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Money Growth, Supply Shocks, and Inflation

Joseph H. Haslag and
D'Ann M. Ozment

Modeling Trends in Macroeconomic Time Series

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Money Growth, Supply Shocks, and Inflation

Joseph H. Haslag and D'Ann M. Ozment

Recently, economists have examined the monetarist and the expectations-augmented Phillips-curve models of inflation to determine which model is a better predictor of the inflation rate. These studies raise an important question: Does money growth contain information that is useful in predicting the inflation rate?

Joseph H. Haslag and D'Ann M. Ozment specify a general model of the inflation rate that encompasses both the Phillips-curve and the monetarist models. They find that their general, encompassing model is a better predictor of the inflation rate than either the monetarist model or the expectations-augmented Phillips-curve model of inflation. Furthermore, the authors find that changes in money growth play an important, independent role in predicting the inflation rate.

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Modeling Trends in Macroeconomic Time Series

Nathan S. Balke

How predictable are real GNP, prices, and other macroeconomic data over long time horizons? The answer depends on the nature of their trends. In this article, Nathan S. Balke describes alternative models of trend for economic data, discusses the implications of these models for forecasting and business-cycle analysis, and reviews some of the existing evidence for and against various models of trend.

In addition, Balke conducts a case study of real GNP and the price level. He finds that a simple linear time trend may adequately reflect the long-run behavior of real GNP. The price level, on the other hand, appears to be affected by infrequent but dramatic events that have long-lasting effects. Consequently, the price level is much more difficult to forecast.

Joseph H. Haslag
Senior Economist
Federal Reserve Bank of Dallas

D'Ann M. Ozment
Assistant Economist
Federal Reserve Bank of Dallas

Money Growth, Supply Shocks, and Inflation

What role does money growth play in determining the inflation rate? Empirical studies examining the inflation rate differ in their answer to this question. Some models stress the roles that wage growth and factor scarcity play in determining the inflation rate. These models—often referred to as the expectations-augmented Phillips-curve models—generally omit money growth from the estimated regressions on the grounds that any information contained in money growth is already accounted for by either the unemployment or output gap. In other models, however, changes in the inflation rate stem from too much money chasing too few goods. Such specifications are often associated with monetarist models. Not surprising, monetarist models of the inflation rate prominently feature the effect of changes in money growth.[1] Hence, the monetarist models place substantial weight on the information contained in money growth for predicting inflation. Different specifications are understandable because they are derived from competing theories. Nevertheless, an important question is raised: Does money growth contain information that is useful in predicting the inflation rate?

Recently, literature has developed that addresses a closely related question; that is, which model—the expectations-augmented Phillips curve or the monetarist—is a better predictor of the inflation rate? Three recent papers illustrate the findings. In the first of these articles, Yash P. Mehra (1988) compared a monetarist model with the Phillips-curve model specifications to determine which model was a better predictor of the inflation rate. Mehra found that the monetarist model's performance depended on which measure of money was used in the analysis. When the money measure was M2, the evidence suggested that the monetarist model predicted inflation more accurately than the Phillips-curve specification. When the monetarist model included M1 in the specification, however, Mehra's findings suggested that the Phillips-curve model was a more accurate predictor of inflation.[2]

In the second article, John K. Hill and Kenneth J. Robinson (1989) compared predictions from three competing models of the inflation rate. In the first model, M2 growth was the sole explanatory variable. In the second model, wage growth replaced M2 as the independent variable, while in the third model, factor scarcity measures were the independent variables. Hill and Robinson concluded that models containing wage growth or a combination of the unemployment rate and the capacity utilization rate more accurately predicted inflation than a model whose sole explanatory variable was M2 growth.

In the third paper, David J. Stockton and

We wish to thank Nathan Balke, Eduard Bomhoff, Kent Hill, and especially Evan F. Koenig for helpful comments on earlier copies of this article. Any remaining errors are solely our responsibility.

[1] Some monetarist models specify a reduced-form equation for the inflation rate. Such a specification is consistent with changes in money growth influencing inflation through a real-balance effect. Alternatively, Eugene F. Fama (1982) uses the quantity theory framework as the basis for a model in which changes in inflation result when money-supply growth exceeds money-demand growth.

[2] Mehra compares forecasts using alternative models of the inflation rate from 1977:1 to 1987:4, focusing on the root mean squared error (RMSE) of the different forecasting models. His rankings change when he considers different subperiods. For the period 1977:1 to 1982:3, the monetarist model with M1 as the money measure has a lower RMSE than the Phillips-curve model, which in turn has a lower RMSE than the M2 model. For the sample 1981:1 to 1987:4, the evidence suggests that the Phillips-curve model is superior.

Charles S. Struckmeyer (1989) used nonnested specification tests to compare monetarist models against the expectations-augmented Phillips-curve model.[3] Stockton and Struckmeyer did not find evidence supporting one model over another. Rather, they concluded that these "results suggest that each model identifies some critical determinant of inflation but that no one specification is sufficiently general to 'encompass' the results of its competitors" (Stockton and Struckmeyer 1989, 283).[4]

The purpose of this article is to specify a general model of the inflation rate that answers two questions. First, is there enough useful information contained in money growth to warrant including this variable in an inflation-rate equation? Second, does a general model that encompasses both the expectations-augmented Phillips-curve model and the monetarist model predict inflation more accurately than either of the two individual models?

Overall, the evidence presented in this article is consistent with the notion that the encompassing model is superior (in the sense that it is a better predictor of the inflation rate) to either the monetarist or expectations-augmented Phillips-curve models found in the literature.[5] In particular, the evidence suggests that changes in money growth do play an important, independent role in predicting inflation.

A theoretical model of inflation

The first aim of this article is to provide a theoretical structure that encompasses both the monetarist and expectations-augmented Phillips-curve theories of inflation. We use a theoretical framework of aggregate demand and aggregate supply to derive the general inflation-rate model. By assuming that the labor market always clears at its full-employment level, making the aggregate supply curve vertical, we obtain and estimate a monetarist specification. By assuming that prices are marked-up over wages, making the aggregate supply curve horizontal, we obtain and estimate an expectations-augmented Phillips-curve model. The general inflation-rate model, with a positively sloped aggregate supply curve, encompasses both of these alternative models in the sense that by restricting particular coefficients in the general model to equal zero, the general model collapses to one or the other of the special cases.

What are the fundamental forces that cause movements in the inflation rate? We assume that the inflation rate moves to prevent the emergence of disequilibrium in the commodities market. For example, suppose that demand growth exceeds supply growth at the current rate of inflation. Our intuition tells us that the inflation rate increases to depress demand growth (and perhaps to stimulate supply growth), thereby maintaining equilibrium.

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[3] *The version of the expectations-augmented Phillips-curve model estimated by Stockton and Struckmeyer is presented originally in Gordon (1985). Note that Gordon (1982) also examined the role that the exchange rate played in determining inflation. The coefficient on the exchange variable, however, was not statistically different from zero.*

[4] *The P* model also proposes that money and the output gap jointly determine movements in the inflation rate. In their "general" specification, Jeffrey J. Hallman, Richard D. Porter, and David H. Small (1991) estimate a model in which changes in the inflation rate are a function of the deviation in velocity from its trend value and the output gap. The authors find that these two separate effects are not significantly different from one another. With the price gap term (that is, P−P*) capturing both M2 effects and output gap effects, the evidence suggests that both money and the output gap jointly (and significantly) determine changes in the inflation rate.*

[5] *Recently, Yash Mehra (1990) examined the role that unit labor costs and the output gap played in predicting movements in the inflation rate. Mehra concludes that unit labor costs do not help to predict the inflation rate, but that changes in the output gap do help to predict changes in the inflation rate. He also states that "the 'incremental predictive' contribution of the output gap remains significant even after one allows for the influence of monetary factors on the price level" (Mehra 1990, 38). Mehra finds evidence that monetary variables—specifically, the interest rate—are significant in a model with the output gap also included.*

The analysis presented in this article differs from Mehra's in several key aspects. The most important difference is that his estimating equation first differences the inflation rate, appealing to the absence of stationarity in the implicit price deflator. We measure the inflation rate using the fixed-weight price deflator, and the inflation rate is stationary. Moreover, in Mehra's analysis money affects the price level indirectly through the P error-correction term. It is not clear, therefore, that a monetary variable adds significant information in terms of predicting the inflation rate based on Mehra's results.*

Conversely, if supply growth exceeds demand growth, the inflation rate decelerates to induce greater demand growth and thus prevent disequilibrium from emerging.

We proceed by specifying a simple model of aggregate demand and aggregate supply, thus identifying the factors that influence demand growth and supply growth. Aggregate demand and aggregate supply are assumed to be given by the following expressions:

$$(1) \qquad y_t^d = a_1(M_t - p_t) + a_2 G_t$$

$$(2) \qquad y_t^s = y_t^p - \phi_1(w_t - p_t - \omega_t^*),$$

where y denotes output, d denotes demand, s denotes supply, t is the current time period, M is the money supply, p is the price level, G is government expenditures, y^p is the potential level of output, w is the nominal wage rate, ω^* is the full-employment real wage rate, and a_1, a_2, and $\phi_1 > 0$ are parameters.[6] Each variable in equations 1 and 2 is measured in log levels.

Equation 1 is an aggregate output demand schedule, indicating that output is positively related to the level of real money balances and government spending.[7] In short, equation 1 indicates that an aggregate demand curve drawn in p-y space is downward-sloping and shifts to the right in response to increases in either nominal money balances or government spending.

Equation 2 is an aggregate supply schedule, relating that output supply is positively related to the level of potential output but inversely related to deviations in the real wage rate from its full-employment level. Equation 2 indicates that the aggregate supply schedule will have a positive slope in p-y space. The aggregate supply schedule shifts to the right in response to increases in potential output and the growth rate of market-clearing real wages and to decreases in nominal wages.

To complete this model, we specify an equation that describes how wage growth is determined. We assume that wages are contracted before all the shocks that affect the economy are realized. In essence, workers are attempting to secure a real wage rate using expected inflation and the demand pressures observed last period. This type of nominal wage contracting is formalized in the following representation of wage growth:

$$(3) \quad \hat{w}_t = \lambda \hat{w}_{t-1} + (1-\lambda)[\pi_t^e + \hat{\omega}^{*e}] + \delta(\overline{U}_{t-1} - U_{t-1}),$$

where π^e is the expected inflation rate, $\hat{\omega}^{*e}$ is the expected growth rate in the market-clearing real wage rate, U denotes the unemployment rate, $\overline{U}$ is the natural rate of unemployment, and λ and $\delta > 0$ are parameters. We assume that wage growth is positively related to lagged values of wage growth, the expected growth rate of the market-clearing real wage rate, and the gap between the natural and actual unemployment rates.

