values.

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"'The supply response of the economy to monetary impulses' is still the central issue, for both theory and policy" -- James Tobin[1]

I. INTRODUCTION

The prerequisites for an informed discussion of anti-inflationary demand-management policy are a quantitative assessment of the response of inflation to alternative degrees of demand restraint, and an estimate of the real output loss associated with each hypothetical policy. Central to the planning of an anti-inflationary strategy is the concept of the "constant inflation" or "natural" rate of unemployment, below which inflation accelerates and above which inflation decelerates. Policymakers planning to stop inflation by restrictive demand-management policy must know how high the unemployment rate must be maintained to induce slower inflation, and how rapidly inflation will adjust per unit of time for a given excess of unemployment above the natural rate.

The traditional quantitative tool to address these issues has been the econometric Phillips curve equation, which explains the current inflation rate as depending on the unemployment rate and lagged inflation, i.e., on labor market "tightness" and on "inertia" that delays the adjustment of inflation to changes in labor market conditions. Econometric Phillips curves have been under attack for most of the past decade, partly because the relation between inflation and unemployment has been positive rather than negative over much of that time. While the consensus view of a decade ago estimated the natural unemployment rate to be about 5 percent, the actual recorded unemployment rate between early 1971 and late 1980--6.4 percent--was accompanied not by a deceleration of inflation but a doubling of inflation (in the GNP deflator) from about 5 percent to almost 10 percent. The juxtaposition of the unemployment and inflation figures seems to imply, as Robert Hall and others have argued, that the natural unemployment rate in the U.S. in the late 1970s had reached close to 7 percent.[2] This conflict between high unemployment and accelerating inflation led commentators like Robert Lucas and Thomas Sargent to announce the demise of the Phillips curve and, with it, the collapse of Keynesian economics.[3]

This paper finds that the Phillips curve has been prematurely buried. The Phillips-curve specification--that inflation depends on inertia and on real aggregate demand in the form of a labor-market tightness variable--is less wrong than incomplete. Just as today's undergraduate students learn that accelerations of inflation depend on a Marshallian scissors of demand and supply shifts, so the econometric explanation of inflation requires the inclusion not just of inertia and aggregate demand variables, but also of variables to represent the impact of external supply shocks and government intervention in the price-setting process. This paper, which is the fourth of a series on the U.S. inflation process, provides new estimates of the natural unemployment rate and the responsiveness of inflation to demand-management policy that are neither as pessimistic as those based on traditional Phillips curves nor as optimistic as those incorporating the Lucas-Sargent assumption of instantaneous price responsiveness to anticipated nominal demand disturbances.[4]

There are four distinguishing features of this study:

1. *Inflation depends on inertia, and on both demand and supply shifts.* A careful treatment of supply factors, especially the relative prices of food and energy and the impact of the 1971-74 Nixon price controls program, helps to explain why inflation and unemployment were

positively related in the early 1970s, and leads to improved estimates of the impact of demand variables on inflation.

2. Demand effects include the influence of exchange rates. Traditional Phillips curve equations allow the impact of aggregate demand to enter only through a single real variable, the unemployment rate (usually its inverse, and often weighted to correct for demographic shifts). The specification adopted here allows demand policy to enter through two additional channels, the rate of change of real or nominal demand, and the change in the effective exchange rate of the dollar (which in turn depends on monetary and fiscal policy). The exchange rate variable makes a critical contribution to our explanation of inflation behavior in the 1970s, particularly the low inflation rate in 1976 and its acceleration in 1978. Further, the exchange rate variable, when combined with an equation that links exchange rate behavior to monetary policy, substantially increases the responsiveness of inflation to monetary restriction and leads to a lower estimate of the associated loss of real GNP.

3. Inflation is explained without explicit reference to wage behavior. Some past studies of inflation, including those of George Perry, have estimated only wage equations, without presenting separate estimates of the responsiveness of the price-wage markup to aggregate demand conditions.[5] Since the wage equation captures only part of the impact of demand on inflation, it implies an overly pessimistic verdict on the outcome of restrictive demand-management policy. By concentrating on the relation of inflation to past inflation and both demand and supply factors, this paper circumvents the need to estimate separate wage equations. Sensitivity tests indicate that the omission of a wage equation actually improves our ability to explain historical inflation data.

4. The direct impact of money on prices is tested explicitly. Some critics of the Phillips curve approach state, usually without explicit empirical proof, that past changes in the money supply are the dominant influence on inflation. If the reaction of inflation is sufficiently prompt, a monetary disturbance can change the inflation rate without any response in the real variables (like unemployment or real output) that typically play the key explanatory role in Phillips curve equations, causing such equations to be fundamentally misspecified. In a contest with traditional specifications, we find that short lags on past monetary changes are a good substitute for changes in unemployment, and long lags are a good substitute for the level of unemployment. A dynamic simulation of an equation including long lags on money can explain inflation data for the 1970s as well as, although no better than, a similar equation excluding money. The major drawback of the equation with money is the long-run instability of its estimated form and its implausible long-run behavior in simulations of alternative policy regimes.

Two types of quantitative analysis of the impact of aggregate demand on inflation are presented. First, the robustness of the basic inflation equation is tested by comparing it with alternative specifications. What difference is made by specifying the growth of aggregate demand to operate through nominal monetary changes rather than a real variable like unemployment? Is there any evidence of shifts in the importance of the demand variables between the first and last halves of the 1954-80 interval? Is a separate wage equation necessary to track the inflation process, or can the process be adequately summarized in a single equation that ignores wages? The second task of the paper is more directly related to the present concerns of the policymakers. What would have been the consequences for inflation of alternative demand management policies during the 1975-80 period? What is the implied natural rate of unemployment during the 1970s and at present? And what would be the outcome for inflation and real GNP of alternative monetary growth rates over the next decade?

The paper begins in Part II with a brief examination of the basic data for 1954-80 on inflation, the growth of nominal GNP and money, the ratio between actual and "natural" real GNP, and two measures of unemployment. Part III discusses methodology and shows the formal relationship of our single basic inflation equation to conventional wage and price markup equations. Part IV tests for shifts in coefficients between the two halves of the sample period. Part V compares the basic equations with variants that directly introduce lagged changes in the money supply and provides new evidence on patterns of Granger causality among prices, unemployment, and money. The basic specification is compared in Part VI with equations that explain wage change and the relation of prices to wages separately with the same set of right-hand variables. Historical simulations are the subject of Part VII, while Part VIII develops simulations of hypothetical future demand growth policies based on both the basic equation and alternative specifications.

II. BASIC DATA ON INFLATION, AGGREGATE DEMAND, AND UNEMPLOYMENT

Although regression equations are the basic tool of analysis in this paper, nevertheless some basic features of the postwar inflation process can be identified in a simple summary of the raw data, as in Table 1. Sections 1 and 2 of the table list means and standard deviations of key variables for five evenly-divided subperiods within the span of our overall sample period that extends from 1954:Q2 to 1980:Q4. The first three columns show quarterly rates of change at annual rates, and the last three columns show levels of the ratio of actual to natural real GNP, and two measures of the unemployment rate (the official rate and Perry's demographically weighted rate). The level of natural real GNP used to compute the output ratio in column (4) is the "$QPOT_1$" series estimated by Jeffrey Perloff and Michael Wachter, extrapolated after 1978 at a growth rate corresponding to the official Council of Economic Advisers potential GNP series (2.8 percent in 1979 and 1980), and adjusted for the 1980 revisions in the National Income and Product accounts.

The first outstanding fact in section 1 of the table is the simultaneous increase in both inflation and unemployment during 1970-80 as compared to 1954-65, with inflation rising from an average of 1.7 percent in the first two subperiods to 6.9 percent in the last two subperiods, while official unemployment rose from 5.4 to 6.4 percent, and the weighted unemployment rate rose from 4.4 to 4.7 percent. The output ratio duplicates the story told by the weighted unemployment rate, as would be expected, since a demographic correction was used by Perloff and Wachter in creating their natural output series. The following "Okun's Law" regression shows the close connection between the weighted unemployment rate (U^W), and the

TABLE 1

Data on Inflation, Nominal Demand Growth, the Output Ratio, and Unemployment

	Quarterly Rates of Change at Annual Rates			Averages (Percent)		
	Fixed Weight GNP Deflator	Nominal GNP	M1B	Deviation of P-W Output Ratio From 100%	Official Unemployment Rate	Perry Weighted Unemployment Rate
	(1)	(2)	(3)	(4)	(5)	(6)
1. Average over Interval						
a. 1954:Q2-1959:Q3	2.20	5.44	2.09	-0.70	5.08	4.24
b. 1959:Q3-1964:Q4	1.28	5.39	2.37	-1.87	5.71	4.58
c. 1965:Q1-1970:Q2	3.80	7.61	4.75	3.24	3.89	2.68
d. 1970:Q3-1975:Q4	6.33	9.04	5.85	-0.84	6.04	4.40
e. 1976:Q1-1980:Q4	7.52	10.42	7.14	-2.16	6.73	4.97
2. Standard Deviations over Interval						
a. 1954:Q1-1959:Q3	1.31	5.27	2.03	2.36	1.08	1.04
b. 1959:Q3-1964:Q4	0.59	3.25	2.34	1.65	0.58	0.61
c. 1965:Q1-1970:Q2	1.34	2.71	2.60	1.27	0.43	0.38
d. 1970:Q3-1975:Q4	2.46	4.06	2.09	2.91	1.27	1.12
e. 1976:Q1-1980:Q4	1.87	4.14	3.26	1.64	0.80	0.69
3. Average over four quarters ending in inflation peaks and troughs[a]						
a. Trough, 1954:Q3	0.84	-0.46	1.54	-0.82	5.19	4.32
b. Peak, 1957:Q1	3.96	6.42	0.95	0.75	4.10	3.28
c. Trough, 1958:Q4	1.04	5.05	3.25	-4.57	6.84	5.93
d. Peak, 1959:Q4	1.89	5.82	2.05	-1.43	5.45	4.51
e. Trough, 1961:Q4	0.70	7.22	2.71	-3.93	6.69	5.56
f. Peak, 1970:Q1	5.47	5.37	2.90	2.46	3.68	2.50
g. Trough, 1972:Q2	3.69	9.18	6.12	-0.29	5.85	4.27
h. Peak, 1974:Q3	10.31	6.82	4.58	-1.10	5.59	3.93
i. Trough, 1976:Q4	5.05	8.89	5.83	-3.99	7.68	5.85
j. Peak, 1980:Q4	9.29	8.97	6.88	-3.40	7.17	5.33

[a] Peaks and troughs are those of the four-quarter percentage change in the fixed-weight GNP deflator.

output ratio ($\hat{Q}$), the latter measured as a deviation from 100 percent.

$$(1) \quad U^W_t = \underset{[46.2]}{3.96} - \underset{[-12.0]}{0.243}\,\hat{Q}_t - \underset{[-6.39]}{0.142}\,\hat{Q}_{t-1} - \underset{[-1.78]}{0.040}\,\hat{Q}_{t-2},$$

where $R^2 = .976$, D-W $= 1.55$, S.E.E. $= 0.178$,

and the coefficient of first-order serial correlation = 0.79.

Thus the output ratio is 100 percent when the weighted unemployment rate is 3.96 percent, and this corresponds to an official unemployment rate in 1980 of 5.8 percent. The Perloff-Wachter output ratio, and the associated values of the weighted and official unemployment rates, are used only as a point of departure for our investigation, which will attempt to determine whether the Perloff-Wachter output ratio overstates natural real GNP and understates the corresponding natural rate of unemployment. Stated another way, we must determine whether the acceleration of inflation in the 1970s can be explained when on average the Perloff-Wachter output ratio was negative throughout the decade.

Between the first and last sub-periods the acceleration of inflation of 5.3 percentage points was accompanied by similar accelerations in nominal GNP and monetary growth of, respectively, 5.0 and 5.1 percentage points. (It is interesting that velocity growth was so stable across the five sub-periods, ranging only from 2.9 to 3.4 percent.) But within each sub-period the relationship between inflation, nominal GNP, and money was not nearly so close. The second section of the table shows the standard deviations within each of the five intervals of each variable. The variance of inflation and the output ratio was greatest in the early 1970s, whereas the variance of adjusted nominal GNP growth was greatest in the 1950s, and the variance of monetary growth was greatest in the late 1970s. In fact, the variance of monetary growth was relatively low in the early 1970s, just when the variance of inflation, the output ratio, and unemployment was highest. These summary statistics reflect our finding that postwar inflation cannot be adequately characterized simply as a lagged adjustment to one or more of the other variables included in Table 1, but rather its explanation requires an explicit quantitative treatment of supply shocks and of government intervention in the inflation process.

A different subdivision of the data is presented in the bottom section of Table 1. The dates shown are those of the trough and peak inflation rates (measured as four-quarter chages) corresponding to each of the five NBER business cycles. The upward ratcheting of the peaks and troughs after 1961 is clearly evident, although the 1980 inflation peak fell short that reached in 1974 (another clue that supply shocks played a special role in the highly variable inflation of the early 1970s). The correlation of inflation and either demand or monetary growth is extremely weak across inflation peaks and troughs, and is negative between 1970 and 1976. The negative Phillips curve relation between inflation and unemployment is evident before but not after 1970.

III. METHODOLOGY

Two Equations or One?

Just as the Phillips-curve econometricians and the Lucas-Sargent classicists hold different views about the impact of aggregate demand on inflation, so they also set up their empirical studies differently. The traditional procedure has been to specify a wage equation and then to assume that the price level is marked up over "standard" unit labor cost, that is, the wage rate divided by a productivity trend. Some traditional studies, which do not provide estimates of the markup equation, imply that their estimated coefficient on the level of unemployment in the wage equation is the only channel through which aggregate demand can alter the inflation rate.[6]

In contrast proponents of the Lucas-Sargent approach focus directly on an equation in which the inflation rate rather than wage change is the dependent variable.[7] The effect of demand is entered through changes in nominal money or nominal GNP, and there is no attention to variables representing labor market tightness. This single-equation approach has several advantages over the traditional two-equation mainline framework that emphasizes wages.

First, wage and price markup equations cannot be distinguished as truly structural equations applying to behavior in particular markets. The behavior of wages, for instance, can be explained just as well by real GNP as by labor market variables like unemployment, suggesting that the wage equation does not provide us with any special insight about the working of labor markets. Indeed, if the "Okun's Law" relationship linking the output ratio and the unemployment rate works well, as in equation (1) above, then output variables can mimic the behavior of labor-market variables over the business cycle.[8] Second, traditional wage and price equations may be particularly prone to simultaneous equations bias. If current prices explain wages and current wages explain prices, then the coefficient on a variable that influences both simultaneously--whether a demand proxy like real GNP or a supply variable like price-control effects--may be biased downward if it is measured with error and part of its true effect is "soaked up" by the right-hand wage or price variable.

A third problem is that the use of separate wage and price markup equations leads to an artificial separation of the variables that "belong" in each equation. Thus the inflationary impact of the payroll tax or Kennedy-Johnson wage guidelines depends not just on their coefficient in the wage equation, but on the response of prices to that particular source of wage variation. Finally, the two-equation approach is inconvenient and clumsy. The full impact of a variable on the inflation rate cannot be learned from the simple inspection of a table, but requires multiplying and adding coefficients.

On all of these counts a single inflation equation, which relates the rate of price change to its own lagged values, seems superior. The equation is openly a convenient characterization of the data rather than an attempt to describe structural behavior. Because the underlying structure may shift, the coefficients in the estimated equation may shift, so that any such single-equation approach should pay special attention to tests of the stability of coefficients across sub-intervals within the sample period.

Details of the Specification

Our single inflation equation is derived from separate wage and price markup equations. Because economic theory gives us no guidance as to the exact form of the impact of aggregate demand on inflation, we shall postulate that the level and rate of change of a real utilization variable --either the output ratio or weighted unemployment--enters both the wage and price markup equations. The level of the real demand variable is denoted below by X_t, and its rate of change as x_t. An important restriction on the wage equation is that we rule out a "wage-wage spiral," that is, the dependence of the rate of wage change on the inherited "norm" of lagged wage change due to the attention paid by workers to wage differentials.[9] Instead, the influence of inertia on wage change (w_t) is assumed to enter through a single term, defined as lagged price change (p_{t-1}) plus the "equilibrium" growth rate of the real wage (λ_t). While the wage-wage view is plausible, any role of lagged wages must be purged from the wage equation if we are to be able to develop a single inflation equation that is free from the need to explain wage behavior. Section VI below demonstrates that lagged price changes perform much better than lagged wages in a wage equation.