Lagged values of nominal wage growth are included to account for labor contracts that do not terminate simultaneously. John B. Taylor (1979) first proposed that termination points for labor contracts are staggered. Workers attempt to recoup relative wage deterioration and thus instigate persistence in nominal wage growth over time.[8] The following conditions are satisfied in the steady state: $U_{t-1} = U_{t-1}$, $\hat{w}_t = \hat{w}_{t-1}$, $\pi_t^e = \pi_t$, and $\hat{\omega}^* = \hat{\omega}^{*e}$. In the steady state, equation 3 implies that $\hat{w}_t - \pi_t = \hat{\omega}^*$. Thus, the steady-state condition says that

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[6] *This specification uses government purchases of goods and services as the measure of fiscal policy. Other researchers have used the federal budget deficit as the fiscal policy measure. Indeed, aggregate demand may be sensitive to items in the government budget constraint other than just spending on goods and services. When we used the high-employment government budget deficit as the fiscal policy measure, however, the results are not substantively different from those reported in this article.*

[7] *The aggregate demand schedule is essentially the same as the output demand schedule specified by John B. Taylor (1979). One concern with the specification of equation 1 is that it omits lagged values of real balances and government spending. Yet, economists generally believe that the effects of changes in monetary variables are distributed over time. Lagged values of money growth are introduced into the model through expected inflation. We do not intend that the interpretation of the coefficients on lagged values of money growth be limited to how money affects inflation through expected inflation. Rather, the interpretation of coefficients on lagged money growth in the reduced-form setting that we estimate should be a hybrid of the expected inflation channel and the aggregate demand channel.*

[8] *See Gray (1976) and Fischer (1977) for a more detailed exposition of the wage-contracting models.*

changes in the growth rate of real wages equal the growth rate of the market-clearing real wage rate.

Equations 1, 2, and 3 together define the inflation-rate equation implied by this model. Setting output demand equal to output supply, differentiating with respect to time, and substituting for wage growth with equation 3 yields the following expression for the inflation rate:

$$(4)\quad \begin{aligned}\pi_t = 1/(a_1+\phi_1)\{&a_1\hat{M}_t + a_2\hat{G}_t - \hat{y}_t^p + \phi_1[\lambda\hat{w}_{t-1} \\ &+(1-\lambda)\pi_t^e] - \phi_1[\lambda\hat{\omega}^{*e} + (\hat{\omega}^* - \hat{\omega}^{*e})] \\ &+\phi_1\delta(\overline{U}_{t-1} - U_{t-1})\}.\end{aligned}$$

With $\phi_1 > 0$, equation 4 indicates that the inflation rate is positively related to changes in money growth and government-spending growth, each a factor that influences the growth rate of aggregate demand.[9] Furthermore, the equation indicates that the inflation rate is positively related to changes in last period's wage growth and the unemployment-rate gap but negatively related to changes in potential output growth and the actual growth rate of the market-clearing real wage rate. Furthermore, with $\lambda < 1$, equation 4 indicates that the inflation rate is positively related to the expected inflation rate and the expected growth rate of market-clearing real wages.

Why is there a qualitative difference between the effect that a change in the growth rate of the *expected* market-clearing real wage rate has on the inflation rate and the effect that a change in the growth rate of the *actual* market-clearing real wage rate has on the inflation rate?[10] The expected growth rate of market-clearing real wages is based on all information available to workers in time period $t-1$. The workers information set consists of expected changes in productivity growth, labor force growth, and the growth rate of quantities of raw materials. Consequently, expected changes in $\hat{\omega}^*$ are built into the labor contracts that determine today's nominal wage growth. In contrast, unexpected changes in $\hat{\omega}^*$ are not built into today's labor contracts. Because labor contracts are not perfectly indexed to accommodate unexpected changes, the impact on the inflation rate due to expected and unexpected changes in the growth rate of the market-clearing real wage rate will differ.

Equation 4 represents a general theoretical model of the inflation rate. The characterization of the aggregate supply function distinguishes this general model from two special cases: the expectations-augmented Phillips-curve model and the monetarist model. In particular, the slope of the aggregate supply curve (that is, $1/\phi_1$) differentiates the estimated inflation equation. In the following sections, we detail these differences for the monetarist and the expectations-augmented Phillips-curve models. For each special case, the appropriate specification of the underlying inflation equation is derived.

The monetarist model

In the monetarist model, the inflation rate is primarily determined by movements in the output demand schedule. The key assumption is that wages are flexible so that the labor market always clears (formally, $w_t - p_t = \omega_t^*$). With real wages always equal to their market-clearing level, equation 2 implies that the aggregate supply schedule is a vertical line, intersecting the horizontal axis at potential output. Note that, for the purpose at hand, to assume that the labor market always clears is equivalent to setting ϕ_1 equal to zero in equation 2. Thus, the monetarist model of inflation can be regarded as a special case of the general model developed here.

Figure 1 depicts the monetarist model graphically with the downward-sloping aggregate demand schedule and a vertical aggregate supply schedule. The intersection of the aggregate demand and aggregate supply curves determines the price level. To illustrate the effects of changes in aggregate demand, consider the effects of an increase in the money supply. As Figure 1 shows, a larger money stock translates into a rightward shift in the aggregate demand curve from D_0 to D_1, resulting in an excess demand for commodi-

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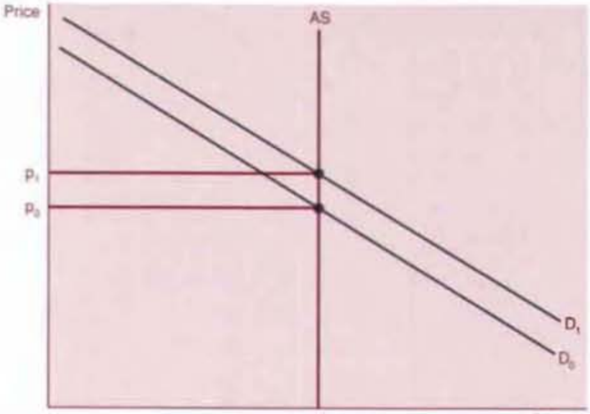
[9] *We assume throughout this article that the parameters are constant over time. Thus, the derivative of each parameter with respect to time is zero.*

[10] *See Gordon (1985) for a more complete discussion of potential output and the appropriate interpretation of productivity in such a framework.*

Figure 1
Monetarist Model



ties at the initial equilibrium price level, p_0. To prevent the emergence of disequilibrium, the price level rises to p_1, thus reducing real money balances, lowering aggregate quantity demanded, and maintaining equilibrium. Thus, when exogenous forces increase aggregate demand, the observed impact is higher prices.

In the monetarist model, shifts in the output supply schedule arise because of factors that affect the level of potential output. To illustrate the effect of a change in aggregate supply on the price level, consider a change in productivity. With the full-employment conditions satisfied, an increase in productivity growth, for example, results in the output supply schedule shifting out as potential output increases. Other things being equal, greater productivity means that aggregate supply increases, and there is an excess supply of commodities at the initial price level. To prevent the emergence of disequilibrium in the commodities market, the price level would fall.

With $\phi_1 = 0$, the general model of the inflation rate (that is, equation 4) reduces to the following expression:

$$(5) \qquad \pi_t = 1/a_1[a_1\hat{M}_t + a_2\hat{G}_t - \hat{y}_t^P].$$

Equation 5 indicates that the inflation rate is a function of money growth, government-spending growth, and factors that affect the growth rate of potential output.

In short, the monetarist model emphasizes the role of money growth through its impact on aggregate demand growth. Because wages are flexible, the labor market clears at its full-employment level. Increases in productivity growth, employment growth, or the availability of raw materials, for instance, translate into a lower inflation rate because output supply growth increases relative to output demand growth.

The expectations-augmented Phillips-curve model

In this section, we assume that there is some degree of wage stickiness that permits under- and overemployment as potential outcomes. This means that we relax the key assumption imposed in the monetarist representation, namely that the labor market clears at the full-employment level. In addition, we incorporate the notion of a price-markup scheme, in which firms are willing to supply any quantity of output, provided that the output price satisfies a reservation-markup condition. Graphically, a price-markup scheme implies a horizontal aggregate supply curve at a level equal to the wage rate plus a reservation-markup level.

In the expectations-augmented Phillips-curve setting, ω^* is no longer appropriately interpreted as the market-clearing real wage rate. Instead, it is more appropriate to interpret ω^* as a target real wage rate that reflects the desired markup of price above unit-labor costs. As equation 2 shows, an increase in the real wage rate above the target level reduces output supply. Conversely, when the market real wage rate falls below target level, output supply rises. To assume that firms adhere strictly to the markup scheme is equivalent to letting ϕ_1 go to infinity, so that the aggregate supply curve becomes horizontal at the level $w_t - \omega_t^*$.

Figure 2 presents a graphical depiction of the case in which $\phi_1 = \infty$. In this setup, a change in money growth—or anything else that affects aggregate demand growth—has no immediate effect on the inflation rate. To illustrate, consider the effect of a rightward shift in the aggregate demand schedule from D_0 to D_1, resulting from an increase in money growth. Because the aggregate supply schedule is horizontal, more money

Figure 2
Phillips-Curve Model

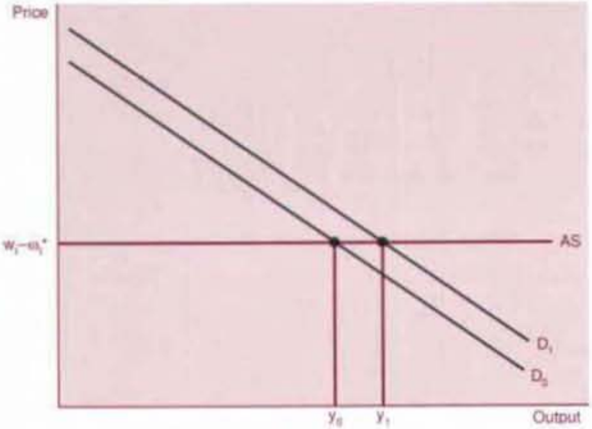
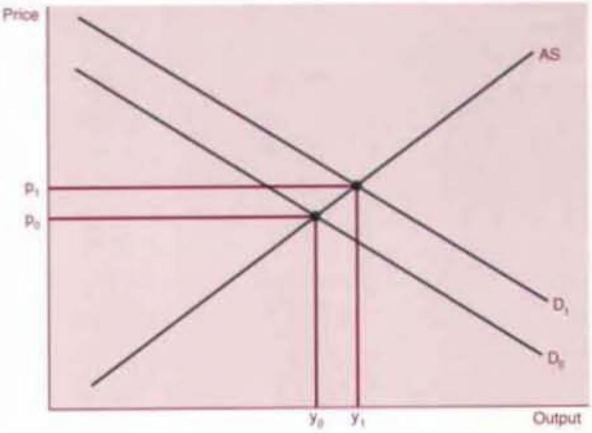


Figure 3
General Model – Shift in Aggregate Demand



translates into more output, from y_0 to y_1, but price does not change.

Formally, with $\phi_1 = \infty$, the inflation-rate equation (that is, equation 4) is expressed as

$$(6) \qquad \pi_t = [\lambda \hat{w}_{t-1} + (1-\lambda)\pi_t^e] - [\lambda \hat{\omega}^{*e} + (\hat{\omega}^* - \hat{\omega}^{*e})] + \delta(\overline{U}_{t-1} - U_{t-1}).$$

In general, equation 6 indicates that the inflation rate is closely related to factors that shift the aggregate supply schedule, such as wage growth. If money growth is to affect inflation in the expectations-augmented Phillips-curve model, it is through the unemployment-rate gap term. As shown in Figure 2, an increase in money results in higher output. Thus, more money lowers the unemployment rate and translates into higher inflation through faster wage growth. Any information from accelerating money growth is already captured in the unemployment-rate gap term. Hence, the expectations-augmented Phillips-curve model maintains that money growth does not contain any independent information relevant for predicting the inflation rate.

The general model

The key feature of the general model is the absence of conditions on the slope coefficient, ϕ_1. More generally, the slope of the aggregate supply schedule is neither infinite nor zero. As such, equation 4 is a more general version of both the monetarist and expectations-augmented Phillips-curve models.

Figure 3 depicts this general representation as an upward-sloping supply curve. An increase in money supply shifts the aggregate demand schedule rightward from D_0 to D_1 and translates into an increase in both the price level (from p_0 to p_1) and output (from y_0 to y_1). Both price and output move in response to a shift in the aggregate demand schedule, as compared to the more specific findings presented in the monetarist case—in which only prices were affected—and the expectations-augmented Phillips-curve case—in which only output was affected. Hence, the general model encompasses both the monetarist and expectations-augmented Phillips-curve models.

Both the monetarist and expectations-augmented Phillips-curve models impose testable restrictions on the general model. For the monetarist model, neither lagged values of wage growth nor the unemployment-rate gap affect the inflation rate. For the expectations-augmented Phillips-curve model, neither money growth nor government-spending growth affect the inflation rate. If one can reject the hypotheses associated with either of these special case models, then the general model is superior in terms of predicting inflation.

An empirical specification

The theoretical specification derived above includes several variables that do not translate directly into observable data. Consequently, estimating equation 4 as stated is somewhat difficult. Specifically, there are factors that determine the growth of market-clearing real wages that should be included in a specification of the inflation rate. Many of the same variables will affect the level of potential output growth. In this section, we propose several observable variables that should be included in an empirical analysis of the inflation rate.

Generally, the growth rate of the market-clearing real wage rate depends on factors that enter into the production function and into either the labor demand or labor supply specifications. Specifically, productivity growth and the growth rate of raw materials affect the demand for labor, and labor force growth affects the supply of labor.[11] These factors also may influence the inflation rate through their effects on potential output.

To illustrate, consider the effect of a change in productivity growth on the growth rate of the market-clearing real wage. An increase in productivity growth results in greater demand for workers. To prevent disequilibrium in the labor market, the growth rate of market-clearing real wages must rise in response to the increase in the demand for workers. An increase in the supply of raw materials (due to some exogenous factor) similarly translates into greater demand for workers. As the growth rate of raw materials increases, the market-clearing real wage rate rises, translating into a lower inflation rate. Similarly, an increase in either productivity growth or the growth rate of raw materials will increase the growth rate of potential output, resulting in a lower inflation rate. Thus, to the extent that productivity growth and the availability of raw materials are important factors affecting the market-clearing real wage rate, equation 4 predicts that increases in the growth rates of these variables translate into a lower inflation rate.

When labor force growth increases, however, the effects on the market-clearing real wage rate and potential output are opposite in sign. Consider an increase in labor force growth. To prevent disequilibrium in the labor market, a faster growing labor force means that the growth rate of the market-clearing real wage rate falls and the inflation rate rises. Alternatively, a higher growth rate of the labor force means that the growth rate of potential output rises, and the inflation rate must fall to prevent disequilibrium in the goods market. On net, the effect on potential output growth will dominate so that inflation is directly related to labor force growth.

The next question is, How do we measure these factors? Following Gordon (1985), Stockton and Struckmeyer (1989), and Mehra (1990), we measure productivity as output per hour of all persons in the nonfarm business sector. Labor force growth is measured as the percentage change in the labor force participation rate. Following Tatom (1981) and Hafer (1983), supply shocks to raw materials are captured by movements in the price of food relative to the general price level and in the price of energy relative to the general price level. Relative price movements serve as proxies when the dominant movements in the quantities stem from exogenous shocks to the supply of raw materials. Because the price movements are not the result of major changes in domestic demand, exogenous shifts in the supply curve mean that the relative price of raw materials is negatively related to equilibrium quantities.

Because the expected value of the growth rate of the market-clearing real wage rate is in equation 4, expected values of the growth rates of productivity, the labor force, and raw materials also enter into the inflation-rate equation. We choose to use the unconditional expected value—the sample mean—as expected value. Thus, each of these variables series enter the estimating equation measured as deviations from the mean value.

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[11] Investment would also likely affect the growth rate of the market-clearing real wage rate. We omit the investment variable from our discussion because it is not easy to identify whether movements are the result of shifts in the demand curve or the supply curve. Shifts in the demand curve are already implicitly embodied in the aggregate demand curve equation. Interpreting the coefficient on the investment variable is very difficult when shocks occur to both the demand for and supply of investment.

Another variable that is not directly observable is the expected inflation rate. In general, one would expect that the factors included in equation 4 would also be used in forecasting the inflation rate. We assume that expected inflation is conditioned on information available at time $t-1$. Thus, expected inflation is represented as being dependent on lagged values of all the variables that enter into the general inflation-rate specification. Thus, the variables in equation 4 along with lagged values of the inflation rate constitute the information set that agents use to forecast the inflation rate. In addition, using lagged values to capture the expected inflation rate is a simple way to introduce dynamic effects of these variables on the inflation rate.[12]

Thus, using observable data to capture the effects of changes in the growth rate of the market-clearing real wage rate and the expected inflation rate conditioned on information available in period $t-1$, the inflation-rate equation estimated is represented by the following expression:

$$\begin{aligned}(7)\quad \pi_t = c_0 &+ \sum_{i=0}^{m_1} \beta_i \hat{M}_{t-i} + \sum_{i=0}^{m_2} \delta_i \hat{G}_{t-i} + \sum_{i=1}^{m_3} \tau_i \pi_{t-i} \\ &+ \sum_{i=1}^{m_4} \lambda_i \hat{w}_{t-1} + \sum_{i=1}^{m_5} \zeta_i LBF_{t-i} \\ &+ \sum_{i=1}^{m_6} \mu_i \hat{PG}_{t-i} + \sum_{i=1}^{m_7} v_i RPE_{t-i} \\ &+ \sum_{i=1}^{m_8} \xi_i RPF_{t-i} + \sum_{i=1}^{m_9} \theta_i \, gap_{t-1} + \gamma D_t,\end{aligned}$$

where c, β, δ, τ, λ, ζ, μ, v, ξ, θ, and γ are parameter estimates; m_i, $i = 1, ..., 9$ represent the lag lengths of the variables included in the information set used to calculate the expected inflation rate; *gap* denotes the unemployment rate less its natural rate; and *D* is a dummy variable that takes on the value of 1 from 1971:1 to 1972:4 when price controls were in effect. Other variables are defined in the Appendix.

With the specification of the empirical model, it is useful to identify the implicit restrictions imposed on equation 7 that yield the monetarist and expectations-augmented Phillips-curve models. Although the expected inflation rate does not appear in the monetarist model presented in equation 5, it is fairly common in the literature to include lagged values of the inflation rate and money growth in estimating the equation to account for dynamics. In addition, supply-shock variables—such as the relative price of energy—sometimes appear in the monetarist specifications. Supply shocks would affect potential output, which appears in equation 4. Thus, the key difference between the monetarist specifications and the general one is that the unemployment-rate gap and lagged values of wage growth do not appear in the monetarist model. The de facto restriction placed on the general model is that neither the unemployment-rate gap nor wage growth contain information that significantly help to predict inflation. In other words, the general model is not superior to the monetarist specification if we cannot reject the null hypothesis that the coefficients on lagged values of wage growth and lagged values of the unemployment-rate gap are jointly equal to zero.

How does equation 7 differ from the expectations-augmented Phillips-curve models that are estimated? Most important is the inclusion of demand-schedule shift parameters, such as money growth, that appear in the output demand schedule. Movements in the aggregate demand curve affect the price level when the aggregate supply curve is *not* horizontal. Consequently, the effects of changes in both money growth and government-spending growth are implicitly assumed to be equal to zero in the expectations-augmented Phillips-curve specification. Formally, by imposing the conditions that the coefficients on contemporaneous and lagged values of money growth and the contemporaneous value of government-spending growth jointly equal zero, equation 7 collapses to the expectations-augmented Phillips-curve model.

Hence, the general specification of the inflation rate presented in this section encom-

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[12] *An alternative way to introduce dynamics into the inflation-rate equation is to use the conditional expected value of the variables that influence the expected growth rate of the market-clearing real wage rate. Indeed, if the expectation is conditioned on the series' historical behavior (for instance, an autoregressive process), then lagged values of productivity growth, labor force growth, and the growth rate of raw materials would enter into the inflation equation through* $\hat{\omega}^{*e}$ *instead of through expected inflation. Because the qualitative effects on inflation due to changes in* $\hat{\omega}^{*e}$ *and* π^e *are the same, we choose to introduce the dynamics through the expected inflation rate.*

Table 1
Simple Correlation Coefficients Between the Inflation Rate and Selected Variables

Variable	Correlation Coefficient	*P*-value*
$\hat{M}_t$	.506**	.0001
RPE_t	.393**	.0001
RPF_t	.183**	.046
$\hat{PG}_t$	−.383**	.0001
$\hat{w}_{t-1}$	.681**	.0001
$U_{t-1} - \bar{U}_{t-1}$	−.006	.9519
LBF_{t-1}	.114	.217

* *P*-value is the significance probability of the correlation.
** The correlation coefficient is significantly different from zero.

NOTE: The variables are defined in the Appendix.

passes both the monetarist and the expectations-augmented Phillips-curve models because it relaxes conditions imposed by each model. The general model reduces to the monetarist model if the labor market clears instantaneously so that wage growth and the unemployment-rate gap do not contain information that is significant in terms of predicting inflation. On the other hand, the general model reduces to the expectations-augmented Phillips-curve model if neither money growth nor government-spending growth contain information that is significant in terms of predicting inflation. Whether the general model is superior to either the monetarist model or the expectations-augmented Phillips-curve model depends on whether the evidence suggests that both of these null hypotheses are rejected.