In addition to the real demand and inertia variables, wage change is allowed to depend on a vector of supply variables (z_{wt}) that shift the rate of wage change for any given values of lagged prices and the demand variables. Among the supply shifts that might enter the wage equation are the impact of wage controls and of changes in the payroll tax and minimum wage. When an error term (ε_{wt}) is included the wage equation becomes:

$$(2) \quad w_t = \alpha_0 + \alpha_1(p_{t-1} + \lambda_t) + \alpha_2 X_t + \alpha_3 x_t + \alpha_4 z_{wt} + \varepsilon_{wt}.$$

In the steady state the actual growth in the real wage ($w_t - p_t$) will be at the equilibrium rate (λ_t) only if $\alpha_1 = 1$, the level of the real demand variable is constant at $X_t^* = -(\alpha_0/\alpha_2)$, and the supply and error terms have realizations equal to zero. Thus the term "equilibrium" to describe λ_t is used in the highly restricted sense of a "no shock" equilibrium. In exactly the same sense, the "natural rate" of output or unemployment (X_t^*) is compatible with steady wage growth only if the same set of restrictive conditions is satisfied. In the long run the λ_t term plays no role in the inflation process *if* the productivity variable in the price equation below (σ_t) equals λ_t. But some have argued that a decline in productivity growth can cause an acceleration of inflation if firms and workers try to maintain the old path of real wages, rather than instantly allowing the growth rate of real wages to decelerate in proportion to the productivity slowdown ($\lambda_t > \sigma_t$). Our distinction between the real wage and productivity is introduced to test empirically whether productivity behavior has been a separate determinant of the observed rate of inflation (an independent channel is introduced in Appendix A, which contains equations that translate monetary growth into unemployment. Slower growth in productivity--and thus in potential output--reduces the unemployment rate relative to the natural unemployment rate for any given growth rate of money and thus in our basic equation in Table 2 causes the inflation rate to accelerate).

The price markup equation relates current price change (p_t) to the current change in "standard" unit labor cost ($w_t - \sigma_t$), the same demand variables as appear in (2), a vector of supply shift variables (z_{pt}) that influence the level of prices relative to wages, and an error term (ε_{pt}):

$$(3)\quad p_t = \beta_0 + \beta_1(w_t - \sigma_t) + \beta_2 X_t + \beta_3 x_t + \beta_4 z_{pt} + \varepsilon_{pt}.$$

The fact that the current wage enters the price equation, but only lagged price change enters the wage equation, is an expositional convenience that does not restrict the empirical work presented below.[10] Among the supply shift variables (z_{pt}) that could enter into the price equation are government price controls, changes in foreign exchange rates and in the relative prices of food and energy, and shifts in indirect tax rates.

When (2) is substituted into (3), we obtain a single inflation equation:

$$(4)\quad p_t = \beta_0 + \beta_1\alpha_1 p_{t-1} + \beta_1(\alpha_1\lambda_t - \sigma_t) + (\beta_2+\beta_1\alpha_2)X_t + (\beta_3+\beta_1\alpha_3)x_t$$
$$+ \beta_4 z_{pt} + \beta_1\alpha_4 z_{wt} + \varepsilon_{pt} + \beta_1\varepsilon_{wt}.$$

The long-run equilibrium properties of (4) can be seen more easily if we combine the separate z variables, error terms, and coefficients from the wage and price equations:

$$(5)\quad p_t = \gamma_0 + \gamma_1 p_{t-1} + \gamma_1(\lambda_t - \sigma_t) + (\gamma_1 - \beta_1)\sigma_t + \gamma_2 X_t + \gamma_3 x_t +$$
$$\gamma_4 z_t + \varepsilon_t,$$

where $\gamma_0 = \beta_0+\beta_1\alpha_0$; $\gamma_1 = \beta_1\alpha_1$; $\gamma_2 = \beta_2+\beta_1\alpha_2$; $\gamma_3 = \beta_3+\beta_1\alpha_3$;

$\gamma_4 z_t = \beta_4 z_{pt} + \beta_1\alpha_4 z_{wt}$; and $\varepsilon_t = \varepsilon_{pt} + \beta_1\varepsilon_{wt}$.

What are the conditions necessary for (5) to generate a constant equilibrium rate of inflation? First, the coefficient on lagged price change (γ_1) must be unity. Second, the equilibrium real wage term in the wage equation and standard productivity growth in the price equation must be equal ($\lambda_t - \sigma_t = 0$). Third, the coefficient on standard unit labor cost in the price equation must be unity ($\beta_1 = 1$).[11] Fourth, the rate of change in the real demand variable, as well as every supply shift variable, must also be equal to zero ($x_t = z_t = 0$). Finally, the level of the real demand variable must be at its "natural rate," $X_t^* = -(\gamma_0/\gamma_2)$. Correspondingly (5) lays out those events that can cause the inflation rate to accelerate, including an excess of λ_t over σ_t, a level of real demand above the natural rate ($X_t > X_t^*$), a positive rate of growth of the real demand variable, and any adverse supply shock.

Clearly X_t^* represents the "natural rate of output" only if all of the other conditions stated in the previous paragraph are valid. If there is, for instance, an adverse supply shift ($z_t > 0$), inflation can accelerate even if $X_t = X_t^*$. An excess of λ_t over σ_t, or a positive realization of any z_t variable, pushes the "constant inflation" level of real demand below the value of X_t^*. Thus the framework of equation (5) has the potential of explaining why inflation accelerated during the 1970s, despite the fact that the Perloff-Wachter output-ratio measure summarized in Table 1 was negative on average during the decade.

Endogeneity Problems

Leaving aside the possible endogeneity of elements in the z_t supply vector, a topic discussed in Part VII below, a weakness of equation (5) is the appearance of two endogenous variables, the level and rate of change of real demand (X_t and x_t, respectively). A bias in the coefficient on both demand variables, and particularly on the rate of change effect (x_t), may be introduced from two sources. First, if x_t is represented by the change in real GNP, measurement error may introduce a spurious negative correlation between the dependent variable (p_t) and x_t, the output change variable, thus biasing downward the parameter γ_3, since in the United States national accounts nominal GNP and prices are measured independently, with real GNP as a residual.[12] Thus any error that exaggerates the rate of price increase in a given quarter would depress the official growth rate of real GNP by an equal amount, since data for nominal GNP are collected independently. This type of measurement error can be avoided by using a real demand variable collected from an independent data source, e.g., Perry's weighted unemployment rate, to measure both X_t and x_t.

Second, for any given growth rate of nominal GNP, a supply shock ($z_t > 0$) raises the inflation rate and reduces real GNP growth. In principle the impact of any supply shock that shifts the inflation rate for given values of the output variables is supposed to be captured by the vector of z_t variables included in the equation. But errors in the measurement of the z_t variables may introduce a spurious negative correlation between the inflation rate and the change in either output or unemployment. For instance, with fixed nominal GNP growth, imagine that an oil price increase raises the inflation rate and reduces output growth by one percentage point in the initial quarter, and that the "oil shock" variable times its coefficient erroneously indicates only a 0.5 percent upward shift in the inflation schedule. The explanation of the other 0.5 percentage point acceleration of inflation would be captured by a coefficient of -0.5

on the output change variable if there were no other observations; more generally when the "true" coefficient on output growth (γ_3) is positive, then the estimated coefficient would be biased toward zero. Given the close negative association between real output and unemployment in (1), the same bias would apply (with the opposite sign) to unemployment variables. To test the possibility that this "supply shock bias" might affect the estimated equation, an alternative version is estimated below in which the real rate of change variable is replaced by the lagged growth rate of the nominal money supply.

The GNP deflator seems the natural choice as dependent variable in a study of the basic U.S. inflation process. Given any specified path of nominal GNP and "natural" (or potential) real GNP, determination of the path of the GNP deflator automatically yields as residual the output ratio ($\hat{Q}_t$), and, through equation (1), the unemployment rate. A pitfall introduced by the GNP deflator stems from the use of shifting current-period expenditure weights in its construction, leading to a confounding of price changes with changes in the mix of output. In a quarter in which there is a sharp change in a particular category of nominal spending, as in the case of an auto strike or oil embargo, the value of the deflator may rise or fall due to shifting weights, even if there were no effect of nominal GNP on any individual price change. Fortunately this problem can be avoided through the use of the published "fixed-weight" GNP deflator that insulates true price changes from expenditure shifts, just as studies of wage inflation during the past decade have adopted the practice of employing a dependent variable that is corrected for changes in the inter-industry employment mix.[13]

IV. THE BASIC INFLATION EQUATION AND ITS SENSITIVITY TO CHANGES IN SPECIFICATION AND DATING

The Point of Departure: A Naive Phillips Curve

Our starting place is the simple Phillips curve that incorporates only the effects of real demand and inertia. Although most Phillips curve research has stressed the relationship between wage change and the level of the unemployment rate, a quasi-Phillips-curve equation can be estimated within our framework by regressing the rate of inflation on its own lagged values and the current level of the Perry weighted unemployment rate (U_t^W). This is equivalent to the estimation of (5) with the omission of the demand growth, productivity, and supply shift terms. As in all of the equations presented in this paper, the level of the unemployment rate appears in its linear rather than its inverse form (used in most previous studies). Since the inverse form improves the fit by only a trivial amount, less than one percent, I prefer the linear form which makes the coefficients on the constant and unemployment terms easier to interpret.[15] Also in common with the other equations in this paper, the role of the lagged dependent variable may be either to represent the adaptive formation of the *expected* rate of inflation, or simply the role of *inertia* in the inflation process through the influence of three-year wage contracts and other similar institutional phenomena. Since these two interpretations cannot be distinguished empirically, there is no point in trying to decide which is valid.[14]

To standardize the equations in the paper and economize on the number of permutations of equations that must be estimated, the lagged dependent variable is entered into every equation as a fourth-degree polynomial extended over 24 lagged values with a zero end-point constraint. In Table 2, column (1) illustrates an equation in which the quarterly rate of change of the fixed-weight GNP deflator (expressed as an annual rate) is regressed on this polynomial distributed lag, on the level of the weighted unemployment rate, and on a constant term.

The estimated coefficients in column (1) seem satisfactory at first glance. The Phillips curve slope--the coefficient on U_t^W--is strongly significant and indicates that a permanent one-percentage-point reduction of the unemployment rate is accompanied by 0.6 percentage points extra inflation for any given contribution of the lagged inflation variable. But there is a problem in the sum of coefficients on lagged inflation, which lies significantly above unity. Maintenance of the weighted unemployment rate at $-\gamma_0/\gamma_2 = 3.45$ would be associated with an acceleration of inflation. Thus the natural unemployment rate cannot be calculated directly in column (1).

A central focus of this study is the extent to which the natural unemployment rate has increased during the 1970s. A measure of the upward shift implied by column (1) can be provided if we constrain the sum of coefficients on lagged inflation to be unity, and include two dummy variables for the first and last half of the 1970s to measure the shift in the constant term as compared to the sample period as a whole. The constraint is imposed in column (2) by subtracting from the dependent variables the

TABLE 2

Alternative Equations for
the Estimation of the Weighted Natural Unemployment Rate

Sample Period: 1954:Q2-1980:Q4

Dependent Variable: Quarterly Change in GNP Fixed Weight Deflator

t ratios in [ ]

	Unconstrained Equations			Constraint Imposed[a]		
	(1)	(2)	(3)	(4)	(5)	(6)
1. Constant	2.14 [4.69]	3.04 [7.37]	2.45 [3.52]	2.72 [6.68]	3.35 [9.68]	2.45 [6.51]
2. Lagged Inflation[b]	1.22 [19.6]	1.17 [20.3]	--	1.00 [--]	1.00 [--]	--
3. Lagged Inflation,[b] first half	--	--	1.01 [3.10]	--	--	1.00 [--]
4. Lagged Inflation,[b] last half	--	--	1.03 [10.5]	--	--	1.00 [--]
5. Weighted Unemployment Rate	-0.62 [-5.17]	-0.78 [-7.35]	-0.59 [-4.30]	-0.65 [-6.42]	-0.76 [-8.84]	-0.58 [-6.51]
6. Change in Weighted Unemployment	--	--	-0.64 [-1.92]	--	--	-0.66 [-2.61]
7. Productivity Deviation	--	--	-0.08 [-2.03]	--	--	-0.09 [-2.66]
8. Food and Energy Prices[c]	--	0.46 [3.12]	0.74 [3.31]	--	0.48 [3.51]	0.73 [5.21]
9. Foreign Exchange Rate[d]	--	--	-0.11 [-1.70]	--	--	-0.12 [-3.61]
10. Effective Minimum Wage[c]	--	--	0.02 [1.17]	--	--	0.02 [1.87]
11. Social Security Tax[c]	--	--	0.27 [1.00]	--	--	0.21 [0.91]
12. Nixon Controls "on"[e]	--	-1.60 [-3.07]	-1.45 [-2.61]	--	-2.04 [-3.41]	-1.76 [-3.21]
13. Nixon Controls "off"[e]	--	2.92 [5.52]	2.67 [3.86]	--	2.78 [5.35]	2.36 [4.07]
14. Shift, 1970:Q3-1975:Q4	--	--	--	1.05 [3.88]	0.76 [2.47]	0.41 [1.38]
15. Shift, 1976:Q1-1980:Q4	--	--	--	0.94 [3.19]	0.68 [2.54]	0.05 [0.19]
R^2	.867	.916	.942	.317	.682	.837
Sum of Squared Residuals	115.2	72.0	50.2	118.1	73.8	49.2
Standard Error	1.068	0.875	0.823	1.071	0.877	0.785

Notes to Table 2

a. In columns (4) through (6), the constraint is imposed by subtracting from the quarterly change in the GNP fixed weight deflator the 24 lagged inflation variables times their respective coefficients from columns (1) through (3), divided by the sum of coefficients. This difference is the dependent variable in a regression in which all of the other indicated variables appear on the right-hand side.

b. In columns (1) to (3) the indicated figures are sums of coefficients (and their t ratios) when the lagged dependent variable is entered as a fourth-degree polynomial distributed lag on 24 lagged values, with a zero end-point constraint. In lines 3 and 4 the lagged inflation variable is entered twice in the same form, with the first distributed lag fitted to values for 1948:Q2 through 1966:Q4, and the second fitted to values for 1967:Q1 through 1980:Q4.

c. For each variable marked with footnote "c," both the current and four lagged values are entered into the equation, with the listed coefficient indicating the sum of all five coefficients and associated t ratio on the sum.

d. Same as note c, except that the current and three lagged values are entered.

e. The Nixon controls "on" dummy variable is entered as a variable equal to 0.8 for the five quarters 1971:Q3-1972:Q3. The "off" variable is equal to 0.4 in 1974:Q2 and 1975:Q1, and equal to 1.6 in 1974:Q3 and 1974:Q4. The respective dummy variables sum to 4.0 rather than 1.0 because the dependent variable in each equation is a quarterly change expressed as an annual rate, i.e., multiplied by 4.0.

24 lagged inflation variables times their respective coefficients in column (1), all divided by the sum of coefficients (1.22). The results in column (4) imply that the natural weighted unemployment rate rose about one percentage point after 1970:

	Implied Natural Rate of Unemployment	
	Weighted	Official
1956	4.18	5.00
1972	5.23	6.81
1978	5.12	6.80

The conversion from the weighted to the official rate is accomplished simply by adding in the actual difference between the two rates in the listed year. The resulting estimate of an official natural unemployment rate in the 1970s of 6.8 percent corresponds to the back-of-the-envelope estimate of Hall.[16]

Introducing the Supply Shift Variables

Our basic equation (5) contains several variables in addition to those shown in the first column of Table 2, including a vector of supply shifts, a productivity term, and an additional demand variable, the rate of change of real demand. These additional variables are introduced in two stages in Table 2. First, in the second column two key supply shift variables are included--the Nixon controls and changes in the relative prices of food and energy. Then in column (3) the complete set of additional variables is included. Because the exact specification of the supply shift variables was examined in detail in a previous paper, here every equation enters each component of the $\dot{z}_t$ vector with the same definition and lag distribution.[17]

1. *Food-energy Effect.* The most readily available measure of the impact of changes in the relative price of food and energy is the difference between the respective rates of change of the National Accounts deflators for personal consumption expenditures and for personal consumption net of expenditures on food and energy. This measure has the advantages that (a) it incorporates food and energy products with weights reflecting their importance in final spending (as opposed, for instance, to the Producer Price Index for energy that applies multiple weights to crude oil), and (b) it assumes a value of zero when the relative prices of food and energy are constant, thus allowing the "no shock" natural rate of unemployment to be calculated directly in Table 2.[18]

2. *Nixon Controls.* The impact of the price controls during the Nixon administration is assessed with a pair of dummy variables, specified to show the cumulative displacement of the price level by the controls and the extent of its subsequent post-controls rebound. The "on" variable is defined as 0.8 for the five quarters 1971:Q3 through 1972:Q3, and zero otherwise. The "off" variable is defined as 0.4 for the two quarters 1974:Q2 and 1975:Q1, 1.6 for 1974:Q3 and 1974:Q4, and zero otherwise. These dummy variables sum to 4.0, not 1.0, because the dependent variable is multiplied by 4.0 to convert it to an annual rate. Previous econometric evaluations of control effects have been based both on dummy variables and on post-sample dynamic simulations of equations. Blinder and Newton contributed a third method, based on a time series of the fraction of prices actually controlled. In a detailed comparison Frye and Gordon concluded that when the dummy variable and Blinder techniques are used in conjunction with the same specification of other variables, they give identical fits and

measures of the displacement of the price level by controls.[19] The post-sample simulation technique is judged inferior, because it is unable to incorporate information on variables that were unimportant before 1971 but were important thereafter (especially flexible exchange rates). The coefficients displayed in lines 12 and 13 of Table 2 show a substantially greater "off" effect than "on" effect, a result attributed below to the impact of the foreign exchange rate.