Issues in model specification

The data used in our analysis span 1959–88 and are quarterly and seasonally adjusted. (For a detailed description of the variables, see the Appendix.) The specification that we estimate is equation 7. The relative price of raw materials consists of both the relative price of energy and the relative price of food.[13] These features are common to both the monetarist and expectations-augmented Phillips-curve models in the literature.

Table 1 reports the correlation coefficients between the inflation rate and seven potential explanatory variables: the growth rate of the adjusted monetary base ($\hat{M}$), the growth rate of the relative price of energy (RPE), the growth rate of the relative price of food (RPF), the growth rate of productivity ($\hat{PG}$), the lagged value of the growth rate of wages ($\hat{w}$), the lagged value of the unemployment-rate gap ($U-U$), and the lagged value of the labor force participation

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[13] *Mehra (1990) proposes including a dummy variable to account for changes in the inflation rate for the period immediately after price controls were lifted.*

growth rate (*LBF*).[14] Except for the unemployment-rate gap and labor force participation growth, the correlation coefficient is significantly different from zero in each case. The evidence suggests that five of the seven potential explanatory variables are significantly correlated with the inflation rate. This finding does not rule out the possibility that *marginal* information is contained in the unemployment-rate gap and labor force participation growth. Indeed, multiple regression is a direct way to shed light on whether changes in any of the explanatory variables contain marginal information about the inflation rate while holding all other explanatory variables constant.

An important issue in estimating equation 7 is identifying the appropriate lag length for the variables that are assumed to have effects distributed over time. Daniel L. Thornton and Dallas S. Batten (1985) provide evidence that suggests that policy conclusions are sensitive to the lag structure specified. To confront this problem, the Schwartz criterion method was employed to select the correct lag length of the independent variables.[15] The Schwartz criterion indicates that equation 7 should include the contemporaneous value and one lagged value of money growth, and it also indicates that the contemporaneous value of government-spending growth be included in the equation (that is, $m_1 = 1$ and $m_2 = 0$). The Schwartz criterion further indicates that the model should include two lagged values of the inflation rate, the unemployment-rate gap, wage growth, and the growth rate of the relative price of energy (that is, $m_3 = m_4 = m_7 = m_9 = 2$). For productivity growth, labor force participation rate growth, and the growth rate of the relative price of food, the Schwartz criterion indicates that one lagged value of each should be included in the model (that is, $m_5 = m_6 = m_8 = 1$).[16]

The general specification estimated in this article is represented by the following expression:

$$(8)\quad \pi_t = c_0 + \sum_{i=0}^{1} \beta_i \hat{M}_{t-i} + \delta_0 \hat{G}_t + \sum_{i=1}^{2} \tau_i \pi_{t-i} + \sum_{i=1}^{2} \lambda_i \hat{w}_{t-1} + \zeta_1 LBF_{t-1} + \mu_1 \hat{PG}_{t-i} + \sum_{i=1}^{2} \nu_i RPE_{t-i} + \xi_1 RPF_{t-1} + \sum_{i=1}^{2} \theta_i \, gap_{t-1} + \gamma D_t .$$

Empirical results

In this section we report the findings obtained by estimating equation 8. We use these results to draw inferences on the role that money growth plays in determining the inflation rate. In addition, these results shed light on the ability of the general model to predict inflation better than either the monetarist or the expectations-augmented Phillips-curve models.

Table 2 reports the results of estimating equation 8.[17] What do the results suggest about particular variables in the general model? There is at least one statistically significant coefficient (at the 5-percent level) on lagged values of money growth, inflation, the growth rate of the relative price of energy, and wage growth. The coefficient on the lagged value of the productivity growth rate is significant at the 10-percent

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[14] *We use the monetary base in this analysis instead of another monetary aggregate for parsimony. See Haslag (1990) for comparisons of the monetary base to M1 and M2. The evidence presented in that article suggests that money multiplier growth (as measured by either M1 or M2) was not a useful variable for predicting inflation at very short lag lengths, such as those chosen by the Schwartz criterion. In addition, Robert G. King and Charles I. Plosser (1984) maintain that the monetary base is related more closely to inflation than are the broader monetary aggregates.*

[15] *Cheng Hsiao (1981) outlines a procedure for choosing the optimal lag length in a multivariate regression setting. He includes up to eight lagged values of each of the independent variables in the specification.*

[16] *Another important econometric issue is whether simultaneity is a concern, resulting in biased coefficients. To minimize the potential simultaneity bias, we generally used lagged values of explanatory variables. In fact, the only contemporaneous values of right-hand-side variables included in this model are policy variables. Neither money growth nor government-spending growth are contemporaneously correlated with inflation at the 5-percent significance level. Omitting the contemporaneous values does not affect the results reported in this article.*

[17] *We tested the model errors for serial correlation using the Breusch–Godfrey test. In this case, the Breusch–Godfrey*

level. In addition, the coefficients on the first and second lagged values of the unemployment-rate gap are significant at the 6-percent and 8-percent level, respectively. The coefficients that are significant at the 5-percent level indicate that increases in money growth, wage growth, and the growth rate of the relative price of energy result in higher inflation, which corresponds to the theoretical predictions.

Next, we consider the null hypothesis that coefficients on the variables are jointly equal to zero. Effectively, this tests for Granger causality. Under the null hypothesis that the coefficients on contemporaneous and lagged values of money growth jointly equal zero, the *F* statistic is 10.01, which is greater than the critical value of 3.07 at the 5-percent significance level. Similarly, we separately test whether the coefficients on lagged values of wage growth, the unemployment-rate gap, and the growth rate of the relative price of energy are jointly equal to zero. The *F* statistics for lagged values of wage growth and the growth rate of the relative price of energy are 6.15 and 4.59, respectively, which is larger than the 5-percent critical value of 3.07. For lagged values of the unemployment-rate gap, the *F* statistic is 1.90, which is smaller than the 5-percent critical value. The evidence, therefore, suggests that money growth, wage growth, and the growth rate of the relative price of energy are each useful predictors of (Granger cause) the inflation rate. The evidence also is consistent with the notion that productivity growth contributes useful information for predicting (Granger causing) inflation. The evidence suggests that government-spending growth, the unemployment-rate gap, labor force participation growth, and the growth rate of the relative price of food, however, do not predict (Granger cause) the inflation rate.

Is the evidence consistent with the notion that the general model explains inflation better than the monetarist model? The general model reduces to the monetarist model if the coefficients on wage growth and the unemployment-rate gap are jointly equal to zero. Formally, this condition amounts to restricting the coefficients on lagged values of wage growth and lagged values of the unemployment-rate gap to jointly equal zero. Under the null hypothesis that $\lambda_1 = \lambda_2 = \phi_1 = \phi_2 = 0$, the *F* statistic is 4.14, which is greater than the 5-percent critical value of 2.45. Thus, the evidence suggests that the general model is statistically superior to the monetarist model in terms of predicting inflation.

The general model collapses to the expectations-augmented Phillips-curve model if the coefficients on money growth and government-spending growth are jointly equal to zero. Under the null hypothesis that the coefficients on contemporaneous and lagged values of both money growth and government-spending growth are jointly equal to zero, the *F* statistic is 7.13. The 5-percent critical value is 2.68, so the results are consistent with the hypothesis that money growth and government-spending growth are systematically related to inflation. Thus, the evidence suggests that the general model is statistically superior to the expectations-augmented Phillips-curve model in terms of predicting the inflation rate.[18]

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statistic is 1.64, less than the 5-percent critical value of 2.37. Therefore, the evidence is consistent with the hypothesis that the errors are not serially correlated. See Godfrey (1978) for a description of this test for serial correlation. With lagged dependent variables on the right-hand side of the equation, the Breusch–Godfrey test is a more general test for serial correlation. Alternative tests, such as Durbin's h *test, test specifically for the presence of first-order autocorrelation in the residuals. We calculated the test results reported in this article using eight lagged values of the observed residuals.*

In addition, under the null hypothesis that none of the explanatory variables help to explain the variation of inflation about its mean, the F *statistic is 37.76. The critical value at the 5-percent significance level is 1.75. The evidence, therefore, suggests that the adjusted* R^2 *(0.83) is significantly different from zero. Overall, the evidence suggests that the general model explains some of the variation of the inflation rate about its mean.*

[18] *Mehra (1990) examined the issue of whether productivity-adjusted wages affected the inflation rate. In our general framework, Mehra's tests essentially amount to determining if* $\lambda_1 + \lambda_2 + \mu_1 = 0$. *Under the null hypothesis that productivity-adjusted wages do not affect the inflation rate, the* t *statistic is 3.46. The 5-percent critical value is 1.98. Thus, the evidence suggests that a change in trend-adjusted wage growth does affect inflation. The main difference between Mehra's specification and ours is that he uses one lagged value of trend-adjusted productivity growth, whereas we use two lagged values of wage growth and only one lagged value of productivity growth.*

Table 2

Coefficient Estimates for the General Inflation-Rate Equation, 1959–88

Variable	Coefficient Estimates	Standard Error
Intercept	–.215**	.097
π_{t-1}	.394**	.097
π_{t-2}	.144	.089
$\hat{M}_t$	–.018	.057
$\hat{M}_{t-1}$	.218**	.059
RPE_{t-1}	–.005	.014
RPE_{t-2}	.038**	.014
$P\hat{G}_{t-1}$	–.098*	.048
$\hat{w}_{t-1}$	.049	.068
$\hat{w}_{t-2}$	.202**	.063
D	–.173	.117
$\hat{G}_t$	.021	.014
RPF_{t-1}	.013	.030
$U_{t-1} - \bar{U}_{t-1}$	–.205*	.108
$U_{t-2} - \bar{U}_{t-2}$	.192*	.112
LBF_{t-1}	–.064	.098

DIAGNOSTICS:

$\bar{R}^2 = .83$

Breusch–Godfrey test at 8 lags = 1.64

* indicates significance at the 10-percent level.
** indicates significance at the 5-percent level.

NOTE: The variables are defined in the Appendix.

Table 3

Sum of Coefficient Estimates and Tests for Significant Long-Run Effects

Variable	Sum of the Coefficient Estimates	*t* statistics*
$\sum_{i=0}^{1} \beta_i \hat{M}_{t-i}$	.200	3.96
$\delta_0 \hat{G}_t$	.021	1.47

* The *t* statistic is calculated under the null hypothesis that the sum of the coefficients is equal to zero.

NOTE: The variables are defined in the Appendix.

What are the long-run effects of changes in policy variables on the inflation rate? Table 3 presents the results of test statistics calculated under the null hypothesis that the *sum* of the coefficients equals zero. This test determines whether the total (or long-run) multiplier is significantly different from zero. As Table 3 shows, under the null hypothesis that the sum of the coefficients for contemporaneous and one lagged value of base money growth is significantly different from zero, the null hypothesis is rejected at 5-percent significance. For government-spending growth, however, the null hypothesis cannot be rejected at usual significance levels. This evidence suggests that a permanent change in money growth has a permanent effect on the inflation rate, but a permanent change in government-spending growth does not.

In short, the evidence suggests that money growth is a useful predictor of the inflation rate, which is consistent with the monetarist model. Wage growth and the degree of demand pressure are also useful predictors of the inflation rate, which is consistent with the expectations-augmented Phillips-curve model. Thus, the evidence suggests that a general model, which encompasses both of these special cases, is a superior model of inflation when compared to either of the nested models.

Forecasting experiment

The results presented in this article focus on the in-sample properties of the general model. The next question examines the out-of-sample properties. Specifically, how do forecasts from this model compare to those generated by monetarist and expectations-augmented Phillips-curve models of the inflation rate? In this section, we compare the bias and accuracy of forecasts generated by the general model to those of forecasts generated by the expectations-augmented Phillips-curve and monetarist models. The horizon used for this experiment is 1980:1–1988:4.

The 1980s are an important testing ground for the general model, particularly compared to the expectations-augmented Phillips-curve specification. There is general concern that the relationship between money growth and economic activity changed substantially during the 1980s. If this is so, the general model may not perform any better than the expectations-augmented Phillips-curve model in which money growth is left out of the specification. Note that the main difference between the expectations-augmented Phillips-curve model and the general model is the presence of money growth in the general model. Therefore, if the sentiment

Table 4

Forecast Summary Statistics, One-Step-Ahead Forecasts (Forecast Horizon, 1980:1–1988:4)

	Root Mean Squared Error	Mean Error
General model	.192	.087
Expectations-augmented Phillips-curve model	.259	.156
Monetarist model	.442	.165

regarding money growth is correct, then the relationship between money growth and inflation should not add important information during the 1980s. Consequently, the expectations-augmented Phillips-curve model would do just as well in predicting inflation as the general model. In such an instance, forecasts from a model containing money growth information would not be any more accurate than forecasts generated by a model that is identical in every way except for the omission of money growth.

The forecasting experiment employed here is a *real-time* version. This means that one-step-ahead forecasts of the inflation rate in time period *t* use all the information available. Because the model includes lagged values of each of the variables, the researcher is assumed to have the history available when making these forecasts. In addition, the parameter estimates can be updated each period as new information becomes available. Thus, forecasts for 1980:1 use sample information for the period 1959:1–1979:4, forecasts for 1980:2 use sample information for the period 1959:1–1980:1, and so on.

Table 4 reports the summary statistics of forecasts generated by the general model, the expectations-augmented Phillips-curve model, and the monetarist model. The mean errors reported in column 2 of Table 4 are not significantly different from zero. The evidence, therefore, suggests that forecasts are unbiased for each of these three models. The RMSE compares the forecasting accuracy of the three models. As Table 4 shows, the general model has the lowest RMSE, suggesting that it is a more accurate predictor of inflation during the 1980s than either the expectations-augmented Phillips-curve model or the monetarist model.[19] In addition, the RMSE for the general model is roughly three-fourths as large as the RMSE for the expectations-augmented Phillips-curve model. This evidence further suggests that the information contained in money growth contributes to improved forecasts of the inflation rate.

In short, the results from the forecasting experiment generally corroborate the evidence presented from the within-sample estimation. Insofar as the general model extends the expectations-augmented Phillips-curve specification by including money growth, money growth appears to play an important role in predicting the inflation rate. Similarly, insofar as the general model extends the monetarist model by including both additional input price growth variables and

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[19] *The general model employed is not directly comparable to the P* model that Hallman, Porter, and Small used to forecast the inflation rate. In particular, these authors used M2 as the money measure, basing this specification on the assumption that M2 and nominal GNP are cointegrated. The cointegration technology is not applicable when one uses the monetary base as the money measure.*

additional measures of the degree of demand pressure, these factors appear to play an important role in predicting inflation.

Conclusion

The aim of this analysis is to specify a general model of the inflation rate that can be used to test whether or not money growth plays an important role in predicting inflation. The model specified here combines features of two different theories of inflation so that each is nested in our general model.

A simple theoretical framework characterizes inflation as a function of changes in money growth, input price growth, and measures of slack in the economy. The evidence presented in this article suggests that both monetary and nonmonetary aspects included in the model are useful for predicting inflation. Because money growth is a useful predictor of inflation, the evidence is consistent with the notion that the general model is superior to a special case model in which input price growth and slack measures, such as the unemployment-rate gap, alone are used to predict inflation. Likewise, because input price growth and slack measures are useful predictors of inflation, the evidence is also consistent with the notion that the general model is superior to a special case model in which only money growth is used to predict inflation. Thus, the evidence suggests that a general framework that encompasses both models will better explain variation in the inflation rate than either the expectations-augmented Phillips-curve model or the monetarist model.

In addition to the within-sample evaluation, we also compared the three models in an out-of-sample experiment using the 1980s as the forecast horizon. Forecasting accuracy was highest when we used the general model. This finding also provides indirect evidence that money growth remained a useful predictor of inflation during the 1980s. Indeed, if the special case model emphasizing input price growth and slack measures had generated equally accurate forecasts of inflation, then the evidence would suggest that adding money growth to the model did not contribute useful information for predicting inflation.

The results presented in this article suggest that a general, encompassing model will yield better predictions of the inflation rate than the alternative special case models, namely, the monetarist and the expectations-augmented Phillips-curve models of inflation. Because money growth is included in the encompassing model, the results indicate that the effects of monetary policy on inflation should be directly measured. As our evidence suggests, relying solely on movements in slack measures and input price growth omits useful information, particularly from money growth. Thus, policymakers may judge the impact of monetary policy actions on inflation from these parameter estimates and do not necessarily have to infer the effects of different policies from movements in either the input price variables or slack variables.

Appendix

π = fixed-weight GNP price deflator. (Source: U.S. Department of Commerce, Bureau of Economic Analysis.)

$\hat{M}$ = St. Louis adjusted monetary base. (Source: Federal Reserve Bank of St. Louis.)

RPE = price of energy in the fixed-weight personal consumption expenditure deflator relative to the fixed-weight consumption expenditure deflator excluding food and energy. (Source: U.S. Department of Commerce, Bureau of Economic Analysis.)

$P\hat{G}$ = mean-adjusted output per hour of all persons in the nonfarm business sector minus its sample mean. (Source: U.S. Department of Labor, Bureau of Labor Statistics.)

$\hat{w}$ = average hourly compensation of all employees in the nonfarm business sector. (Source: U.S. Department of Commerce publication *Business Conditions Digest*.)

$\hat{G}$ = high-employment government expenditures. (Source: U.S. Department of Commerce publication *Business Conditions Digest*.)

RPF = the price of food in the fixed-weight personal consumption expenditure deflator relative to the fixed-weight consumption expenditure deflator excluding food and energy. (Source: U.S. Department of Commerce, Bureau of Economic Analysis.)

LBF = labor force participation rate; the ratio of people included in the labor force relative to total population. (Source: U.S. Department of Labor, Bureau of Labor Statistics.)

U = the civilian unemployment rate. (Source: U.S. Department of Labor, Bureau of Labor Statistics.)

$\bar{U}$ = natural rate of unemployment. This series is constructed using the methodology developed by Peter Clark (1982).

NOTE: All variables are available online from CITIBASE, the Citibank data set. Hats above the variable denote growth rates, which are calculated using first differences of the logarithms.

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Nathan S. Balke
Assistant Professor of Economics
Southern Methodist University
Visiting Scholar
Federal Reserve Bank of Dallas

Modeling Trends in Macroeconomic Time Series

Traditionally, business-cycle analysts and macroeconomists have decomposed macroeconomic time series, such as real gross national product (GNP), into cyclical and trend components. The cyclical component captured temporary fluctuations associated with the business cycle, while the trend component described long-term economic growth. Before the seminal paper of Nelson and Plosser (1982), trend components were typically modeled as simple linear time trends. Simple linear time trends imply that most of the volatility of time series such as GNP is associated with fluctuations in the cyclical component and not with fluctuations in the secular trend. Nelson and Plosser have challenged this conception of the business cycle by arguing that trends in many macroeconomic time series, such as real GNP, prices, money, and interest rates, randomly fluctuate over time.

The possibility that trends are random, or stochastic, may have important implications for macroeconomics. Whether trends are deterministic or stochastic has important implications for the nature of fluctuations in economic time series and can lead to quite different characterizations of the business cycle. Furthermore, stochastic trends are much more difficult to forecast; consequently, the uncertainty associated with long-term forecasts is much greater than that for deterministic trends.

In this article, I review the distinction between deterministic and stochastic trends. I also review some of the recent evidence concerning the presence of deterministic and stochastic trends. In addition to reviewing the existing literature, I consider a model of trend in which just a few important events or shocks determine most of the long-term volatility in economic data. Models of trend in which there are infrequent permanent shocks may capture fluctuations in the trend better than stochastic trends in which shocks occur every period; yet, they may provide a truer picture of the uncertainty associated with long-term forecasting than do deterministic trends. Finally, I examine real GNP and GNP deflator data from 1869 to 1988. While the evidence suggests that a deterministic trend adequately characterizes the behavior of real GNP, I find that the GNP deflator is better characterized as a stochastic trend. Most of the long-term volatility in the GNP deflator, however, can be described by just a few important events.

Deterministic and stochastic trends

In this section, I highlight some important differences between deterministic trends and stochastic trends by considering some simple examples. As a point of departure, consider the following model:

$$y_t = \tau_t + c_t, \tag{1}$$

where τ_t is the trend component and c_t is the transitory or cyclical component. Let the cyclical component, c_t, be a mean-zero, stationary random variable.[1] In general, the trend and cyclical components can be correlated.

The most commonly used deterministic trends are polynomials in time. Consider the simple

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I wish to thank Thomas B. Fomby, John K. Hill, and Evan F. Koenig for helpful comments.