The estimates in column (2), and the corresponding constrained equation in column (5), add to the "naive Phillips curve" only the impact of Nixon controls and the current change in the relative prices of food and energy. In my research I have found that a number of other variables are useful in explaining postwar inflation. The following list describes the additional variables in the order in which they are entered in column (3), and the corresponding constrained equation in column (6).

3. *Split Lagged Dependent Variable.* The fit of the equation improves markedly when the single distributed lag on past inflation in columns (1) and (2) is replaced by two separate distributed lags in column (3) applied respectively to lagged price data before and after 1967:Q1--chosen because it is the midpoint of the sample period. The improvement in fit occurs because the shape of the lag distribution shortens substantially in the last half of the sample period, from 11.2 to 6.8 quarters. The F value for the significance of the additional lag distribution is 2.06, close to the 5 percent critical value of 2.49. Two factors may have speeded up the responsiveness of the inflation process. First, higher inflation rates have brought increased awareness of inflation behavior, and, second, the share of wage contracts containing escalator clauses increased substantially in the 1970s as compared to the 1960s.[20]

4. *Change in Unemployment.* A significant contribution is made by the change in unemployment, entered as a simple first difference of the Perry weighted unemployment rate. An equation that omits the unemployment change variable exhibits a jump in the coefficient on the level of the unemployment rate from -0.59 to -0.72. The F value for the additional rate of change variable is 3.76, as compared to a 5 percent critical value of 3.98.

5. *Productivity Deviation.* If the equilibrium real wage growth variable in the wage equation (λ_t) and the standard productivity variable in the price markup equation (σ_t) were identical, then the behavior of actual productivity changes would have no influence on the actual inflation rate in equation (5). However in general there is no reason for these two variables to be identical, and thus there is room for tests of the direct influence of actual productivity changes on inflation. Let us imagine that the productivity variable in the wage equation (λ_t) is a constant representing a straight time trend, t_w, whereas the "standard" productivity variable in the price equation (σ_t) is a weighted average of the actual growth rate of productivity (ρ_t) and another constant trend (t_p):

(6) $$\lambda_t = t_w,$$

(7) $$\sigma_t = \mu(\rho_t) + (1-\mu)t_p,$$ [21]

so that the productivity variable that appears in equation (5) becomes:

(8) $$\lambda_t - \sigma_t = t_w - t_p - \mu(\rho_t - t_p).$$

The $(t_w - t_p)$ term becomes absorbed in the constant of the inflation equation and, if it is not zero, becomes part of the estimated natural unemployment rate. In Table 2 we measure the "productivity deviation" $(\rho_t - t_p)$ by specifying t_p as a variable time trend.[22] The productivity deviation variable, the difference between the quarterly growth rate of nonfarm output per hour and this variable trend, enters significantly on line 7 of the equation in column (3). Experimentation with lags indicates that its entire impact occurs in the current quarter. The F value on its inclusion is 4.22, compared to the 5 percent critical value of 3.98.

6. *Foreign exchange rate.* Changes in the effective exchange rate of the dollar have not been included as an explanatory variable in previous studies of inflation, mainly because it has been difficult to find a statistically significant impact. The previous insignificance of the exchange rate appears to have been caused by the impact of the Nixon controls in delaying the adjustment of U.S. domestic prices to the dollar depreciation that occurred in two stages between 1971 and 1973. Our variable is the quarterly change in the effective exchange rate of the dollar, starting in 1975:Q2, the quarter when the post-controls rebound is assumed to terminate. This variable, entered as a current and three lagged values, makes a significant contribution to the equation (with a F value of 2.55 compared to a 5 percent critical value of 2.49) and helps to explain why inflation was so low in 1976 and accelerated so rapidly in 1978. The policy implications of this variable are important, since movements in the exchange rate introduce a direct impact of monetary policy (and the monetary-fiscal mix) on the inflation rate. The artificial device of setting the

exchange rate change equal to zero before 1975 accounts, I believe, for the fact that the Nixon controls "off" coefficient is larger than the "on" coefficient. The cumulative depreciation of the dollar between 1970 and 1975:Q1 was 17 percent, contributing 1.94 percent to the inflation rate when multiplied by the 1975-80 coefficient of -.11. Of this 1.94 points of extra inflation, 1.2 points are captured by the excess positive coefficient on the controls "off" variable, and the remainder is presumably soaked up by other variables.

A question may be raised about the possible endogeneity of the foreign exchange rate variable. Fortunately, there is strong evidence against contemporaneous feedback from inflation to the exchange rate. First, the exchange rate variable enters in the form of the current and three lagged values, but all of its explanatory power comes from the lags; the coefficient on the current variable is insignificant. Second, a regression of the foreign exchange rate on current and four lagged changes in money, nominal GNP, and the GNP deflator yields coefficients on current and lagged inflation that are jointly and individually insignificant. Thus all of the short-run interaction between the exchange rate and inflation is due to the effect of the former on the latter, and any impact in the reverse direction is both imperfect and long delayed.[23]

7. *Effective Minimum Wage and Social Security Tax.* In previous studies I have found these two variables to be significant "self-inflicted wounds," that is, changes in government policy variables that had a direct negative impact on the inflation rate. The effective minimum wage rate is defined as changes in the ratio of the statutory minimum wage to average

hourly earnings in the nonfarm economy, and the effective payroll tax rate as the ratio of total contributions for social security (employee and employer shares) divided by wages and salaries. Neither variable is statistically significant in column (3), but both are included to maintain comparability with previous studies. In addition, their effect in separate wage and price markup equations is of interest and is estimated in Table 5 below.

Sensitivity of Natural Unemployment Rate to Form of Equation

The specification of the equations in columns (1) through (3) is repeated on the right-hand side of Table 2, with a unity constraint imposed on the sum of the coefficients on lagged inflation in each equation in columns (4) through (6). The latter equations also insert two additional constant terms for the first and last half of the 1970s, in order to test for shifts in the natural rate of unemployment. The inclusion of the food-energy and price-control effects in column (5) eliminates roughly one-third of the increase in the weighted unemployment rate between 1956 and 1978, while the complete specification in column (6) eliminates most of the remaining increase:

Natural Rate of Unemployment

	Weighted			Official		
	Col. (4)	Col. (5)	Col. (6)	Col. (4)	Col. (5)	Col. (6)
1956	4.18	4.41	4.15	5.00	5.21	4.97
1972	5.23	5.17	4.56	6.81	6.75	6.14
1978	5.12	5.09	4.20	6.80	6.77	5.88
change, 1956-78	0.94	0.68	0.05	1.80	1.56	0.91

The insignificance of the dummy shift variable for 1976-80 in column (6) indicates that there was no upward shift in the natural *weighted* unemployment rate between the 1950s and late 1970s (the same result occurs when five dummies are included for each five-year sub-period). The marginal significance of the 1970-75 dummy shift variable in column (6) may reflect the treatment of the foreign exchange rate variable, which is set equal to zero before 1975 because the Nixon controls contaminate the timing of its impact on inflation. We calculated above that 1.9 points of extra inflation during 1970-75 would be accounted for by the depreciation of the dollar, if the 1975-80 coefficient on that variable were applied to the cumulative 1970-75 depreciation. Deducting 0.6 percentage points for the excess of the Nixon "off" dummy coefficient over the Nixon "on" coefficient, there remain 1.3 points to be accounted for, or 0.24 points of inflation per year. Subtraction of 0.24 from the estimated 1970-75 dummy shift variable of 0.41 would reduce the estimated shift to 0.17.

Overall, the figures for the official unemployment rate indicate an upward shift in the natural rate of 1.8 percentage points in column (4), 1.6 points in column (5), and only 0.9 points in column (6). Since all of this shift in column (6) is accounted for by the upward drift of the difference between the official and weighted unemployment rates, due to the increasing demographic importance of teenagers and women and a worsening of their relative unemployment rates, column (6) carries the implication that there has been no upward shift in the natural rate for other than demographic reasons. Less inclusive Phillips curves, like those displayed in columns (4) and (5), incorrectly interpret as a shift in the natural rate the impact of the productivity slowdown and exchange rate depreciation, particularly in the 1977-80 period. If U.S. productivity behavior and exchange-rate performance continue to be unfavorable during the 1980s, then column (5) is relevant in estimating the natural rate, but a "neutral" behavior of productivity and the exchange rate (that is, trend productivity growth and a constant exchange rate) would imply that the natural unemployment rate in 1980 was 5.9 percent. An annual time series of the natural rate is presented in Appendix Table B-1.

Sensitivity to Changes in Sample Period

Did the process of price adjustment in the U.S. become less sensitive to demand in the 1970s? George Perry's recent analysis of wage change found a significant shift in the coefficient on unemployment in 1970, with the implication that the Phillips curve had become virtually flat during the past decade.[24] Our basic equation already allows the lag distribution on past inflation to shift between the first and last halves of the sample period. The first three columns of Table 3 examine shifts in the coefficients on the level and change in the umeployment rate, holding constant the influence of lagged inflation and constraining the sum of coefficients on lagged inflation to be unity. Thus column (1) in Table 3 repeats the constrained basic equation from column (6) of Table 2, differing only in the omission of the insignificant constant shift terms. Because the dependent variable in Table 3 is price change minus the constrained effect of lagged inflation, the displayed equations explain the *change* in the rate of inflation (i.e., the second derivative of the price level).[25]

TABLE 3

Sensitivity to Sample Splits of Equations Explaining the Acceleration of Inflation [a, b]

t ratios in [ ]

	Basic Constrained Equation	Split U_t^W	Split U_t^W and ΔU_t^W	Sample Period 54:Q2-69:Q4	Sample Period 64:Q1-80:Q4
	(1)	(2)	(3)	(4)	(5)
1. Constant	2.42 [6.86]	2.44 [6.93]	2.34 [6.49]	5.69 [13.7]	2.67 [6.79]
2. Weighted Unemployment Rate	-0.57 [-7.51]	--	--	-1.34 [-13.8]	-0.75 [-8.32]
3. Weighted Unemployment, first half	--	-0.60 [-7.56]	-0.58 [-7.20]	--	--
4. Weighted Unemployment, last half	--	-0.55 [-7.06]	-0.53 [-6.51]	--	--
5. Change in Weighted Unemployment	-0.67 [-2.74]	-0.64 [-2.64]	--	0.14 [0.34]	-0.30 [-0.63]
6. Change in Weighted Unemployment, first half	--	--	-0.88 [-2.77]	--	--
7. Change in Weighted Unemployment, last half	--	--	-0.23 [-0.53]	--	--
8. Productivity Deviation	-0.08 [-2.47]	-0.08 [-2.46]	-0.08 [-2.55]	-0.07 [-1.56]	-0.01 [-0.63]
9. Food and Energy Prices [c]	0.80 [6.74]	0.74 [5.80]	0.70 [5.29]	0.99 [3.37]	1.10 [6.87]
10. Foreign Exchange Rate [d]	-0.12 [-3.54]	-0.11 [-3.60]	-0.11 [-3.53]	--	-0.36 [-10.4]
11. Effective Minimum Wage [c]	0.02 [1.68]	0.02 [1.69]	0.02 [1.52]	0.04 [2.90]	-0.02 [-0.88]
12. Social Security Tax [c]	0.25 [1.09]	0.27 [1.18]	0.29 [1.26]	0.19 [0.71]	0.11 [0.43]
13. Nixon Controls "on" [e]	-1.38 [-2.90]	-1.55 [-3.12]	-1.54 [-3.14]	--	-1.91 [-3.73]
14. Nixon Controls "off" [e]	2.69 [5.15]	2.63 [5.04]	2.63 [5.04]	--	4.09 [7.02]
R^2	.815	.818	.821	.880	.937
Sum of Squared Residuals	50.5	49.6	48.8	22.7	26.5
Standard Error	0.785	0.783	0.781	0.718	0.785

Notes to Table 3

a. Columns (1) through (3) share the same dependent variable, the identical variable that is used in column (6) of Table 2 and that is explained in notes a and b to Table 2.

b. In columns (4) and (5) the lagged dependent variable is constrained by the same technique used in Table 2, columns (4) and (5), i.e., without a split in the lag distribution on past inflation.

c. through e. See corresponding notes to Table 2.

The coefficient estimates in columns (1) and (2) are virtually identical, indicating no shift in the coefficient on the level of unemployment in explaining accelerations and decelerations of inflation. The F ratio for the significance of the additional unemployment variable is 1.40, compared to the 5 percent critical value of 3.98. In column (3) the "level effect" of unemployment is unchanged, but a split in the coefficient on the unemployment "change effect" results in a low and insignificant coefficient after 1966. However, this shift is insignificant, with a comparison of columns (2) and (3) yielding an F ratio of only 1.25, compared to the 5 percent critical value of 3.98. Comparing columns (1) and (3), the F ratio is 1.33, versus a 5 percent critical value of 3.11. The downward shift in the unemployment change variable may be partially explained by a bias predicted in our discussion of endogeneity problems in part III above. Errors in the measurement of supply shocks tend to create a positive correlation between inflation and the change in unemployment (as unmeasured supply shifts raise inflation, reduce output, and raise the unemployment rate), thus causing a bias toward zero in the coefficient on the change in unemployment.

A greater degree of doubt about the robustness of the unemployment change effect is suggested by columns (4) and (5), which display constrained regression equations fitted to the portion of the sample period ending in 1969, and to the portion beginning in 1964. Each of these equations includes only a single distribution on lagged inflation. The results for the earlier sub-period indicate that all of the impact of demand operated through the level of the unemployment rate, and none through the rate of change, but that the "level effect" was more than double the coefficient in the basic full-period equation in column (1). The results for the later sub-period also indicate a stronger level effect than in the full-period equation, and a weaker change effect. It is interesting that the sum of the coefficients on the level and change effects varies much less across sample priods than the individual coefficients--the respective sums of the level and change coefficients in columns (1), (4), and (5) are -1.24, -1.20, and -1.05.

There are other interesting aspects of the short-sample results in columns (4) and (5). First, the productivity deviation and minimum wage coefficients are much larger in the early period, and are insignificant in the later period. Second, the impact of food and energy prices was actually stronger in the early period (column 4) than in the full period (column 1). These aspects of the equations are confirmed in several other experiments which (a) estimate unconstrained versions of columns (4) and (5), and (b) split the sample period roughly in half between an early 1954-66 sub-period and a late 1967-80 sub-period. A formal Chow test on the equations run in experiment (b) fails by a wide margin to reject the null hypothesis that the first half of the observations obeys the same relation as the sub-period relation for the last half of the sample period. The conclusion is the same, but by a narrower margin, when the Chow test is conducted in reverse in a comparison of the last half of the observations with the sub-period relation for the first half of the sample period.[26] Thus, despite shifts in individual coefficients over time, conventional statistical tests confirm that the basic equation describes a stable relation between inflation and its determinants.

V. COMPARING DIRECT AND INDIRECT CHANNELS OF MONETARY INFLUENCE

Introducing Monetary Variables into the Basic Inflation Equation

Our interest in the direct effect on inflation of changes in the nominal money supply is motivated by three considerations. First, our discussion of endogeneity problems in Part II suggested that if nominal demand were exogenous, errors in the measurement of supply shifts would bias toward zero the coefficient on the change in real demand in our basic equation (5). Second, by forcing the impact of demand to operate entirely through real variables, our basic equation may understate the short-run responsiveness of inflation to changes in monetary policy. Finally, and perhaps most important, a substantial segment of the economics profession considers inflation to be a monetary phenomenon not only in the long run, but also in the short run. Regarding changes in the money supply as basically exogenous, this group views real variables like real GNP and unemployment as contemporaneously determined, and therefore is likely to suspect that our basic equation is plagued by simultaneity problems.