[1] *The unconditional mean, variance, and autocovariances of a stationary random variable are constant over time.*

Figure 1
Example of Stochastic and Deterministic Trends in a Time Series

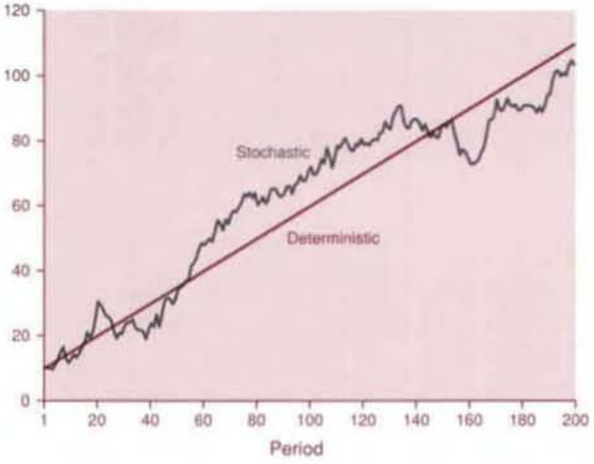
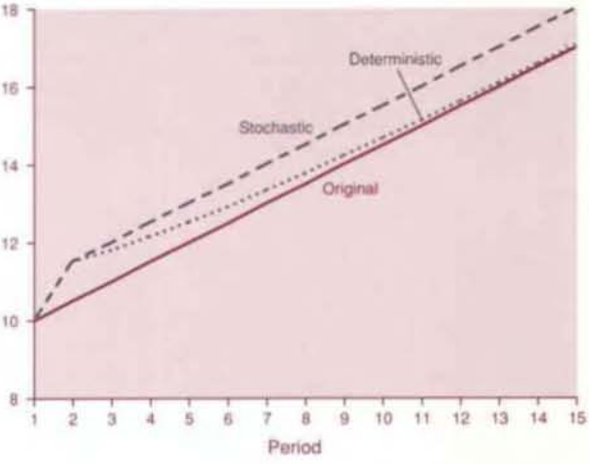


Figure 2
Cumulative Impulse Responses for Stochastic and Deterministic Trends



deterministic trend given by a linear time trend:

$$\tau_t = \tau_0 + \mu t. \tag{2}$$

The change in trend ($\tau_t - \tau_{t-1}$) is equal to a constant (μ). If time series y_t contains a deterministic trend, then this series can be made stationary by detrending with a linear time trend.

A stochastic trend can be described by the equation

$$\tau_t = \mu + \tau_{t-1} + \epsilon_t, \tag{3}$$

where ϵ_t is a mean-zero, stationary random variable. Here, the change or growth in the trend fluctuates around a constant mean. We can rewrite the trend component as

$$\tau_t = \tau_0 + \mu t + \sum_{i=1}^{t} \epsilon_i. \tag{4}$$

Here, the trend component depends not only on the average growth rate (μ) but also on *all* past values of ϵ_i. Thus, shocks in the trend component are permanent. One of the simplest examples of a stochastic trend is a random walk (with drift if μ does not equal 0). In this case, ϵ_t is serially uncorrelated.

To provide the reader with some idea of what the alternative models of trend might look like, Figure 1 displays simulated paths for the trend component for both stochastic and deterministic trend models. The stochastic trend is a random walk with drift, and the parameters used in the simulation are chosen so that, in the absence of any shocks, both models imply the same trend line.[2] The presence of shocks for the stochastic trend, however, leads to a trend component that looks very different from the deterministic trend. In practice, it is not always obvious from examining a plot of the data whether a series has a stochastic or a deterministic trend because the presence of the cyclical component can obscure the trend component. Statistical techniques have been developed to try to distinguish between stochastic and deterministic trends. I discuss some of these techniques below.

Stochastic and deterministic trends imply very different long-run responses to shocks in time series. Shocks to a time series that has a stochastic trend are, in part, permanent; they change the trend, or long-run level, of the time series permanently. The difference in persistence can be dramatic. Figure 2 traces the response of a time series, y_t, to a shock (the cumulative impulse

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[2] *That is, I choose the parameters so that, from the same initial point, the models yield the same forecast profile.*

response function) for a case in which y_t has a simple deterministic trend model and for a case in which y_t is a random-walk (with drift) stochastic trend.[3] Over time, the response of y_t to a shock for the deterministic trend eventually approaches the original trend line. For the stochastic trend case, there is no tendency for y_t to return to its original trend line. Thus, shocks to y_t are permanent for the stochastic trend.

Implications for business-cycle analysis and forecasting

Determining if trends are deterministic or stochastic may be important for several reasons. First, whether shocks to a time series are persistent may have implications for determining the nature and sources of business-cycle fluctuations. Second, the uncertainty associated with long-term forecasting of a time series is very different for a deterministic trend and for a stochastic trend. Third, the ability of conventional econometric methods to make statistical inferences about parameters in a regression model—that is, to test hypotheses about regression coefficients—differs substantially depending on whether or not a stochastic trend is present. Here, I will focus on the implications of stochastic and deterministic trends for business-cycle analysis and forecasting uncertainty.[4]

One implication of the persistence implied by a stochastic trend is that the traditional approach (that is, the approach before Nelson and Plosser 1982) of describing business cycles as fluctuations around a deterministic trend is no longer appropriate. The presence of a stochastic trend implies that fluctuations in a time series are the result of shocks not only to the transitory or cyclical component but also to the trend component.

Indeed, the degree of persistence and the relative volatility of the trend component may have implications for explanations of output fluctuations. For example, in the traditional monetarist or even neo-Keynesian macroeconomic model, aggregate supply determines the long-run level of output.[5] Aggregate demand (and, therefore, monetary policy) does not affect the long-run level of output. If fluctuations in GNP are primarily permanent, then supply-side shocks, such as shocks to technology and labor supply, are important for explaining these fluctuations. Aggregate demand fluctuations, which would typically include the effects of monetary policy, may not be as important in explaining output fluctuations as was once thought if much of the short-term volatility is due to fluctuations in the stochastic trend.[6]

Another implication of a stochastic trend is that the degree of uncertainty associated with long-term forecasting is very different from that of a deterministic trend. Figure 3 plots the forecast and the 95-percent forecast confidence intervals for time-series models with a stochastic trend and a deterministic trend. The left panel shows the optimal forecast when y_t contains a deterministic trend; the right panel shows the optimal forecast when y_t contains a stochastic trend. For both sets of forecasts, the forecaster is assumed to know the parameters of the model.

Figure 3 shows that while the confidence interval for the deterministic trend reaches a maximum interval (in this example, fairly quickly),

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[3] *An example of a deterministic trend series is a simple first-order autoregression of the form*

$$y_t = \alpha + \beta t + \delta y_{t-1} + e_t,$$

where $0 < \delta < 1$. This can be rewritten as

$$y_t = \alpha' + \mu t + \sum_{i=0}^{\infty} \delta^i e_{t-i},$$

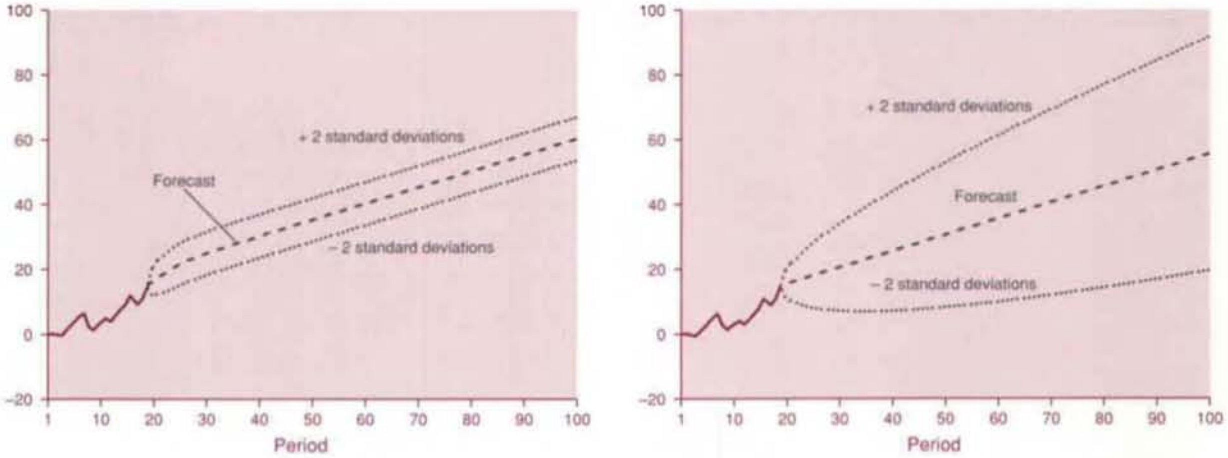
where $\alpha' = \alpha/(1-\delta) - \beta\delta/(1-\delta)^2$ and $\mu = \beta/(1-\delta)$. The cyclical component is given by $\sum_{i=0}^{\infty} \delta^i e_{t-i}$. For Figures 2 and 3, I set δ equal to 0.8.

[4] *See Stock and Watson (1988) for a nontechnical discussion of the implications of stochastic trends for econometric practice. For a formal examination of the implications, see Sims, Stock, and Watson (1990).*

[5] *Most intermediate macroeconomic textbooks, such as Gordon (1990) and Dornbusch and Fischer (1990), contain models with these characteristics.*

[6] *Nelson and Plosser (1982) originally suggested this interpretation. Blanchard and Quah (1989) have used this concept to identify aggregate supply shocks in a multivariate context. However, Campbell and Mankiw (1987) and West (1988) have pointed out that, in the context of other models, the persistence in real GNP could also come from aggregate demand shocks.*

Figure 3
Forecasts and Confidence Intervals


A. Deterministic Trend

B. Stochastic Trend

the confidence interval for the stochastic trend continually increases as the forecast horizon increases. In fact, the variance associated with the optimal forecast of a stochastic trend increases linearly with the time horizon and moves toward infinity as the time horizon lengthens. This behavior suggests that even when the forecaster has perfect information about the nature of the time-series model, very long-term forecasting of a variable with a stochastic trend is fraught with hazard.

Testing for stochastic trends: the current state of debate

Despite a large research effort devoted to the examination of trends and some early evidence supporting stochastic trends, the evidence in favor of stochastic trends is inconclusive. In this section, I briefly review the two commonly used approaches to detecting whether a stochastic trend is present, as well as some of the evidence for or against the stochastic trend.

How have researchers tried to distinguish between a stochastic trend and a deterministic trend? Two approaches have usually been used. Often, economists describe time series with autoregressive models of the form

$$y_t = \alpha + \beta t + \sum_{i=1}^{k} \gamma_i y_{t-i} + e_t, \tag{5}$$

where e_t is a random error, or shock, that has zero mean and is serially uncorrelated. The deterministic and stochastic trends may be described within the context of this model. If $|\Sigma_{i=1}^{k} \gamma_i|$ is less than 1, then y_t contains a deterministic trend plus a stationary transitory component. In this case, a shock to y_t will eventually die out, and y_t will return to its original time trend. If $|\Sigma_{i=1}^{k} \gamma_i|$ equals 1 (and β equals 0), then y_t contains a unit root and has a stochastic trend similar to equation 3, as well as a stationary transitory component.[7] Here, a shock to y_t will have a permanent effect. Thus, one way to determine whether a stochastic trend is present is to test statistically whether a unit root exists; that is, test if $|\Sigma_{i=1}^{k} \gamma_i|$ equals 1 in equation 4. The Dickey–Fuller test (Fuller 1976) and the Phillips–Perron test

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[7] *Note that y_t can be rewritten as*

$$y_t = \alpha + \beta t + (\sum_{i=1}^{k} \gamma_i) y_{t-1}$$

$$+ \sum_{i=1}^{k-1} -(\sum_{j=i+1}^{k} \gamma_j) \Delta y_{t-i} + e_t .$$

If y_t contains a unit root $(\Sigma_{i=1}^{k} \gamma_i) = 1$, then y_t has a stochastic trend. Models in which the growth or change itself has a stochastic trend are said to have two unit roots.

(Phillips and Perron 1988) are two of the most commonly used tests to detect the presence of a unit root.[8]

Another method of evaluating the presence of a stochastic trend is to determine the degree of persistence in the data. Measures of persistence can be obtained by estimating a Box–Jenkins (1976) ARIMA model and then tracing the effect of a shock on the level of the variable, similar to what was done in Figure 2. By determining the long-run response of a time series to a shock (the cumulative impulse response function), one can obtain an estimate of the degree of persistence. An alternative measure of persistence is the variance ratio proposed by Cochrane (1988). This variance ratio is given by

$$(6) \qquad V_k = \text{var}(y_{t+k} - y_t)/[k \bullet \text{var}(y_{t+1} - y_t)].$$

If y_t has a deterministic trend, V_k approaches 0, as k approaches ∞. One advantage of the variance ratio measure is that it does not require the estimation of a specific parametric model. For the random-walk stochastic trend used in Figures 1 and 2, both the cumulative impulse response function and the Cochrane variance ratio (as k approaches ∞) imply persistence measures equal to 1.

Because of the implications associated with a stochastic trend, a large amount of research has been conducted to evaluate whether deterministic or stochastic trends are present in macroeconomic data. For the most part, the evidence is mixed. Nelson and Plosser (1982), using annual data, found that numerous macroeconomic time series, including real GNP, the GNP price deflator, the money stock, and interest rates, showed evidence of a stochastic trend. Schwert (1987), using post–World War II quarterly data, also found widespread evidence of unit roots or a stochastic trend. Others have attempted to determine the degree of persistence in macroeconomic data. Campbell and Mankiw (1987), using estimates of the cumulative impulse response function, found substantial persistence in postwar quarterly real GNP. Campbell and Mankiw (1989), Kormendi and Mequire (1990), and Cogley (1990) have found evidence of stochastic trends and substantial persistence in real GNP for many countries. In a multivariate context, King, Plosser, Stock, and Watson (1987), Shapiro and Watson (1988), and Blanchard and Quah (1989) have attributed a substantial amount of the volatility in real GNP to permanent fluctuations.[9]

Recently, however, other authors have questioned the strength of the evidence in favor of stochastic trends. Cochrane (1988) found that the degree of persistence in annual U.S. real GNP data from 1869 to 1986 was substantially lower than was suggested by the studies of Campbell and Mankiw (1987) using post–World War II quarterly data. DeLong and Summers (1988) also have found that evidence of a stochastic trend in real GNP is substantially weaker for annual data than for quarterly data. Watson (1986) and Clark (1987), using alternative trend-cycle decompositions, found substantially less persistence in quarterly GNP than did Campbell and Mankiw. Several authors—Christiano and Eichenbaum (1990) and Rudebusch (1990)—have argued that it is nearly impossible with a finite amount of data to distinguish between a stochastic trend model and a deterministic trend model that includes a cyclical component that is very persistent (or $|\Sigma_{i=1}^{k} \gamma_i|$ close to 1). These authors argue that many series that were initially identified as having a stochastic trend could be modeled equally well with a deterministic trend.

Shifting trends, segmented trends, and infrequent permanent shocks

Rather than add another voice to the cacophony associated with the unit root and persistence debate reviewed above, in this section I consider an alternative conception of trend, in

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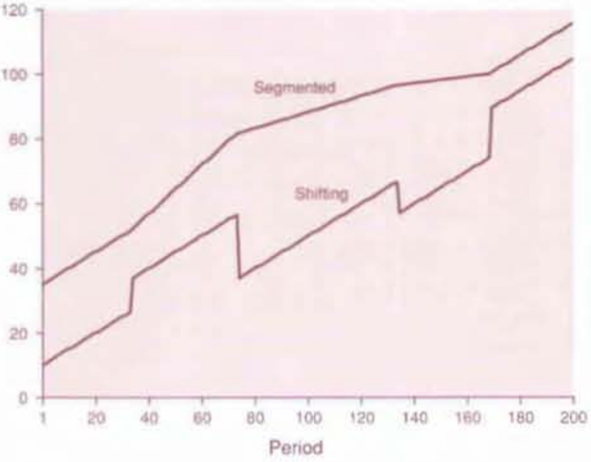
[8] *The Dickey–Fuller test amounts to running the regression*

$$\Delta y_t = \alpha + \beta t + \rho y_{t-1} + \sum_{i=1}^{k} \delta_i \Delta y_{t-i}$$

If ρ is negative enough—that is, below a given critical value—then we reject the unit root hypothesis. There is a rapidly evolving literature on testing for unit roots with the Phillips–Perron test, the usual alternative to the Dickey–Fuller test.

[9] *It is possible that, in a multivariate context, two or more variables share a common stochastic trend. Variables that share a common stochastic trend will also be cointegrated.*

Figure 4
Example of Shifting and Segmented Trends in a Time Series



which relatively infrequently occurring economic events or shocks have important effects on the long-run behavior of economic time series. In this case, permanent shocks occur infrequently, but when they do occur, they are typically large. A model of trend in which permanent shocks occur infrequently has many of the same properties as the standard stochastic trend model described above: the presence of a unit root, a relatively high measure of persistence, and a forecast variance that grows linearly with time. This trend, however, will look like a deterministic trend that occasionally shifts or changes slope. This infrequent shocks stochastic trend may reflect the trend behavior of economic time series, and it may capture the intrinsic uncertainty present with long-term forecasting better than either the simple stochastic trend model, in which permanent shocks occur every period, or the deterministic trend model, in which the linear time trend may or may not change.

Recently, Rappoport and Reichlin (1989) and Perron (1989) have argued that the evidence in favor of a stochastic trend is overstated. In particular, they argue that series such as real GNP are more accurately described by deterministic trends that occasionally shift or change slopes. Figure 4 presents two examples of changing linear time trends: shifting trends, in which there are occasional jumps or changes in the level, and segmented trends, in which there are occasional changes in the slope of a linear time trend.

In a recent paper, Tom Fomby and I argue that shifting and segmented trends, such as those represented in Figure 4, are entirely consistent with the notion of stochastic trends.[10] Our approach is to consider permanent shocks as occurring infrequently, but the time at which they occur is random and unpredictable. Thus, trend components would be given by a model similar to equation 3 except that the shocks (ϵ_t) do not occur every period but only occasionally and the time at which they occur is random. The Appendix briefly describes how these shocks or breaks in trend might be identified.

When permanent shocks occur infrequently, the resulting model of trend is observationally equivalent—that is, indistinguishable in a given sample—to a linear time trend that occasionally shifts or changes slopes. Furthermore, models in which infrequent permanent shocks occur have similar statistical properties, in large samples, to the stochastic trend models described in the previous section. Thus, ARIMA model estimates, Dickey–Fuller tests, and the measures of persistence described above yield the same results for the case in which there are large infrequent permanent shocks, such as the stochastic trend models described in the previous section.[11]

Moreover, the infrequent permanent shocks model implies the same degree of uncertainty about future long-run values as that implied by a stochastic trend. Thus, the forecast confidence interval for a shifting trend, such as the one depicted in Figure 4, is more like that of a stochastic trend than that of a deterministic trend. The reason is that there is additional uncertainty inherent with infrequent, randomly occurring permanent shocks that is not present in the deterministic trend case. Treating shifting or segmented trends like those in Figure 4 as deterministic trends assumes that *no further* shifts or breaks will occur. If the trend line has changed in

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[10] *Much of the analysis in this section is drawn from Balke and Fomby (1990).*

[11] *This is true as long as the variance of the permanent component is the same for the two models.*

the past, it is quite possible that the trend will change again in the future. Forecasts that assume no additional breaks greatly understate the uncertainty associated with the forecasts.

There may also be economic reasons for considering stochastic trends in which permanent shocks occur infrequently. There appear to be many examples of relatively infrequent, heterogeneous random events that have a dramatic impact on economic time series. For example, the oil price shocks of 1973 and 1979 may have had an important effect on long-run economic performance; yet, these events do not occur every period. Wars, with their loss of life and their destruction of capital stock, are another example of infrequent, randomly occurring events that can have important effects on macroeconomic time series. Relatively infrequent but major changes in policy regimes, either fiscal or monetary, may have important long-run effects on economic performance. The founding of the Federal Reserve System and important changes in monetary policy operating procedure—such as those in 1979 and again in 1982—may be examples of policy changes that have had a permanent effect on nominal variables, such as prices and interest rates, if not on real economic performance.[12] Even technological change may be due to infrequent technological breakthroughs. The unit root or stochastic trend in real GNP has often been attributed to productivity shocks. Technological breakthroughs may result in infrequent but important changes in productivity that overshadow the smaller incremental changes in productivity that one might associate with a linear time trend or a random-walk stochastic trend.

In summary, I have suggested an alternative model of trend in which permanent shocks occur infrequently. While this model generates trend components that look similar to a shifting or segmented deterministic trend, the model implies degrees of persistence and forecast uncertainty characteristic of a stochastic trend. Furthermore, there are plausible economic reasons for considering the possibility of infrequent permanent shocks.

Case study: real GNP and the GNP deflator

In this section, I reconsider the long-run properties of real GNP and the GNP deflator, using annual data from 1869 to 1988. For real GNP, the evidence appears consistent with a deterministic trend; evidence of a stochastic trend in the annual real GNP data is relatively weak. Indeed, I show that a deterministic trend model using data from 1869 to 1929 would have provided a reasonable forecast of the level of real GNP in 1988. On the other hand, I argue that the GNP deflator is characterized by a stochastic trend, but one in which only a few shocks account for most of the long-term variability of the price level. These shocks coincide with permanent changes in the inflation rate at the end of the nineteenth century, in the late 1960s, and in the early 1980s. The shocks also include three major permanent changes in the price level associated with World War I, the Great Depression, and World War II.

Real GNP. Table 1 presents Dickey–Fuller and Phillips–Perron tests for unit roots and measures of persistence for real GNP. Both unit root tests reject the unit root (stochastic trend) hypothesis at the 10-percent confidence level, and the Phillips–Perron test rejects at the 5-percent level. While the cumulative impulse response function from an ARIMA(2,1,0) model is 1.43, the Cochrane variance ratio is 0.43. This is substantially less persistence than that implied by a random-walk stochastic trend. This rather weak evidence in favor of a stochastic trend is in line with the results of Cochrane (1988) and DeLong and Summers (1988), who also found little evidence of a stochastic trend, using annual data from 1869 until the 1980s.