The relationship between the money supply and the unemployment variable appearing in our basic equation can be described concisely in three equations. First, the rate of growth of nominal GNP (y_t) by definition equals the sum of the growth rates of money (m_t) and velocity (v_t):

$$(9) \qquad y_t \equiv m_t + v_t .$$

To simplify the subsequent exposition, we shall treat the change in velocity as a serially independent random variable with mean zero and constant variance, but shall consider the impact of other assumptions in the discussion of the empirical results presented below. A second identity links the growth rate of real output (q_t) to the growth of nominal GNP and prices, and, by substitution of (9), to the growth rate of the money supply:

$$(10) \qquad q_t \equiv y_t - p_t \equiv m_t + v_t - p_t.$$

The third equation is an "Okun's Law" relation between the weighted unemployment rate (U_t^W) and the ratio of actual to natural real GNP ($\hat{Q}_t$). Here we rewrite equation (1) above, neglecting the lagged terms.

$$(11) \qquad U_t^W = \psi_0 + \psi_1 \hat{Q}_t + e_t,$$

where e_t is an error term. Taking first differences, (11) can be converted into a relationship between the change in the unemployment rate and the deviation of actual from natural real GNP growth:[27]

$$(12) \qquad \Delta U_t^W = \psi_1(q_t - q_t^*) + \Delta e_t.$$

In our basic inflation equation (5) above, the real demand variable was given the general designation "X," which could stand for the real GNP ratio ($\hat{Q}$), the weighted unemployment rate (U^W), or some other proxy. The empirical version of our equation as estimated in Tables 2 and 3 uses the weighted unemployment rate to represent "X" and can be written in its general form by substituting "U^W" for "X" in equation (5):

$$(13) \qquad p_t = \gamma_0 + \gamma_1(p_{t-1}+\gamma_t-\sigma_t) + \gamma_2 U_t^W + \gamma_3 \Delta U_t^W + \gamma_4 z_t + \varepsilon_t.$$

To replace the unemployment change variable by the change in the nominal money supply, we substitute equation (10) into (12), and (12) into (13). After rearranging, the new inflation equation becomes:

$$(14) \qquad p_t = \frac{1}{1+\gamma_3\psi} [\gamma_0 + \gamma_1(p_{t-1}+\lambda_t-\theta_t) + \gamma_2 U_t^W + \gamma_3\psi(m_t-q_t^*) + \gamma_4 z_t + \nu_t],$$

where ν_t is a composite error term (= $\gamma_3\psi v_t + \Delta e_t + \varepsilon_t$). It is important to note that the condition for monetary neutrality in (14) is no longer a unitary coefficient on lagged inflation, but rather that the coefficients on lagged inflation and on monetary growth sum to unity.[28]

The consequences of inserting a monetary growth rate variable into our basic inflation equation are illustrated in Table 4. To simplify the presentation, the table displays only the coefficients on the level and change of unemployment, and on the rate of change of the money supply. Throughout the M1B definition of the money supply is used. The results hinge on the length of the lag allowed on the monetary variable. When only the current and four lagged values are allowed to be entered, as in section "A" of the table, the impact of the monetary variable is minor. But when the lag distribution is extended to include 24 past monetary values, there is a substantial improvement in the fit of the equation. No results are shown for intermediate lag lengths, as a result of experiments that indicate a deterioration in fit when the lag distribution is truncated in the range between 8 and 20 lagged values.

Line A2 adds the current and four lagged values of M1B change to the basic unconstrained inflation equation displayed in line A1. There is an

TABLE 4

Effect of the Inclusion of Monetary Growth Rate Variables in the Basic Unconstrained Inflation Equation

Sample Period: 1954:Q2-1980:Q4

t ratios in [ ]

	Sum of Squared Residuals	Coefficients and t ratios		
		U^W_t	ΔU^W_t	$\sum_{i=0}^{N} (m-q^N)_{t-i}$
A. Short-run Effects				
1. Basic equation[a]	51.25	-0.60 [-4.45]	-0.62 [-1.88]	--
2. Add Growth of M1B,[b] N=5	48.99	-0.47 [-2.90]	-0.48 [-1.37]	0.17 [1.42]
3. Omit ΔU^W_t	50.25	-0.53 [-3.31]	--	0.21 [1.86]
4. Omit ΔU^W_t and M1B	53.58	-0.72 [-6.07]	--	--
B. Long-run Effects				
1. Basic Equation plus growth of M1B, N=25[c]	43.47	-0.14 [-0.56]	-0.83 [-2.30]	0.91 [2.73]
2. Omit ΔU^W_t	46.57	-0.40 [-1.80]	--	0.67 [2.06]
3. Omit ΔU^W_t and U^W_t	48.59	--	--	1.15 [6.10]
4. Omit ΔU^W_t, U^W_t and $\sum_{j=1}^{24} p_{t-j}$	60.81	--	--	1.34 [21.6]

Notes to Table 4

a. The "basic equation" is unconstrained and is identical to that estimated in Table 2, column (3), with the single exception that the change in the social security tax rate is entered only as a current value, not as a current and four lagged values. This deletion of the insignificant lagged social security tax variables is required by space limitations in our regression package and is carried out uniformly in Table 4.

b. In section A of the table, the monetary growth variable is entered in the form of the current and four lagged values, with no constraints on the lag distribution.

c. In section B of the table, the monetary growth variable is entered in the form of the current and 24 lagged values, with the lag distribution estimated to lie along a fourth-degree polynomial with a zero end-point constraint.

insignificant sum of coefficients on money, and the F ratio on the joint significance of the monetary variables in line A2 is only 0.70, compared to the 5 percent critical value of 2.33. When the unemployment change variable is omitted in line A3, the sum of coefficients on the money change variable becomes significant, but the F ratio (comparing lines A3 and A4) is still only 1.00, indicating that a higher coefficient on unemployment in line A4 substitutes for part of the contribution of the monetary variable in line A3. Thus a monetary change variable in the form of the current and four lagged values does not add any significant explanatory power and appears mainly to be a substitute for the unemployment change variable.

The results are more favorable to a monetary explanation of inflation, however, when the lag distribution is stretched out to 24 quarters. All of the lag distributions displayed in section B of Table 4 share two common features. First, they are highly bimodal, with a peak in the current quarter, then a trough, and a second peak in quarters 14-18. Second, their mean lag lengths are quite long (counting the current quarter as "zero," and the first quarter as "one," the mean lags in the four lines of section B are, respectively, 9.6, 10.2, 8.4, and 10.4 quarters). The addition of the long-lag monetary variable not only improves the fit of the equation, but also substantially reduces the size and significance of the coefficient on the level of unemployment. Comparing lines A1 and B1, the F ratio on the joint significance of the monetary variables is 3.31, compared to a 5 percent critical value of 2.50. Omission of both unemployment variables in line B3 results in a significant loss of explanatory power; the F ratio that compares lines A1 and A3 is 4.36, compared to the critical value of 3.13. Thus it appears that the long-lag money growth variable and at least one unemployment variable (level or rate of change) does better in explaining inflation that either variable alone.

Finally, line B4 shows the marked deterioration in fit when the lagged inflation variables are removed, resulting in a F ratio of 2.28 compared to a critical value of 2.03. Thus an adequate description of the inertia in the inflation process appears to require inclusion of both lagged money and lagged inflation variables, rather than either lagged variable alone. An extra experiment, not shown in Table 4, was to fit separate lag distributions on money for the first and last halves of the sample period. The F ratio on the inclusion of the extra lag distribution on money is 0.33, compared to a critical value of 2.50.

How do the implications of the best-fitting equation in line B1 of Table 4 differ from those of the basic unconstrained equation (column (3) of Table 2 and line A1 of Table 4)? The main difference is that the equation including money exhibits long-run instability, with a sum of coefficients on the money and lagged inflation variables summing to 1.80 in the first half of the sample period and to 1.35 in the last half. In contrast the sums of coefficients on lagged inflation in the basic unconstrained equation are 1.01 and 1.03, respectively. The estimated effects of the supply shift variables are similar, with almost identical coefficients on the productivity deviation and the food-energy effect in the monetary version, and a smaller coefficient on the minimum wage and social security taxes. It is somewhat surprising that the inclusion of the monetary variable does not reduce the impact of the foreign exchange rate; instead that coefficient increases from -0.11 to -0.15.

The interpretation of the monetary equation in line B1 is influenced by our unrealistic assumption in equation (9) above that changes in velocity could be treated as a serially uncorrelated variable with mean zero and constant variance. In fact the change in velocity over the sample period has been about three percent per annum (Table 1 above), and this trend is absorbed in the constant term of the equation. The relation between nominal GNP and money may also explain why the coefficients in line B1 exhibit long-run instability. This comes primarily from the high elasticity of nominal GNP changes to changes in the money supply, rather than from instability in the basic inflation process. In the vector autoregressive equation explaining nominal GNP changes presented in Table 5 below, the sum of coefficients on lagged money in the nominal GNP equation is 1.68 (this finding is parallel to the income elasticity of the demand for M1 of 0.6-0.7 found in studies by Goldfeld and others).[29] A version of line B1 in Table 4 with nominal GNP changes replacing the money supply exhibits less long-run instability; the sum of coefficients in the last half of the sample period on nominal GNP plus the lagged inflation variables is 1.10, in contrast to 1.35 when the money supply is included as on line B1.[30]

Despite the modest improvement in fit in the equations that include money or nominal GNP, there is no change in the conclusion that inertia plays a major role in the inflation process, due to the long mean lags in the influence of both money and past inflation. A complete analysis of the policy implications of the alternative equations, including their predictions regarding the output loss that would accompany a policy of steadily decelerating monetary growth, is contained in part VIII below.

Granger Causality Results

Recently considerable attention has been given to the concept of "Granger causality" as a useful way of describing relations among time series. A series X is said to cause another series Y if the inclusion of lagged values of X significantly improves the fit of regression equations explaining Y that also include lagged values of Y and other available past information. In a recent survey of this literature John Geweke has found that tests in autoregressive models are as good as or superior to other methods for testing causal orderings in time series.[31]

It is interesting to compare the results of Geweke's tests to ours, and to replicate his findings for our data and sample period. Geweke's major conclusion supports our results that inertia plays a major role in the postwar U.S. inflation process. He finds that feedback from M1 to nominal GNP "seems to arise mostly from the relationship between money and real GNP. The hypothesis that M1 and the GNP deflator are uncorrelated at all leads and lags cannot be rejected at the 10 percent level when seasonally adjusted data are used."[32] This, however, is a result characterizing business cycle frequencies. In the long run, feedback from M1 to real GNP nearly vanishes, and almost all of the long run variance in prices is attributed to innovations in M1. Finally, there is some evidence of feedback from nominal and real GNP to M1 at "those frequencies where transactions demand would lead us to expect it."

Table 5 reports on tests similar to those of Geweke for the same 1954-80 sample period as our basic inflation equation, in contrast to

TABLE 5

Granger Causality Results[a]

Sample Period: 1954:Q2-1980:Q4

In Equations Explaining	F ratios on significance of lagged			
	Inflation	Weighted Unemployment Rate	M1B Change	Nominal GNP Change[b]
Inflation	8.65***	1.21	2.15*	--
Weighted Unemployment Rate	1.21	152.40***	2.55**	--
M1B Change	1.52	1.31	2.03*	1.37
Nominal GNP Change	1.73	3.37***	4.51***	--

Notes:

a. asterisks indicate significant at:
   - * 10 percent level
   - ** 5 percent level
   - *** 1 percent level.

b. Lagged nominal GNP change is included only in the equations explaining changes in M1B.

his study of the earlier 1949-69 interval. The endogenous variables included are the same inflation, unemployment level, and money change variables used in Table 4. Nominal GNP change is not included in the inflation or unemployment equations to minimize multicollinearity. All data are seasonally adjusted, and all equations include a constant and trend term, six unconstrained distributed lags on the other endogenous variables, and (unlike Geweke's test) the set of exogenous supply variables that appear in our basic inflation equation.[33] The numbers reported in the table are F ratios on the inclusion of the six lagged values of the variables listed across the tops of the columns.

The results appear basically consistent with those of Geweke, despite the inclusion of 11 years of data after the end of his sample period. Lagged inflation is the main variable driving inflation, reflecting inertia. Short-run feedback from M1B change to inflation is marginally significant, whereas short-run feedback from unemployment to inflation is surprisingly insignificant. The short-run feedback from money change to unemployment is stronger than that from money to prices, as in Geweke's study, while we also confirm that feedback between money and nominal GNP runs almost entirely between the former and the latter. Because all equations exclude current endogenous variables, these results do not rule out contemporaneous feedback between money and nominal GNP.

Taken together, the results in Tables 4 and 5 tell a consistent story in which monetary innovations cause changes in nominal GNP, real GNP, and unemployment in the short run, and in the inflation rate in the long run. The price level is neither perfectly flexible nor perfectly inflexible in response to monetary innovations. There is a substantial short-run response, channeled entirely through unemployment variables in conventional Phillips curves and in our basic inflation equation, and through a combination of unemployment and money variables in Tables 4 and 5. As this initial effect feeds back through the lagged inflation variables, the responsiveness of inflation to monetary innovations becomes larger and that of real GNP and unemployment becomes smaller. It is the task of our simulation experiments in part VIII to quantify the short-run and long-run responsiveness of inflation to monetary innovations, and to test whether the simulation results are sensitive to the direct inclusion of monetary variables in the inflation equation.

VI. THE ROLE OF WAGE EQUATIONS AND "WAGE-WAGE FEEDBACK"

Our explanation of the U.S. postwar inflation process in this paper differs from most previous studies not only in its stress on supply-shift variables, but also in its omission of an equation explaining the behavior of wages. Any inertia in the wage-setting process is captured by the patterns of coefficients on the lagged inflation variables in the inflation equation itself. Several considerations call for an examination of wage determination and parallel equations that explain price change relative to wage change. First, a dynamic simulation of our basic single-equation explanation as compared to a two-equation wage-price model can help to determine which approach provides the best fit to inflation data within the sample period. Second, simulations for future periods under different monetary regimes can compare the dynamic responsiveness of one-equation and two-equation systems. Third, estimation of wage equations is required to test a maintained hypothesis in our original specification in equation (2) that wage change depends on past price change, not past wage change. Fourth, the hypothesis of wage-wage inertia, which has played a major role in recent empirical research and in theoretical analyses of the inflation process by Hall and Okun, needs to be tested directly.[34]

Table 6 is an extension of Table 2. Column (1) in Table 6 is our basic unconstrained inflation equation, exactly the same equation as in column (3) of Table 2. All the unemployment and supply-shift variables are entered identically in every equation in Table 6, and the only difference

TABLE 6

The Relation Between Price and Wage Change

Sample Period: 1954:Q2-1980:Q4

t ratios in [ ]

	Price Change		Wage Change		
	Basic Equation	Markup Version	Lagged Prices	Lagged Wages	Lagged Both
	(1)	(2)	(3)	(4)	(5)
1. Constant	2.45 [3.52]	2.63 [4.24]	-0.16 [-0.13]	2.08 [2.01]	2.00 [2.20]
2. Lagged Inflation[a]	--	--	--	--	0.91 [1.96]
3. Lagged Inflation[a] first half	1.01 [3.10]	--	1.31[b] [4.30]	--	--
4. Lagged Inflation,[a] last half	1.03 [10.5]	--	1.17[b] [6.92]	--	--
5. Lagged Wage Change[a]	--	--	--	--	-0.08 [-0.16]
6. Lagged Wage Change[a] first half	--	0.72[b] [3.03]	--	0.79 [3.23]	--
7. Lagged Wage Change,[a] last half	--	1.03[b] [1.33]	--	1.00 [7.47]	--
8. Weighted Unemployment Rate	-0.59 [-4.30]	-0.41 [-3.18]	-0.42 [-2.92]	-0.36 [-2.51]	-0.40 [-2.56]
9. Change in Weighted Unemployment	-0.64 [-1.92]	-0.64 [-1.95]	-0.81 [-2.42]	-0.67 [-1.86]	-0.81 [-2.33]
10. Productivity Deviation	-0.08 [-2.03]	-0.10 [-2.75]	0.02 [0.49]	0.00 [0.00]	0.01 [0.33]
11. Food and Energy[c] Prices	0.74 [3.31]	0.55 [2.60]	0.37 [1.81]	0.13 [0.59]	0.50 [2.42]
12. Foreign Exchange[d] Rate	-0.11 [-1.70]	-0.06 [-1.00]	-0.04 [-0.62]	-0.04 [-0.73]	-0.18 [-2.95]
13. Effective Minimum[c] Wage	0.02 [1.17]	0.02 [0.86]	-0.02 [-0.86]	-0.02 [-1.04	0.01 [0.47]
14. Social Security Tax[c]	0.27 [1.00]	0.13 [0.48]	-0.32 [-1.18]	-0.35 [-1.16]	-0.27 [-1.03]
15. Nixon Controls "on"[e]	-1.45 [-2.61]	-1.61 [-2.93]	-0.83 [-1.48]	-1.15 [-1.85]	-0.86 [-1.51]
16. Nixon Controls "off"[e]	2.61 [3.86]	2.25 [3.33]	1.61 [2.39]	1.92 [2.65]	1.47 [2.20]
R^2	.942	.942	.898	.874	.900
Sum of Sqd. Residuals	50.2	50.7	48.7	59.9	47.8
S.E.E.	0.823	0.827	0.811	0.899	0.803

Notes to Table 6

a. See note a to Table 4.

b. The lagged wage variable in column (2) is the quarterly change in the fixed-weight average hourly earnings index minus the change in the productivity trend (see footnote 22). The lagged price variable in column (3) is the inflation rate plus the same productivity trend.

c. through e. See corresponding notes to Table 2.

is in the choice of current wage or price change as the dependent variable, and in the choice of lagged wages or prices (or both) as an explanatory variable.

Columns (2) and (3) report price mark-up and wage equations that correspond to the original specification in equations (2) and (3). Because it is difficult to determine *a priori* which of the supply-shift variables influences the price mark-up and which influences wages, all of those variables are entered in each column. The implications of the two-equation system can be compared to the single equation in column (1) by summing coefficients across columns (2) and (3). Such a summation yields roughly consistent results for the inertia variables, the productivity deviation, food and energy prices, and the social security tax. But in the two-equation system the combined impact of the unemployment variables and the Nixon controls appears to be greater, while the influence of the minimum wage rate vanishes. A surprise in the two-equation system is the fact that both the level and rate-of-change effects for unemployment are significant in both the price mark-up and wage equations. This differs from past studies, including my own, which have typically included only a level term in the wage equation and only a rate-of-change term in the price mark-up equation.[35] Another unexpected result is that current and lagged increases in food and energy prices significantly boost the rate of wage change, even when lagged changes in the GNP deflator are included in the wage equation. This tends to argue against the simple wage-wage view stressed by Hall and Okun.

Two direct tests of wage-wage inertia are provided in columns (4) and (5) of Table 6. Column (4) replaces the lagged inflation variables of column (3) with lagged wage change variables, resulting in a 23 percent increase in the unexplained variance. The statistical weakness of the wage-wage explanation is surprising, since feedback is allowed from food and energy prices to wages. Another test in column (5) enters both lagged inflation and wage change in the wage equation. The result is a sum of coefficients on lagged inflation that is close to unity, and on lagged wage change that is of the incorrect sign and is insignificantly different from zero.[36] When column (5) is reestimated with the *difference* between lagged wage and price change entered instead of lagged wage change itself, the resulting sum of coefficients is -0.55, rather than the coefficient of 1.0 that would be required to validate pure wage-wage inertia.[37] Overall, lagged inflation contributes significant explanatory power in wage equations and seems superior to the alternative hypothesis of wage-wage inertia. Simultaneity problems do not influence these results, since current inflation is not included as a right-hand variable in any of the wage equations in Table 6. I have previously attributed the influence of lagged prices in wage equations to the importance of shifts in labor demand along a relatively inelastic supply curve for labor.[38]

Additional hypotheses can be tested with the structure of wage and price equations displayed in Table 6, but most of these are outside of the scope of this paper. One issue which has received much recent attention is the inflationary impact of the treatment of homeownership in the Consumer Price Index.[39] When the difference between the change in the CPI and in the fixed-weight GNP deflator is entered into the basic wage equation in Table 6, column (3), in the form of eight lagged values, the resulting sum of coefficients is 0.35 with a t ratio of 2.1. When the same variable is entered into the basic inflation equation in column (1), the sum of coefficients is 0.35 with a t ratio of 1.7. The F ratio on the inclusion of this extra lag distribution in the inflation equation is 1.44, as compared to the 5 percent critical value of 2.50. Thus it appears that differences in measurement procedures between the CPI and GNP deflator affect the overall inflation process, and that this effect is channeled through the use of the CPI as an escalator in wage contracts. This additional variable is not included in the basic inflation equation used in the simulations described in the next two sections, because it is clearly endogenous (depending on interest rates) and for an adequate treatment would require that we go beyond the scope of this paper by building a model of interest-rate behavior. Fortunately this omission is not a serious one, since the significance level of the CPI variable is marginal, and because its inclusion causes only minor changes in other coefficients.

VII. COUNTERFACTUAL SIMULATIONS WITHIN THE SAMPLE PERIOD

Our inflation equation can be used to measure the quantitative impact of specific supply shifts and of alternative demand policies. Every simulation illustrated in this section is "dynamic," that is, applies the fitted coefficients on the lagged dependent variable to those generated within the simulation rather than to the actual historical values. We first present simulations in which the actual values of the unemployment and productivity variables are entered. Next, equations are added that explain unemployment, productivity, and the foreign exchange rate, in order to allow us to examine the responsiveness of inflation to alternative counterfactual demand policies.

Tracking Ability in Dynamic Simulations

The inflation equation included in all simulations in Parts VII and VIII is the constrained version listed in Table 2, column (6). This equation was estimated in a form that constrains the sum of coefficients on the lagged dependent variable to be unity, so that the equation can track a steady state relation between money growth and inflation in our simulations of hypothetical future demand management policies. The equation, as in Table 2, also includes small coefficients on dummy variables for the first and last halves of the 1970s (these were the dummy variables used to compute the shifts in the natural rate of unemployment, as listed at the bottom of page 28).

The first pair of columns in Table 7 compares four-quarter averages of the actual inflation rate with those fitted in a dynamic single equation simulation of the 1971-80 period, that is, a simulation in which

TABLE 7

Actual and Fitted Values
in Dynamic Simulations of the
1971-80 and 1978-80 Intervals

	Inflation Rate			Unemployment Rate	
		Simulated with Unemployment			Simulated with Unemployment
	Actual	Exogenous	Endogenous	Actual	Endogenous
	(1)	(2)	(3)	(4)	(5)
A. Four Quarters Ending					
1971:Q4	4.40	4.20	4.52	5.95	5.97
1972:Q4	4.12	4.15	4.44	5.58	5.29
1973:Q4	6.75	7.16	7.51	4.85	4.57
1974:Q4	10.31	10.43	10.14	5.59	6.08
1975:Q4	7.05	6.78	6.57	8.48	8.88
1976:Q4	5.05	5.73	5.17	7.68	8.27
1977:Q4	6.41	6.07	5.64	7.03	7.24
1978:Q4	8.33	8.43	8.08	6.00	6.06
1979:Q4	8.51	9.37	9.11	5.79	5.62
1980:Q4	9.29	8.82	8.52	7.17	6.84
Cumulative Error	--	-1.06	0.20	--	-0.87
B. Four Quarters Ending					
1978:Q4	8.33	8.37	8.24	6.00	6.02
1979:Q4	8.51	9.37	9.54	5.79	5.74
1980:Q4	9.29	8.83	8.82	7.17	7.01
Cumulative Error	--	-0.58	-0.76	--	0.05

fitted values of the lagged dependent variable are fed back into the equation but all other variables are taken as exogenous. The cumulative error is -1.06 percent, meaning that the actual price level is about one percent less than the simulated price level after ten years, so that the mean error in tracking the inflation rate is only -0.10 percent per year. The standard error of the simulation (not shown in the table) is 0.751, close to the 0.785 standard error listed in Table 2 for the estimated equation over the entire 1954-80 period. For purposes of comparison, an identical simulation was computed for a two-equation model containing the wage and price mark-up equations listed in Table 6, column (2) and (3). The resulting standard error for the inflation rate over the same period was 0.833, indicating an increase in the unexplained variance of about 20 percent. This confirms that wage equations, while interesting in their own right, are not necessary for a historical understanding of the U.S. inflation process. By way of contrast, a dynamic simulation of the best-fitting equation that directly enters lagged changes in the money supply (Table 4, line B1) has a standard error of 0.751, exactly the same as the basic equation.

A more challenging task is to track historical inflation rates in a three-equation model in which the unemployment rate and productivity deviation are made endogenous. The inflation equation is the same as before, but equations are added that explain changes in the unemployment rate and the productivity deviation as a function of current and lagged changes in the output ratio (i.e., ratio of real to natural real GNP). The unemployment equation is a first-difference version of our "Okun's Law" equation (1) above, and the productivity equation reflects the lagged adjustment of hours to changes in output. Detailed listings of coefficients and further comments on these "auxiliary" equations are contained in Appendix A. The purpose of the three-equation model is to allow changes in both the inflation and unemployment rates to be calculated for changes in the exogenous supply shift variables and for specified time paths of nominal GNP. When nominal GNP is specified, an identity can be used to calculate the change in the output ratio corresponding to any inflation rate, and then the auxiliary equations can be used to compute the unemployment rate and productivity deviation. An iterative procedure is used to make the initial given inflation rate converge to that predicted by the inflation equation.

The third column of Table 7 shows the fitted values of the inflation rate in a dynamic simulation of the three-equation model. The cumulative and mean errors are actually smaller than those in the simulations of the one-equation model. Columns (4) and (5) show how closely the unemployment rate can be tracked in this simple model that takes nominal GNP and the supply shift variables as exogenous, and uses coefficients estimated from the full 1954-80 period, but which uses no information on the actual values of inflation, unemployment, or the productivity deviation after 1970 in the calculations of the fitted values.

The bottom section (B) of the table repeats the simulations for the last three years of the sample period. The results are very close to those from the decade-long sample period. The most interesting, and potentially serious, error in all the inflation simulations is the tendency to predict too high an inflation rate in 1979 and too low a rate in 1980.

Decomposing the Impact of Supply Shifts

The estimated impact of the various supply shift variables in the inflation equation can be calculated by successively setting each to zero in dynamic simulations like those of Table 7. Should the unemployment rate or nominal GNP be chosen as the exogenous variable in these counterfactual simulations? Either choice is unsatisfactory. This can be seen in Table 8, where column (1) repeats the fitted values from the single-equation simulation that treats unemployment as exogenous (Table 7, column (2)), and where column (2) computes an artificial inflation series by setting equal to zero the coefficients on changes in the relative prices of food and energy, the foreign exchange rate, productivity deviation, effective minimum wage rate and social security tax, and on the Nixon control dummy variables. The result in column (2) is an estimated increase in the inflation rate from 5.3 in 1971 to 6.1 percent in 1973, followed by a decline to 3.7 percent in 1980. This time path reflects, of course, the historical fact that the unemployment rate dipped below our estimate of the natural unemployment rate in 1972-73, and again in 1979, but was above the natural rate during the rest of the decade. This is an unrealistic simulation of a world without supply shocks, because much of the high unemployment experienced during 1974-77 and in 1980 was a direct result of the supply shocks themselves, so it is doubtful that the low simulated 1980 inflation rate would have been achieved.

On the other hand, simulations with the growth of nominal GNP or the money supply treated as exogenous and with supply shifts suppressed

TABLE 8

Change in the Inflation Rate, 1971-80,
When Sources of Inflation Are Suppressed in A Dynamic Simulation
(Unemployment Rate Exogenous)

	Simulated Inflation Rate		Effect of				
	All Supply Shifts Exogenous	Suppress All Supply Shifts	Productivity Deviation	Foreign Exchange	Min. Wage and Soc. Sec.	Food and Oil	Nixon Controls
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Four Quarters Ending							
1971:Q4	4.20	5.34	-0.17	0.04	-0.07	-0.22	-0.72
1972:Q4	4.15	5.58	-0.35	0.41	-0.09	0.05	-1.45
1973:Q4	7.16	6.07	-0.11	0.56	0.07	1.41	-0.84
1974:Q4	10.43	5.76	0.19	1.33	0.09	2.32	0.72
1975:Q4	6.78	4.15	-0.24	0.70	0.41	1.84	-0.08
1976:Q4	5.73	4.26	-0.21	0.09	0.31	1.25	0.03
1977:Q4	6.07	4.28	-0.27	0.64	0.27	1.15	0.00
1978:Q4	8.43	4.59	-0.04	1.79	0.39	1.73	-0.03
1979:Q4	9.37	3.74	0.05	1.33	0.49	2.94	-0.01
1980:Q4	8.82	3.74	0.04	1.38	0.49	3.24	0.03
Cumulative Difference[a]	-1.06	19.77	-1.12	7.71	2.17	14.44	-2.37

Note: a. The cumulative difference in columns (1) and (2) is the difference between actual and predicted inflation. In columns (3) through (7) the difference refers to the change in the fitted inflation rate when the coefficients on the supply shift terms are successfully set to zero. The sum of the differences in columns (3) through (7) equals the difference between column (2) and column (1).

lead to a predicted 1980 inflation rate of 8.1 percent and an unemployment rate of 4.5 percent. This is equally unrealistic, because much of the acceleration in nominal GNP and money growth after 1975 occurred as policymakers partially accommodated the supply shifts in order to prevent a larger increase in unemployment than actually occurred. The growth in nominal GNP, money, and prices would all have been lower in the late 1970s in the absence of supply shifts. The fact that 1980 inflation without supply shifts and with nominal GNP exogenous is predicted to 8.1 percent, only slightly less than the predicted 8.8 percent with supply variables included, illustrates the neutrality property displayed by our estimated inflation equation--over a period as long as a decade, inflation depends almost entirely on the growth of nominal demand, and supply shifts serve mainly to influence the unemployment rate.

The right-hand section of Table 8 illustrates the estimated effects of the separate right-hand variables when unemployment is exogenous. The figures show the extra inflation in each year contributed when the estimated coefficients of the listed variable are included in the equation as compared to the inflation that occurs when the coefficients are set at zero. It is not surprising to find that the most important of the supply-shift variables in contributing to inflation was the change in the relative price of food and energy, followed by the change in the foreign exchange rate.[40] The lack of importance of the productivity deviation is explained not just by the small size of its coefficient, but also by the fact that the step-like slowing of the productivity trend is estimated from the entire sample period, so that the mean of the productivity deviation is zero (see footnote 22 above). The impact of the minimum wage rate and social security tax is minor, enough to contribute about half a point of inflation in 1980 and a two-percent higher price level in that year. Finally, the cumulative effect of the Nixon controls is negative despite the fact that the "on" and "off" coefficients are equal; this result is an artifact of the dynamic simulation, which allows any variable having an early impact a longer change to be built into the lagged dependent variable than another variable having a later impact.[41]

To Accommodate or Not to Accommodate?

After the first OPEC oil shock in 1973-74 economists debated the merits of accommodating the shock by allowing a one-time jump in the money supply to "pay for" the jump in oil prices. Other economists argued that in this circumstance, as in all other circumstances, the best policy was a constant growth rate rule for the money supply. In this section we present the verdict of our inflation equation regarding the costs and benefits of alternative monetary policies after the first OPEC shock.

In the previous section we described the auxiliary equations that generated paths for the unemployment rate and productivity deviation with nominal GNP treated as exogenous. In this section we need to go further and allow for the impact of monetary policy on inflation through the channel of changes in the foreign exchange rate. Although a complete treatment of exchange rate determination requires a consideration of differentials between domestic and foreign interest rates, an exchange-rate equation is presented in Appendix A that provides a surprisingly good fit to data for 1972-80 including as exogenous variables only the growth rates of money, nominal GNP, and the relative price of food and energy. When this equation is joined by a simple vector autoregressive equation that explains nominal GNP changes by its own lagged values and by current and lagged changes in the money supply, it is possible to generate alternative scenarios corresponding to different monetary growth rates. The basic inflation equation plus the four auxiliary equations allow five variables to be treated as endogenous--inflation, unemployment, the productivity deviation, and the growth rates of nominal GNP and the effective exchange rate.

Table 9 shows the impact of two counterfactual monetary growth paths. The first is a "constant growth-rate rule" (CGRR) path that sets M1B growth each year exactly 2.0 points above the growth rate of natural real GNP. Because the latter declines between 1975 and 1980, the CGRR path for M1B growth in Table 9 also displays a deceleration. The second "accommodative jump" path is designed to generate the same cumulative growth in M1B that actually occurred between 1975:Q1 and 1980:Q4 but in a different time configuration, with an initial jump followed by a CGRR policy that sets the rate one percentage point faster than the "pure" CGRR policy. This hypothetical policy is displayed only to show the mechanical properties of the model, since it is unlikely that the Federal Reserve could actually achieve such precise control of the money supply.

The results show the expected reduction of inflation and increase in unemployment under the pure CGRR path. But the tradeoff is more favorable than in the typical simulation of large-scale econometric models. By the end of 1980 the inflation rate is three percentage points lower with CGRR,

TABLE 9

Impact of Alternative Monetary Policies

1975-1980

(M1B Growth Exogenous)

	M1B Growth			Inflation Rate[a]			Unemployment Rate[a]		
	Actual	CGRR Path	Jump Path	Actual	CGRR Path	Jump Path	Actual	CGRR Path	Jump Path
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Four Quarters Ending									
1975:Q4	5.21	5.87	10.28	7.05	0.00	0.25	8.48	0.00	-0.33
1976:Q4	5.82	5.57	6.57	5.05	0.06	2.33	7.68	-0.06	-1.78
1977:Q4	7.77	5.28	6.28	6.41	-0.24	1.77	7.03	0.11	-1.15
1978:Q4	7.86	5.28	6.28	8.33	-1.50	0.75	6.00	0.86	0.25
1979:Q4	7.36	4.74	5.74	8.51	-2.35	-0.25	5.79	1.19	1.26
1980:Q4	6.87	4.74	5.74	9.29	-2.93	-1.08	7.17	0.97	1.61

Notes: a. The inflation and unemployment figures shown for the simulated paths refer to the difference when the indicated money growth rates are entered as compared to a control solution that enters the actual growth rate of money.

while the unemployment rate is about one percentage point higher. The cumulative loss in output over the six-year simulation is only 5.7 percent of real GNP. The alternative "accommodative jump" path, as would be expected, initially generates more inflation and a reduction in the unemployment rate, but then generates the reverse as money growth rates fall below those that actually occurred. The cumulative loss in output relative to the actual path taken by the money supply is negligible, only 0.4 percent of real GNP. In both cases, however, the cumulative output loss figure is an understatement by ignoring the further losses that would occur if the simulation were allowed to run after 1980.

VIII. SIMULATIONS OF HYPOTHETICAL FUTURE POLICIES

Limitations of Simulations Across Policy Regimes

Simulations of our basic inflation equation are of interest only if the parameters will remain invariant to alternative hypothetical policy regimes.[42] Is there reason to believe that key parameters would shift between a world of 7 percent monetary growth and a world of 2 percent monetary growth? Such a policy change, although it seems drastic from the perspective of 1981, would simply throw into reverse the policy shift that allowed the growth rate of M1B to accelerate from 2 percent in 1954-64 to 7 percent in 1976-80 (see Table 1 above).[43] Our confidence in the relevance of policy simulations is bolstered by the finding in Part IV that a Chow test fails to reject the null hypothesis that the first half of our sample period obeys the same inflation equation as the last half.

Two sets of parameters are allowed to shift in our basic inflation equation. First, the lag distribution on past inflation is fitted separately to the first and last halves of the sample period, with the conclusion that the mean lag shortened from about 11 to about 7 quarters. Would a reversal to an earlier monetary policy regime cause the lag to lengthen? This would occur if agents became less concerned about inflation and were willing to accept a greater fraction of nominal contracts in preference to escalated contracts. I doubt that such a shift is likely in the near future, because agents will want to experience a substantial period of stable prices before abandoning indexed contracts. Another consequence of rapid monetary growth has been the advent of the flexible exchange rate system, which in our inflation equation makes the inflation rate more responsive to variations in money growth. While a stable inflation rate in the U.S. is unlikely to cause a return from flexible exchange rates to Bretton Woods, nevertheless the likely impact of U.S. monetary policy on other nations needs to be considered explicitly in any simulation of future events.

As is illustrated below, the inclusion of the foreign exchange rate variable allows our model to generate a sharp slowdown in the inflation rate in a relatively short time with a relatively low cost in terms of lost output. This occurs because a slowdown in the rate of monetary growth relative to nominal GNP growth, as occurs during a transition period before nominal GNP growth responds, is estimated to cause an appreciation of the exchange rate (the events of 1980:Q4 and 1981:Q1 demonstrate the responsiveness of the exchange rate to changes in interest rates and in the growth of velocity). In addition, the subsequent slowdown in nominal GNP growth is estimated to cause an additional appreciation. If it were interpreted literally, our foreign-exchange-rate equation would predict a continuous and permanent appreciation following a return to low rates of growth in money and nominal GNP, with continuous downward pressure on the inflation rate. This would be unrealistic, however, because the exchange-rate equation contains no variables for other nations, and they would surely respond to a new monetary regime in the U.S. All our simulations assume a response by other nations after two years, and this is implemented by making the exchange rate respond not to nominal GNP growth itself, but rather to the difference between current nominal GNP growth and a four-quarter moving average of nominal GNP growth two years earlier. Following the arrival of money at its new lower steady state, this treatment causes the exchange-rate appreciation to disappear after roughly two years.

Our inflation equation implies that the impact of high interest rates caused by monetary restriction is to dampen inflation through the exchange-rate effect. This impact might be mitigated by two other effects of high interest rates that are ignored, those operating through capital costs and through the CPI measurement error. In previous research I was unable to find an effect of interest rates on inflation through the capital-cost channel.[44] As for the CPI channel, its omission is a defect of the simulations, but there may be two offsetting implications. Initially a restrictive monetary policy raises both nominal and real interest rates, boosting the CPI and adding to inflation. But then as other variables, particularly the unemployment rate and the exchange rate, cause inflation to decelerate, the nominal interest rate will fall relative to the real rate, and this will reduce the growth of the CPI relative to the GNP deflator and help to decelerate the GNP deflator further.

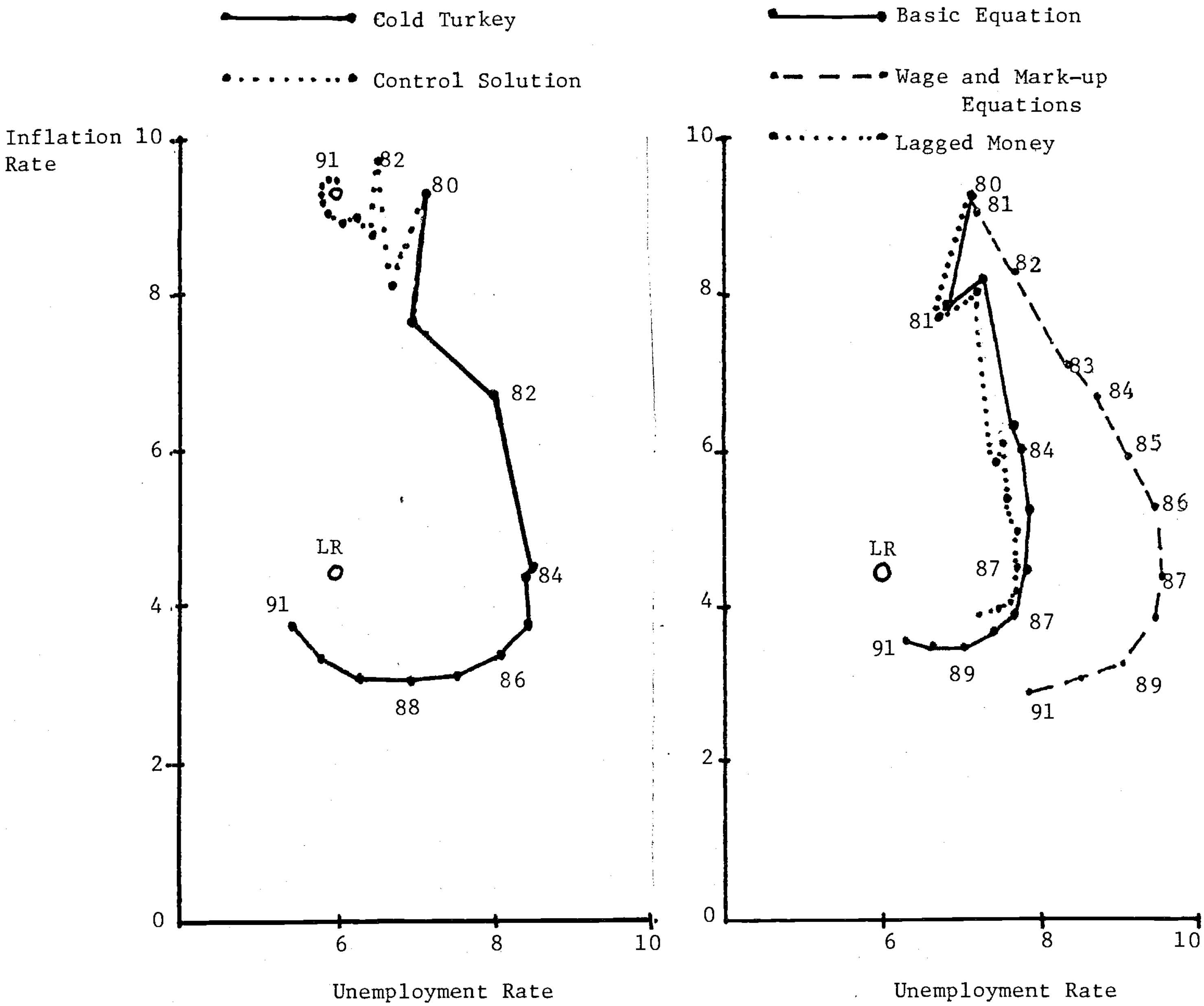
Our simulations are all based on specified growth paths for the growth of the money supply (M1B). Some "cold turkey" simulations are based on an instantaneous 5 percent drop in the rate of monetary growth. Like the "accommodative jump" simulation described in the previous section, the "cold turkey" experiments assume an unrealistic degree of control by the Federal Reserve over the money supply. They are presented not because they are plausible, but to allow the characteristics of the model simulations to be clearly perceived in the figures. A final qualification is that the relation between nominal GNP growth and M1B growth is determined by an equation estimated to the entire 1954-80 sample period. If financial innovations or the flexible exchange rate system have altered the relationship between nominal GNP and money in the last few years, our simulations may contain an error. We may, for instance, have understated the growth in the velocity of M1B if financial innovations have accelerated the movement into other assets. In addition, we have ignored the impact of an exchange-rate appreciation in reducing the foreign trade surplus, thus creating a channel of negative feedback from exchange rates to velocity.

The Control Solution and the Arithmetic of Disinflation

The U.S. economy was not in long-run equilibrium in early 1981, thus posing a problem in the choice of a benchmark for our policy simulations. In the eight quarters ending in 1980:Q4 the growth of M1B averaged 7.1 percent at an annual rate. Our nominal-GNP equation predicts that maintenance of that money growth rate permanently would be associated with a 10.3 percent growth rate of nominal GNP, reflecting the historical behavior of velocity. Since the excess of nominal GNP growth over natural real GNP growth, roughly 7.5 percent in this case, must be equal to the inflation rate in the long run, the U.S. inflation rate of 9.3 percent in 1980 was almost two percentage points above the long-run equilibrium rate.[45] Turning the arithmetic around, if we ignore the possibility of faster growth in velocity or slower growth in natural real GNP than we have assumed, a steady state with 9.3 percent inflation would require M1B growth of 9 percent.

The situation of the U.S. economy in early 1981 is explained by the supply shocks and exchange rate changes of 1977-80 that pushed the inflation rate above the long-run equilibrium level, together with overshooting in response to the acceleration of nominal demand growth in the late 1970s. Because our dynamic simulations set all of the supply shift variables equal to zero after 1981:Q1, they exhibit the property that continuation of 7 percent growth in M1B will cause the inflation rate to fall to 7.3 percent while the unemployment rate is declining to its natural rate of 6.0 percent. The *elimination* of adverse supply shifts itself creates a beneficial supply shift, allowing policymakers to achieve a simultaneous reduction in inflation and unemployment, just as occurred in the U.S. between 1975 and 1976. The relatively optimistic set of simulations presented here reflects the assumed absence of further increases in the relative price of food and energy, or in the effective social security tax and effective minimum wage.[46]

To avoid confusing the deceleration of the inflation rate that would occur with continued 7 percent M1B growth and the further deceleration that would accompany a slower monetary growth, our control solution displayed as the dotted line in Figure 1a sets the monetary growth rate at 9 percent in order to generate a long-run inflation rate equal to the 1980 rate of 9.3 percent.[47] As is the case in all of the dynamic simulations in this part of the paper, the simulation extends from 1981:Q1 to 1991:Q4, and uses the four auxiliary equations of Appendix A to translate specified patterns of monetary growth into the unemployment, productivity deviation, and exchange rate variables that appear on the right-hand side of our basic inflation equation from Table 2, column (6). The zig-zag pattern displayed in Figure 1a by the control solution in 1981 and 1982 reflects the response of the foreign exchange rate to the



(a) Basic Equation: Control vs. Cold Turkey Solutions

(b) "Volcker" Simulation: Three Alternative Equations

FIGURE 1

Alternative Simulations, 1981:Q1 - 1991:Q4 deceleration of the monetary growth to 9 percent from an extremely rapid 12 percent annual rate in the last half of 1980. This exchange-rate effect soon dies out, and the control solution thereafter smoothly approaches the long-run values of 9.3 percent inflation and 6.0 percent unemployment indicated by the open circle in Figure 1a.

The "Cold Turkey" and "Volcker" Approaches to Disinflation

A dramatic contrast is provided by the "cold turkey" solution which suddenly and permanently reduces M1B growth to 4.0 percent in 1981:Q1, implying a long-run equilibrium inflation rate of 4.4 percent, shown by the open circle labelled "LR" in Figure 1a. The economy's adjustment to this monetary shock is surprisingly rapid, with inflation falling to 4.4 percent by 1984, and then overshooting for the rest of the decade as a result of the high unemployment rates reached during the process of adjustment. The cold turkey simulation presents a more optimistic view regarding the possibility of achieving a permanent reduction in the inflation rate than is implied by the consensus of existing large-scale econometric models. Arthur Okun popularized the view that the cost of a permanent one-percentage-point reduction in the inflation rate is 10 percent of a year's GNP, or a 50 percent output loss to cut inflation by five percentage points.[48] In contrast, the cumulative loss of output in the cold turkey simulation as opposed to the control solution is 29 percent, as shown on line 1d of Table 10. As shown on the same line, contributing to the relative degree of optimism in this simulation is the

TABLE 10

Summary of Policy Simulations, 1981-91

	Inflation in 1991	Unemployment in 1991	Peak Unem- ployment Rate[a]	Cumulative Exchange-Rate Appreciation	Cumulative Percentage Output Loss
	(1)	(2)	(3)	(4)	(5)
1. Basic Inflation Equation					
a. Control Solution	9.4	5.9	6.7 (1981)	-12.1	8.7
b. Cold Turkey	3.7	5.4	8.6 (1984)	22.8	37.7
c. Volcker Path	3.6	6.2	7.8 (1985)	20.8	37.2
d. Impact of Cold Turkey (b-a)	-5.7	-0.5	--	34.9	29.0
e. Impact of Volcker Path (c-a)	-5.8	0.3	--	32.9	28.5
2. Equation with Lagged Money					
a. Control Solution	9.0	5.1	6.7 (1981)	-12.1	1.2
b. Cold Turkey	3.8	7.1	8.4 (1985)	22.8	50.0
c. Volcker Path	3.9	7.3	7.8 (1987)	20.8	42.1
d. Impact of Cold Turkey (b-a)	-5.2	2.0	--	34.9	48.8
e. Impact of Volcker Path (c-a)	-5.1	2.2	--	32.9	40.9
3. Wage and Price Mark-up Equations					
a. Control Solution	9.4	6.7	6.9 (1981)	-12.1	24.0
b. Cold Turkey	2.8	6.6	10.2 (1985)	22.8	73.0
c. Volcker Path	2.9	7.8	9.6 (1987)	20.8	70.0
d. Impact of Cold Turkey (b-a)	-5.6	-0.1	--	34.9	49.0
e. Impact of Volcker Path (c-a)	-5.5	0.9	--	32.9	46.0

Note: a. The peak unemployment rate is calculated on a four-quarter average basis, beginning in the four quarters ending in 1981:Q4.

behavior of the foreign exchange rate, which in 1991 is 35 percent higher with the cold turkey policy than with the control solution policy.

The effect of an alternative and more realistic monetary policy is illustrated in Figure 1b. Corresponding to the stated intention of the Federal Reserve Board to achieve a deceleration in M1B growth of one-half percentage point per year, the "Volcker path" slows money growth at that pace from 6.9 percent in 1980:Q4 to 4.0 percent (reached in 1985:Q4). Corresponding to the gradualist nature of this policy, the inflation rate decelerates more slowly and the peak unemployment rate is 7.8 percent as compared to 8.5 percent under cold turkey. The period of high unemployment lasts longer, however, accounting for the fact that the cumulative output loss under the two disinflationary policies is almost identical, as is the cumulative appreciation of the dollar.

Sensitivity of Simulation Results to Specification Changes

Our analysis of historical dynamic simulations in Part VII reported that data for 1971-80 could be tracked equally well by our basic equation and by an alternative equation that added a long distributed lag of past changes in the money supply (equivalent to Table 4, line B1). We also tested the tracking ability of a wage equation combined with a price mark-up equation (Table 6, columns (2) and (3)) and found a substantial deterioration in tracking ability. The behavior of the economy in response to a Volcker path of monetary deceleration is simulated with the money and wage-price equations and is compared with the basic equation in Figure 1b. Each of these simulations shares in common the same auxiliary equations, and thus identical time paths of money, nominal GNP, and exchange rates. The less responsive the inflation rate, of course, the greater will be the transitional unemployment rate experienced during the period of adjustment.[49]

The equation that includes lagged money behaves almost identically to the basic equation through 1985, as shown by the dotted line in Figure 1b. But then the economy seems to "get stuck" at a relatively high rate of unemployment, leading this simulation to generate a higher cumulative output loss than the basic equation (Table 10, line 2e). This occurs because the lagged money terms reduce the coefficient on the level of unemployment rate almost to zero, thereby eliminating the mechanism by which the basic equation gravitates to the natural unemployment rate. The pattern of coefficients on lagged inflation and lagged monetary changes does not generate the substantial overshooting required to reduce the unemployment rate to the natural unemployment rate, so in 1991 the unemployment rate is still 7.3 percent. The control solution displays a tendency to drift in the opposite direction, and yields a 5.1 percent unemployment rate in 1991.

The wage and price mark-up equations produce an adjustment path that exhibits more sluggish behavior than the basic equation, and thus implies higher unemployment rates and a higher cumulative output loss during the period of adjustment. The cumulative output loss is 46 percent along the Volcker path (Table 10, line 3e), similar to Okun's estimate of a 50 percent loss, and this is an understatement because the economy still has not arrived at the natural unemployment rate in 1991. The sluggish behavior of the wage and price mark-up system reflects the longer implicit adjustment lags introduced by the interaction of two lag distributions, one in each equation. Thus the impact of the higher unemployment and foreign exchange rates in the wage equation cannot affect inflation until it feeds into the price mark-up equation through a lag distribution that has a mean lag of 6 quarters.

Further evidence on the characteristics of the different equations is provided in Figure 2, where the left frame illustrates the difference between the cold turkey and control solutions. As shown by the circle marked "LR," in the long run the difference should be -5 percent for the inflation rate and zero for the unemployment rate. By 1991 both the basic equation and the wage/price-mark-up equations have completed most of their adjustment, with the latter displaying a more sluggish response and a greater degree of overshooting. The equation that includes lagged money displays the same tendency to "get stuck" and in 1991 generates an unemployment rate with the cold-turkey policy two percentage points higher than with the control solution policy. The right-hand frame of Figure 2 shows that the response of the basic equation becomes much more sluggish if the foreign-exchange effect is artificially suppressed while the other coefficients remain the same. The cumulative output loss along the cold turkey path rises from 29 percent to 48 percent.

The degree of response of the inflation rate can be stated alternatively as the percentage of the deceleration in nominal GNP along the cold-turkey path, as opposed to the control path, taking the form of a deceleration of inflation. The more rapid response of the basic equation, and that including lagged money, is clear here in comparison with the wage/price-mark-up equations:

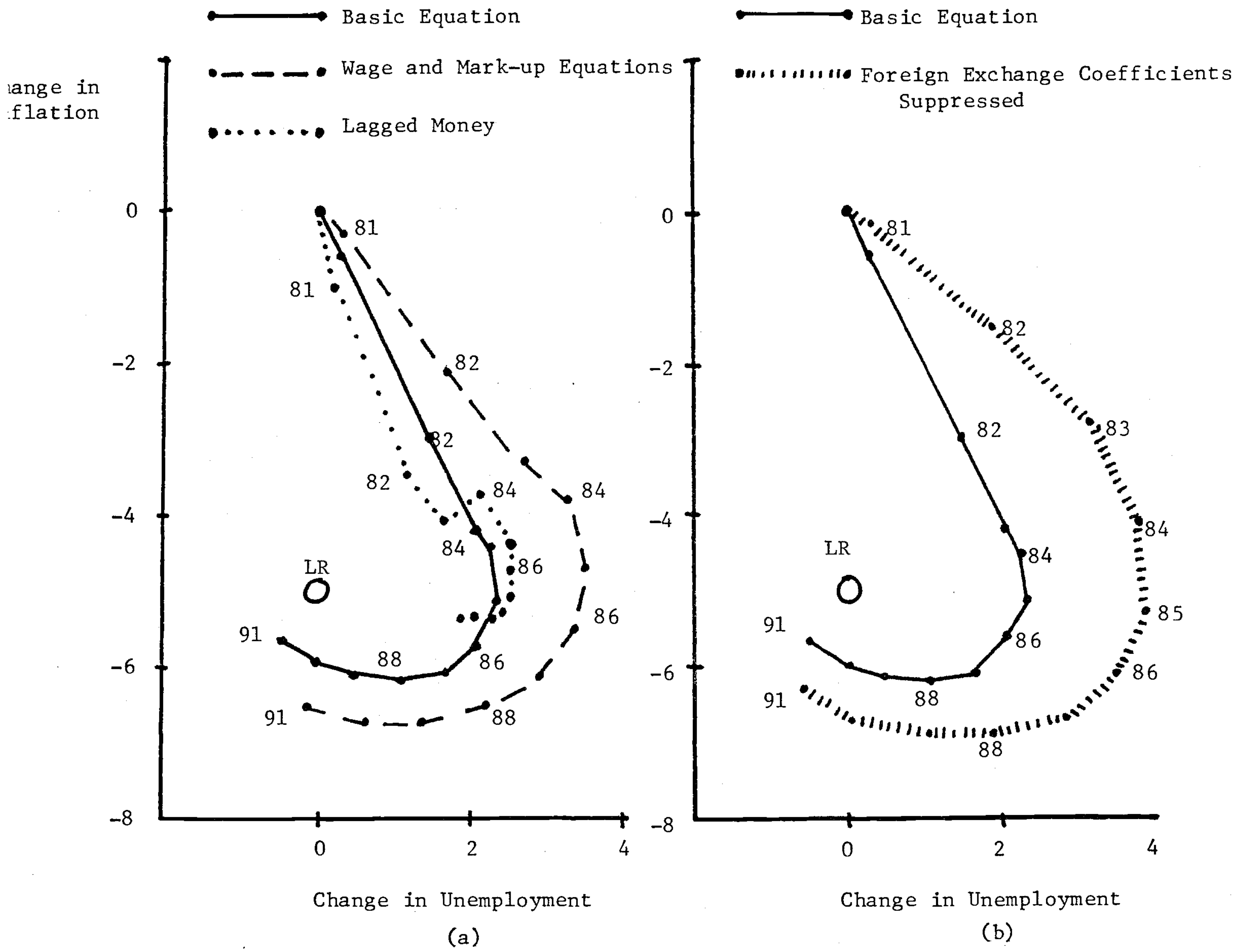


FIGURE 2

Difference between Cold Turkey and Control Simulations

Percent of Nominal GNP Response Taking the Form of Slower Inflation, Cold Turkey Minus Control Solution

Four Quarters Ending in Fourth Quarter	Basic Equation	Including Lagged Money	Wage plus Price Markup Equations
1981	22	39	13
1982	58	66	42
1983	88	85	70
1984	87	73	77
1985	100	86	92

IX. SUMMARY AND CONCLUSIONS

This paper has explored a number of central issues in the relations among inflation, unemployment, and the foreign exchange rate of the dollar, and the growth rates of wages and the money supply. The conclusions should be of equal interest to econometricians attempting to understand the behavior of the postwar U.S. economy, and to policymakers attempting to devise a strategy for achieving lower rates of inflation and unemployment. The main conclusions can be grouped under seven headings.

1. *Alternative Concepts of the Natural Rate of Unemployment.* The natural rate of unemployment, that is, the unemployment rate consistent with a constant rate of inflation, can be defined either for an existing set of conditions or for a hypothetical state in which there are no supply shocks. Our estimate of the "no-shock natural unemployment rate" is 5.9 percent for 1980. The increase in this rate from 5.1 percent in 1954 is attributed entirely to the shifting demographic composition of the labor force and of relative unemployment rates. A striking finding is that the natural rate never fell below 5 percent throughout the 1954-80 period, implying that the 4 percent unemployment goal of the Kennedy and Johnson Administrations was incompatible with a constant inflation rate.

2. *Variance of Inflation in the 1970s.* The behavior of inflation during the decade between 1971 and 1980 cannot be explained by the simple "inertia" and "labor market tightness" variables included in traditional Phillips curve equations. Critical additional contributions are made by changes in the relative prices of food and energy, by changes in the effective exchange rate of the dollar, and by government intervention in the form of the Nixon price controls and their termination. Much of the

acceleration of inflation in the 1970s is attributed to changes in the relative prices of food and oil and in the exchange rate rather than to a shortfall of the actual unemployment rate below the natural rate. Our preferred inflation equation exhibits neutrality with respect to changes in the nominal money supply--after a decade such nominal disturbances only alter the inflation rate and have no impact on the unemployment rate.

3. *Effect of the Foreign Exchange Rate in the Past and Future.* The demise of the Bretton Woods system and the advent of floating exchange rates have increased the responsiveness of the U.S. inflation rate to monetary policy. Changes in the effective exchange rate of the dollar, through their influence on the prices of exports and import substitutes, help to explain why inflation was so low in 1976 and why it accelerated so rapidly between late 1977 and early 1979. Granger causality tests indicate that lagged exchange rate changes influence inflation but lagged inflation does not cause exchange rate changes. Most important, our basic equation that includes the foreign exchange rate predicts that a policy of ending inflation through restrictive monetary policy would have a much smaller cost in the form of lost output than an alternative equation that sets the exchange rate coefficient to zero.

In the late 1970s it was a commonplace that exchange rate movements helped to account for the low inflation rates experienced by Switzerland, West Germany, and Japan. It has been less widely recognized that a monetary deceleration in the U.S. in the 1980s can cause the dollar to appreciate and reverse the inflation differentials among nations from those of the 1970s. The counterpart to slower inflation in the U.S., at least initially, will be faster inflation and lower real GNP in foreign countries experiencing depreciations. Policies of exchange rate stabilization by these countries will require that they duplicate the monetary restriction initiated by the U.S., thus allowing the U.S. to achieve a worldwide slowdown in the growth rates of money and prices.

4. *Sensitivity to Specification Changes.* The major shifts in the U.S. inflation process in the last decade have been a faster response time, measured as a reduction in the mean lag in an inflation equation on past values of the inflation rate, and the shift to floating exchange rates. Splits in the sample period indicate that our basic equation is stable across the first and last halves of the 1954-80 period, but there is a tendency for the coefficients on the change in unemployment and in the effective minimum wage to be lower after 1966.

5. *Direct Impact of Money in the Inflation Process.* In our inflation equation, short lags on past changes in the money supply are a substitute for current changes in the unemployment rate, and long lags are a substitute for the current level of the unemployment rate. Although capable of fitting the historical data as well as our basic equation, versions that include lagged changes in the money supply display implausible behavior in long-run simulations.

6. *Evidence Against Wage-Wage Inertia.* Several dynamic models of the inflation process--including that of the late Arthur Okun--are based on the assumption of feedback from lagged wages to current wages, rather than from lagged prices to current wages as in our model. Several alternative specifications reject the hypothesis of wage-wage inertia. When

lagged price and wage variables are allowed to compete on equal terms, the contest is decisively won by lagged price changes.

7. *The Cost of Disinflation.* Our basic equation implies that inflation can be reduced by five percentage points at the cost of 29 percent of GNP, or about $760 billion in 1980 prices. This contrasts to the traditional consensus estimate of a 50 percent output loss (about $1,310 billion). The major factor explaining our more optimistic verdict is the channel of influence from restrictive monetary policy to inflation through the appreciation of the exchange rate. Nevertheless, we support the conclusion of the traditional Phillips-curve literature that stopping inflation is not costless; our inflation equation predicts that a continuation of current Federal Reserve policy will achieve a four-percent inflation rate by 1987 at the cost of an unemployment rate that remains modestly above the levels of early 1981 at least until 1988. The costs of disinflation warrant a continued search for beneficial supply shocks, e.g., reductions in taxes and regulations that directly raise business costs and reduce productivity.

Directions for Future Research

The analysis of the past and likely future behavior of inflation is inevitably a complex undertaking. Every possible explanatory variable--both those included in this paper and those excluded from consideration--can be specified in a several alternative ways and allowed to enter with alternative lag lengths. While this paper and others in this series have exhaustively examined a number of variables, questions still remain.

How sensitive is the impact on inflation of the productivity slowdown to different specifications of the productivity trend? What accounts for the weak estimated impact of the social security tax on inflation, i.e., which economic sectors bear the burden of the tax and why? Can evidence be found for a robust effect on inflation of the user cost of capital, or capital taxes, or personal taxes? Much experimentation not reported in this paper has convinced me that direct "supply-side" effects of tax rate changes on the inflation rate are so weak as to be invisible. But there are numerous unanswered questions that remain, which require both an improved specification of tax changes and other supply-side effects, and which can be answered with added assurance only after the passage of time allows the accumulation of further evidence on the effects of foreign exchange rates and other central determinants of the U.S. inflation process.

FOOTNOTES

[1] James Tobin, "The Monetarist Counter-Revolution Today--An Appraisal," Economic Journal, vol. 91 (March 1981), p. 36.

[2] Robert E. Hall, "Labor Markets in Recession and Recovery," in NBER 1979 Research Conference: A Summary, (National Bureau of Economic Research, 1979), pp. 5-84.

[3] See Robert E. Lucas, Jr., and Thomas J. Sargent, "After Keynesian Macroeconomics," in After the Phillips Curve: Persistence of High Inflation and High Unemployment, Conference Series No. 19, Federal Reserve Bank of Boston, 1978, pp. 49-72.

[4] This series of papers began with an attempt to explain U.S. inflation in annual data with a single equation covering the entire period between 1892 and 1978: Robert J. Gordon, "A Consistent Characterization of a Near-Century of Price Behavior," American Economic Review, vol. 70 (May 1980), pp. 243-9. A second paper used the same specification to examine the impact of episodes of government intervention in the postwar U.S. inflation process: Jon Frye and Robert J. Gordon, "Government Intervention in the Inflation Process: The Econometrics of Self-Inflicted Wounds," American Economic Review, vol. 71 (May 1981), pp. 288-94. The third paper provides a direct test of the Lucas-Sargent "policy ineffectiveness proposition" in quarterly data extending back to 1892: Robert J. Gordon, "Price Inertia and Policy Ineffectiveness," NBER working paper, June 1981.

[5]Among others, see George L. Perry, "Changing Labor Markets and Inflation," Brookings Papers on Economic Activity, 3:1970, pp. 411-41; Perry, "Slowing the Wage-Price Spiral: The Macroeconomic View," BPEA 2:1978, pp. 259-91, and Perry, "Inflation in Theory and Practice," BPEA 1:1980, pp. 207-41.

[6]The three papers by Perry cited in the previous footnote contain the term "inflation" or "wage-price spiral" in their title yet contain only wage equations. They were influential in leading to the low estimates of inflation responsiveness popularized by Arthur Okun in "Efficient Disinflationary Policies," American Economic Review, vol. 68 (May 1978), pp. 348-52.

[7]Actually the most cited "new classical" empirical work by Barro, for example, Robert J. Barro and Mark Rush, "Unanticipated Money and Economic Activity," in Stanley Fischer, ed., Rational Expectations and Economic Policy (University of Chicago Press, 1980), pp. 23-48, fits an equation in which the dependent variable is the price level rather than its rate of change. The failure to difference the price level leads to serial correlation in the residuals and severely biased coefficients, a classic example of spurious regression examined in the work of C. W. J. Granger and P. Newbold, "Spurious Regressions in Econometrics," Journal of Econometrics, vol. 2 (1974), pp. 111-20, and Charles I. Plosser and G. William Schwert, "Money, Income, and Sunspots: Measuring Economic Relationships and the Effects of Differencing," Journal of Monetary Economics, vol. 4 (1978), pp. 637-60.

[8]The level and change of the output ratio were first introduced into a wage equation in Robert J. Gordon, "Can the Inflation of the 1970s be Explained?" BPEA, 1:1977, pp. 253-77. See Table 3 on pp. 266-7 and the discussion on p. 279.

[9]The "wage-wage" mechanism is stressed by Robert E. Hall, "The Process of Inflation in the Labor Market," BPEA, 2:1974, pp. 343-93, Arthur Okun, Prices and Quantities: A Macroeconomic Analysis (Brookings Institution, 1981), and Perry, "Inflation in Theory and Practice," pp. 207-41, and in fact dates back to Keynes' view that workers care about relative wage rates.

[10]If lagged wage change also enters the price equation, then lagged values of the right-hand variables in the wage equation enter the reduced form equation (4). In fact the empirical work below allows flexible lags on all variables.

[11]This does not deny a role for the prices of other inputs, for example, capital or raw materials, since these variables can be entered as relative prices. See the more complete specification of the price mark-up equation in Robert J. Gordon, "The Impact of Aggregate Demand on Prices," BPEA, 3:1975, p. 620.

[12]Nominal GNP is estimated from sources like retail sales, investment surveys, and government expenditure data. The price data used for the deflation of individual components of GNP come primarily from the two major Bureau of Labor Statistics price indexes, the Consumer and Producer Price Indexes.

[13] The fixed-weight wage index was first constructed and used for quarterly research in Robert J. Gordon, "Inflation in Recession and Recovery," BPEA, 1:1971, pp. 105-66.

[14] The distinction between backward and forward looking expectations is discussed by Perry, "Slowing the Wage-Price Spiral," pp. 268-70.

[15] The 5 percent F value for the significance of the inverse as compared to the linear form in Table 2, column (1), is only 1.19, compared to a critical value of 3.98.

[16] Hall, "Labor Markets in Recession and Recovery," pp. 5-8.

[17] See Jon Frye and Robert J. Gordon, "The Variance and Acceleration of Inflation in the 1970s: Alternative Explanatory Models and Methods," NBER working paper, September, 1980.

[18] This is not the conceptually correct variable to include in our equations that explain the GNP deflator, since no allowance is made for the price of food and energy exports and imports. The conceptually correct measure was used in Gordon, "The Impact of Aggregate Demand," pp. 613-620. There was insufficient time in the preparation of the present paper to allow the 1975 variable to be reconstructed and updated from the revised National Accounts, but reestimation of the basic inflation equation for the 1954-75 period using the 1975 variable indicates virtually no change in results.

[19] The analysis of Alan Blinder and William J. Newton is contained in Alan Blinder and William J. Newton, "The 1971-74 Controls Program and the Price Level: An Econometric Post-Mortem," NBER working paper 279, 1978. The comparison of the Blinder-Newton technique is contained in the paper by Frye

and Gordon, "Variance and Acceleration of Inflation," Figure 1, p. 52. In this paper the timing of the dummies has been adjusted to reflect the December, 1980, revisions in the National Income and Product Accounts, which concentrates more of the 1974 inflation upsurge in the third and fourth quarters.

[20]Historical data on escalator coverage in major union contracts is found in the following sources:

1958-73: H. M. Douty, Cost-of-Living Escalator Clauses and Inflation, Council on Wage and Price Stability, Washington, D.C., 1975.

1974: July issue of Monthly Labor Review.

1975-80: January issues of the Monthly Labor Review; and Bargaining Calendar 1980, U.S. Dept. of Labor, BLS, Bulletin 2059, 1980.

[21]For previous uses of this specification, see Gordon, "Inflation in Recession and Recovery," pp. 128-9, and Gordon, "The Impact of Aggregate Demand," pp. 619-20.

[22]The time trends run between actual levels of nonfarm output per hour achieved in the first quarter of the sample period (1954:Q2) and three succeeding quarters when the Perloff-Wachter output ratio was approximately 100 percent: 1964:Q3, 1972:Q1, and 1978:Q4. The extrapolation after 1978:Q4 was computed to correspond to the slowdown in the growth of potential GNP assumed in the Economic Report of the President, 1980. The computed trend lines are: 1954:Q2-1964:Q3, 2.56 percent; 1964:Q3-1972:Q2, 2.11 percent; 1972:Q2-1978:Q4, 1.22 percent, and after 1978:Q4, 0.5 percent.

[23]The weak long-run relation between inflation differentials and exchange rate movements is examined in Jacob Frenkel, "The Collapse of Purchasing Power Parity," European Economic Review, vol. 15 (1981).

[24] Perry, "Inflation in Theory and Practice," BPEA, 1:1980.

[25] The constraint on the lagged dependent variable is imposed to simplify the interpretation of the shift in coefficients on the unemployment variables. Comparisons in unconstrained equations mix together the impact of shifts in the coefficients on unemployment and on the lagged inflation variables.

[26] In each case listed below, the F ratio is below the 5 percent critical value, indicating failure to reject the null hypothesis that the additional observations obey the same relation as the shorter period.

	F ratio	5 percent critical value
Full compared to late, unconstrained	1.02	1.81
Full compared to late, constrained	0.69	1.75
Full compared to early, unconstrained	1.65	1.79
Full compared to early, constrained	1.72	1.74

[27] (12) follows from (11) if we make the approximation that $\hat{Q}_t - \hat{Q}_{t-1} = q_t - q^*_{t-1}$. The conditions under which this approximation holds are set out in Gordon, Macroeconomics, 2nd ed., footnote 1, p. 291.

[28] Again ignoring any trend in velocity, inflation in the long-run must be equal to the excess of monetary growth over natural output growth, $p_t = m_t - q^*_t$. Thus the condition for steady inflation becomes

$$\frac{\gamma_1 + \gamma_3\psi}{1 + \gamma_3\psi} = 1.$$

[29] Stephen M. Goldfeld, "The Demand for Money Revisited," BPEA, 3:1973, pp. 577-638.

[30] Several other versions of these equations have been estimated. There is little change in the results, other than a minor deterioration in fit, when current values of nominal GNP or money are omitted, and only the 24 lagged values are included.

[31] John Geweke, "Causality, Exogeneity, and Inference," working paper 8025 (University of Wisconsin-Madison Social Systems Research Institute, December 1980).

[32] Ibid., p. 32.

[33] These are the dummy variables for the Nixon controls; the current productivity deviation; the current and four lagged values for the changes in the relative price of food and energy, the effective social security tax, and the effective minimum wage; and the current and three lagged values for the foreign exchange rate.

[34] The hypothesis that the U.S. inflation process is characterized by "nominal wage inertia," while that in other countries is characterized by "real wage inertia," is central to the papers of Jeffrey D. Sachs, "Wages, Profits, and Macroeconomic Adjustment: A Comparative Study," BPEA, 2:1979, pp. 269-319, and William H. Branson and Julio J. Rotemberg, "International Adjustment with Wage Rigidity," European Economic Review, Vol. 13, (May 1980), pp. 309-332.

[35]Although I have never previously included the level of unemployment or output in a price-change equation, one previous paper of mine found that the rate of change of real output was more significant than the output ratio in a wage equation that included both. See Gordon, "Can the Inflation of the 1970s be Explained?" Table 3, columns (5) and (6), p. 266.

[36]The lag distributions on past inflation or wage change are estimated separately in columns (1) through (4) for the first and last halves of the sample period. A single distribution, without a sample split, is estimated for both past inflation and wage change in column (5), due to space limitations in our regression package.

[37]If one estimates $w_t = \delta_1 p_{t-1} + \delta_2 (w_{t-1} - p_{t-1}) + \beta X$, coefficients of $\delta_1 = \delta_2 = 1.0$ would be required to validate the view that "only lagged wages matter."

[38]Robert J. Gordon, discussion of Hall, "The Process of Inflation in the Labor Market," pp. 394-99.

[39]Alan S. Blinder, "The Consumer Price Index and the Measurement of Recent Inflation," BPEA 2:1980, pp. 537-565, and Robert J. Gordon, "The Consumer Price Index: Measuring Inflation and Causing It," The Public Interest, (Spring 1980), pp. 112-34.

[40] Recall that exchange rate variable is set to zero before 1975:Q2. How is the impact of the 1971-73 depreciation to be included? Following the argument on the top half of page 29 above, we attribute to changes in the foreign exchange rate (1) the excess of the Nixon "off" coefficient over the Nixon "on" coefficient, and (2) half of the coefficient on the dummy variable for 1970-75.

[41] The effect of the controls is based on "on" and "off" coefficients that are set equal to each other, because the estimated excess of the "off" over the "on" coefficient is attributed to the effects of the exchange rate rather than the controls (see the previous footnote).

[42] The general point that parameters depend on policy regimes is stated in Robert E. Lucas, "Econometric Policy Evaluation: A Critique," in K. Brunner and A. Meltzer, eds., The Phillips Curve and Labor Markets, a supplemental series to the Journal of Monetary Economics, vol. 1 (North-Holland, January 1976), pp. 149-59.

[43] The hypothesis that the feedback from lagged values of real GNP and money to the current money supply was constant across the sub-periods 1949-63 and 1964-74 was rejected at high confidence levels in Salih Neftci and Thomas J. Sargent, "A Little Bit of Evidence on the Natural Rate Hypothesis from the U.S.," Journal of Monetary Economics, vol. 4(2) (April 1978), pp. 315-19.

[44] Robert J. Gordon, "The Impact of Aggregate Demand on Prices," pp. 643-45.

[45]Nominal GNP growth (y) is equal by definition to the sum of the growth rates of real GNP and the GNP deflator (q + p). This implies $y - q^* \equiv q - q^* + p$. Since actual and natural real GNP growth must be equal in the long run, in that situation $y - q^*$ must be equal to p.

[46]A small dash of realism is introduced by allowing the food-energy, minimum wage, and social security tax variables to assume their actual values for 1981:Q1.

[47]In this part of the paper all figures refer to four-quarter changes ending in the fourth quarter of the given year. If the 1980 inflation rate of 9.3 percent seems low, this results from our practice of expressing quarterly growth rates as annual rates by multiplying the quarterly rate by 4.0 (thus ignoring compounding) and then computing four-quarter growth rates by adding successive quarterly rates. Compounding (as in Table 8.1 of the National Income and Product Accounts) yields an inflation rate of 9.6 percent for the four quarters ending in 1980:Q4, in contrast to our 9.3 percent.

[48]Arthur M. Okun, "Efficient Disinflationary Policies," American Economic Review, vol. 68 (May 1978), p. 348.

[49]To allow the money and wage-price equations to generate a long-run steady state, the relevant sum of coefficients on lagged nominal variables has been constrained to sum to unity, as in the basic equation.

APPENDIX A

"Auxiliary" Equations Used in Simulations

The primary purpose of the inflation equations estimated in this paper is to determine the time path of the economy's adjustment to demand disturbances and supply shocks. Following a change in the growth rate of the money supply, which we assume to be under perfect control by the Federal Reserve, changes occur in four explanatory variables in our basic inflation equation--the level and change of the unemployment rate, the deviation of productivity growth from its trend, and the change in the foreign exchange rate. This appendix presents the equations used to compute the responses of these variables to changes in monetary growth.

The primary objective in specifying each equation is to exclude endogenous variables that would require equations of their own, e.g., the interest rate. An additional objective is to make each equation "neutral" in the long run with respect to the growth rate of money; after an initial transition period the model forces productivity to grow at its trend rate, and the unemployment rate to be constant. Long-run constancy is also imposed on the foreign exchange rate. Unless otherwise stated, each equation is estimated over the same sample period as the basic inflation equation, 1954:Q2 to 1980:Q4.

From Money to Nominal GNP

The only endogenous variable that enters the model without appearing in the inflation equation is the difference between nominal GNP growth and natural real GNP growth ($\hat{y}_t$). This is explained entirely by its own lagged values, and current and lagged changes in the money supply relative to natural real GNP growth ($\hat{m}_t$). This specification frees us from the need to guess the growth rate of natural real GNP in the future; historical values are from Perloff and Wachter updated by the author, as described on p. 6 of the paper.

$$\text{(A.1)} \quad \hat{y}_t = \underset{[6.16]}{4.10} + \sum_{i=1}^{4} b_i \hat{y}_{t-i} + \sum_{i=0}^{3} c_i \hat{m}_{t-i} \qquad R^2 = 0.373, \text{ S.E.E.} = 3.47, \text{ D-W} = 2.03.$$

b_1	0.138	[1.27]	c_0	0.332	[2.49]
b_2	-0.082	[-0.77]	c_1	0.479	[3.22]
b_3	-0.100	[-0.94]	c_2	0.079	[0.47]
b_4	-0.195	[-1.91]	c_3	0.221	[1.42]
Sum	-0.237	[-1.27]	Sum	1.111	[4.60]

From Nominal GNP to Unemployment and Productivity

An identity allows the deviation of real GNP from natural real GNP growth ($\hat{q}_t$) to be calculated from an initial guess for the inflation rate ($\tilde{p}_t$).

$$\text{(A.2)} \quad \hat{q}_t = \hat{y}_t - \tilde{p}_t + DIF_t.$$

Iterative solution allows $\tilde{p}_t$ to converge to the inflation rate (p_t) calculated in the basic inflation equation. DIF_t, included in the historical but not in the future simulations, is the difference between the growth rates of the implicit and fixed-weight GNP deflators.

The weighted unemployment rate (U_t^W) is related to real GNP growth and the lagged deviation of productivity growth from trend (θ_{t-1}) by the following "Okun's Law" relationship:

$$\text{(A.3)} \quad U_t^W - U_{t-1}^W = 0.021\,\theta_{t-1} + \sum_{i=0}^{2} d_i \hat{q}_{t-i} \qquad R^2 = 0.787, \text{ S.E.E.} = 0.18 \quad \text{D-W} = 1.81.$$

$d_0 = -0.260$ [-13.0] $d_2 = -0.011$ [-0.50]

$d_1 = -0.197$ [-6.67] Sum = -0.467 [-16.9]

In the long run, when inflation is equal to $\hat{y}_t$, actual and natural real GNP growth are equal, productivity grows at its trend rate (see equation A.4), and the weighted unemployment rate is constant.

The productivity deviation variable is explained by current and lagged changes in output, unemployment, and the relative price of food and energy (p^{FE}):

$$\text{(A.4)} \quad \theta_t = \underset{[7.24]}{0.933}\, \hat{q}_t + \sum_{i=0}^{2} f_i p_{t-i}^{FE} + \underset{[2.74]}{2.71}(\Delta U_{t-1}^W - 0.468\, \hat{q}_{t-1})$$

$R^2 = 0.623$, S.E.E. = 1.94, D-W = 1.87.

$f_1 = -0.179$ [-0.84]

$f_2 = -0.332$ [-1.33]

$f_3 = -0.006$ [-0.02]

Sum = -0.517 [-2.73]

The device of explaining unemployment by lagged productivity, and productivity by lagged unemployment, helps the model stay on track during historical simulations when productivity behavior experiences shocks that cannot be explained simply by the lagged adjustment of employment to changes in output. The constant term (0.468) used to adjust output growth is the sum of coefficients on output in the unemployment equation, so that in the long run $\theta_t = \hat{q}_t = \Delta U_t^W = 0$.

The Foreign Exchange Rate

The experience of 1980 and 1981 has dramatized the sensitivity of the exchange rate of the dollar to changes in the interest rate differential between dollar-denominated and foreign assets. However, entering domestic and foreign interest rates into a foreign exchange rate equation here would require numerous additional equations to explain interest rate movements. To avoid this additional complexity, we take advantage of the short-run relation between changes in velocity and interest rate movements, and explain changes in the effective foreign exchange rate of the dollar (r_t, as represented by the series "amx" from the *International Financial Statistics)* as depending on changes in velocity and nominal GNP:

$$\text{(A.5)} \qquad r_t = \underset{[2.10]}{14.2} - \underset{[-3.45]}{21.4}\, D73 + \underset{[2.25]}{2.66}\, p_t^{FE} + \sum_{i=0}^{4} g_i(\hat{m}_{t-i} - \hat{y}_{t-i} - 3.2) + \sum_{i=0}^{4} h_i \hat{y}_{t-i}.$$

$R^2 = 0.708$, S.E.E = 7.58, D-W = 1.63,

Sample period = 1972:Q2 - 1980:Q4.

$g_0 =$ 0.046 [0.07]	$h_0 =$ 0.425 [0.87]
$g_1 =$ -1.929 [-3.26]	$h_1 =$ -0.790 [-1.48]
$g_2 =$ -0.504 [-0.71]	$h_2 =$ -1.173 [-1.86]
$g_3 =$ -1.177 [-1.66]	$h_3 =$ -0.555 [-0.76]
$g_4 =$ -1.055 [-1.51]	$h_4 =$ -0.741 [-0.81]
Sum = -4.620 [-2.65]	Sum = -2.834 [-2.54]

Here "D73" is a dummy variable for 1973-Q1 - 1973:Q2. The constant term "3.2" is the long-run trend of velocity growth implicit in equation (A.1). Equation (A.5) states that when velocity is growing at its trend rate, the dollar appreciates with $\hat{y}_t < 5.02$ and depreciates with $\hat{y}_t > 5.02$. To avoid the implication of a permanent appreciation in future simulations following a restrictive monetary policy that brings $\hat{y}_t$ below 5 percent, it is assumed that foreign nominal GNP growth responds with a two-year lag. This assumption is implemented in future simulations by subtracting from (A.5) the following:

$$14.2 + .25\left(\sum_{i=1}^{4} \hat{y}_{t-6-i} \right)\left(\sum_{i=0}^{4} h_i \right).$$

As a result, the exchange rate is constant in the long run in all future simulations.