Furthermore, there is little evidence of large, infrequent permanent shocks in the real GNP series.[13] While the Great Depression and World War II have a dramatic impact on the real GNP series, they cannot be classified unambiguously as

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[12] *See Mankiw, Miron, and Weil (1987) for an analysis of the effects on interest rates of the founding of the Federal Reserve System.*

[13] *The Appendix suggests alternative methods for examining the presence of shifts or changes in trend. See Balke and Fomby (1990) for a detailed examination of both the real GNP series and the GNP deflator series.*

Table 1
Unit Root Tests and Measures of Persistence for Real GNP, 1869–1988

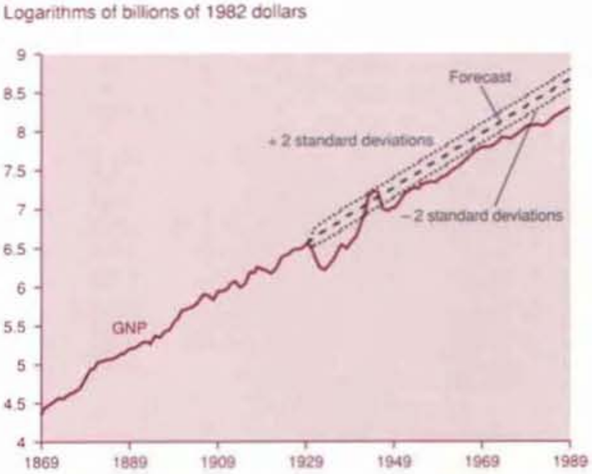
Unit root tests	
Augmented Dickey–Fuller t statistic with four lags	–3.27
Phillips–Perron t statistic with $m = 4$	–3.46
Measures of persistence	
Cochrane variance ratio (V_k, $k = 30$)	.57
Cumulative impulse response function from ARIMA(2,1,0) model	1.43

NOTE: Real GNP data were in logarithms. Asymptotic critical values for both t statistics are –3.12 at the 10-percent significance level and –3.41 at the 5-percent significance level.

permanent shocks. A casual examination of Figure 5 suggests that these events did not substantially alter the long-run level of output. Also, an autoregressive model with a deterministic trend, using just data for 1869 to 1929, would yield a forecast of real GNP in 1988 that would not be far off the mark (see Figure 5). While the level of GNP in 1988 is outside the 95-percent confidence interval implied by this forecast, this forecast interval is understated somewhat because it does not consider the additional uncertainty associated with estimating the parameters of the deterministic trend. Overall, the evidence seems to suggest that a deterministic trend is an adequate characterization of trend for real GNP, although there appears to be slightly more uncertainty associated with long-run forecasts of trend than with the pure deterministic trend model.

GNP Deflator. Table 2 presents Dickey–Fuller tests and measures of persistence for the GNP deflator. The Dickey–Fuller statistic clearly fails to reject a unit root in the price level. The measures of persistence for the GNP deflator are relatively large; in fact, they are several times larger than is implied by a random walk. From these statistics, a shock to the price level would cause a permanent increase in the price level that is nearly three times the size of the original shock. Thus, the evidence that the price level contains a

Figure 5
Real GNP



SOURCES OF PRIMARY DATA: Balke and Gordon (1989)
U.S. Department of Commerce

Table 2

Unit Root Tests and Measures of Persistence for GNP Deflator, 1869–1988

Unit root tests	
Augmented Dickey–Fuller t statistic with four lags	−1.64
Phillips–Perron t statistic with $m = 4$	−1.68
Measures of persistence	
Cochrane variance ratio (V_k, $k = 30$)	3.76
Cumulative impulse response function from ARIMA(2,1,0) model	2.26
Measure of long-term variability	
$\mathrm{Var}(y_{t+k} - y_t)/k$, $k = 30$	.0092

NOTE: GNP deflator data were in logarithms. Asymptotic critical values for both t statistics are −3.12 at the 10-percent significance level and −3.41 at the 5-percent significance level.

stochastic trend is very strong.

There is evidence, however, that just a few permanent shocks explain most of the long-run volatility and persistence in the GNP deflator. In previous work (Balke and Fomby 1990), we found that six breaks in a linear time trend explain most of the volatility in the long-run price level.[14] These breaks correspond to permanent changes in the inflation rate or the growth rate of prices around 1898, 1968, and 1983 and to major permanent changes in the price level associated with World War I, the Great Depression, and the aftermath of World War II.

To assess the importance of these shocks for explaining the long-run behavior of the GNP deflator, we simply detrend the data with appropriate dummy variables to capture the effects of the shocks. Table 3 presents these results. The dummy variables *D1917*, *D1931*, and *D1946* capture the permanent shocks to the price level caused by World War I, the Great Depression, and World War II. Note that these dummy variables are equivalent to a shift in a linear time trend. The dummy variables *DT1898*, *DT1968*, and *DT1983* capture the effects of a permanent shock to the growth rate of prices. These dummy variables imply a change in the slope of the time trend.

From this intervention model, we can construct the trend component for the GNP deflator. Figure 6 plots the GNP deflator and the implied trend component. As we can see from Figure 6, this simple model of trend appears to capture the long-run behavior of prices reasonably well. Once we account for the six shocks, much of the persistence and almost all of the long-run variability in the GNP deflator disappear. Table 3 contains measures of persistence and a measure of the long-term variability of the GNP deflator, once the six breaks have been accounted for. Comparing the statistics in Table 3 with those in Table 2, we see that extracting these breaks reduces the variance ratio measure of persistence of the GNP deflator and the long-run variability, as measured by $\mathrm{var}(y_{t+k} - y_t)/k$, by more than 95

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[14] *We also found evidence of a break in the price level in 1878 and a break in the growth rate in 1934, but these shocks are not nearly as important quantitatively as the other shocks identified here.*

Table 3

A Shifting–Segmented Trend Model for the GNP Deflator

A. Estimated Trend for Deflator

$$p_t = \underset{(.018)}{2.292} - \underset{(.001)}{.015\,t} + \underset{(.002)}{.033\,DT1898} + \underset{(.002)}{.052\,DT1968} - \underset{(.008)}{.032\,DT1983}$$

$$+ \underset{(.025)}{.320\,D1917} - \underset{(.024)}{.364\,D1931} + \underset{(.026)}{.407\,D1946}.$$

$\bar{R}^2 = .996$; standard error of estimate = .0514; Durbin–Watson = 1.03.

(Figures in parentheses are standard errors.)

Definitions of dummy variables

$DT1898 = t - 1897$ for $t \geq 1898$; 0 otherwise.

$DT1968 = t - 1967$ for $t \geq 1968$; 0 otherwise.

$DT1983 = t - 1982$ for $t \geq 1983$; 0 otherwise.

$D1917 = 1$ for $t \geq 1917$; 0 otherwise.

$D1931 = 1$ for $t \geq 1931$; 0 otherwise.

$D1946 = 1$ for $t \geq 1946$; 0 otherwise.

B. Properties of Detrended Deflator

Measures of persistence	
Cochrane variance ratio (V_k, $k = 30$)	.11
Cumulative impulse response function from ARIMA(2,1,0) model	.67
Measure of long-term variability	
$\text{Var}(y_{t+k} - y_t)/k$, $k = 30$	.00029

NOTE: GNP deflator data were in logarithms.

percent. Thus, the long-run behavior of prices, as measured by the GNP deflator, appears to be driven primarily by these six breaks.

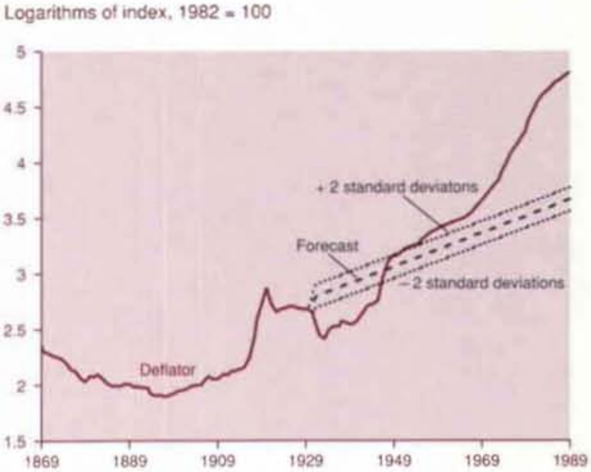
Having determined quantitatively how important these breaks are for explaining the long-term behavior of the price level, we might find it useful to examine whether these shocks correspond to any particular economic events. Clearly, the shocks of 1917, 1931, and 1946 coincide with World War I, the Great Depression, and the aftermath of World War II. Wartime demand and a dramatic increase in domestic money supply had spurred rapid inflation just before and during U.S. participation in World War I. While part of the wartime increase in the price level was offset by rapid deflation during the 1920–21 economic contraction, the war brought about a large and permanent increase in the price level. For similar reasons, prices rose dramatically as a result of World War II, but this rise was postponed until after price controls were lifted in 1946. The decline in aggregate economic activity and the drastic reduction in the nominal money supply during the early stages of the Great Depression led to a dramatic reduction in the aggregate price level.

While a little less obvious, the permanent changes in the growth rate of prices suggested to

Figure 6
GNP Deflator and Estimated Trend Component

SOURCES OF PRIMARY DATA: Balke and Gordon (1989)
U.S. Department of Commerce

Figure 7
GNP Deflator



SOURCES OF PRIMARY DATA: Balke and Gordon (1989)
U.S. Department of Commerce

have occurred in 1898, 1968, and 1983 also coincide with economic events. Much of the world, including the United States, experienced declining prices during the latter third of the nineteenth century. However, because much of the world was on the gold standard, the gold discoveries in South Africa, Alaska, and Colorado during the 1890s led to an increase in the growth rate of the money supply. As a result, prices in the United States, as well as in many other countries, began to rise by the end of the 1890s. This rise in prices continued unabated until World War I.[15] The break identified in 1968 coincides with the increased inflation caused by the Vietnam War expansion. Finally, the shock in 1983 reflects the successful effort by the Federal Reserve to reduce inflation in the early 1980s. Since the "Volcker disinflation" of the early 1980s, the United States has not experienced the high inflation rates that were common in the 1970s. Note that with the possible exception of the breaks in 1898 and 1931, all the other major breaks in the trend level of prices can be associated with changes in the conduct of monetary policy, fiscal policy, or both.

One might argue that the trend model for the GNP deflator is a manifestation of a deterministic trend that just happens to shift three times and change slopes three times. Indeed, detrending the GNP deflator, as in Table 3, is also consistent with a deterministic trend that shifts or changes slope. To consider the GNP deflator a deterministic trend, however, would greatly understate the variance associated with any long-term forecast of the price level. As a way of illustrating this point, suppose we had access to data only up until 1929. On the basis of these data, one might argue that the GNP deflator had a deterministic trend that happened to change slopes in 1898 and to shift in 1917. If, however, we used this model to forecast the GNP deflator in 1988, our forecast would be far off the mark (see Figure 7). Not only does our forecast miss the major shifts in the price level during the Great Depression and after World War II, but it misses the changes in the growth rate in the late 1960s and the early 1980s. More important, the price level in 1988 is far outside the confidence interval associated with the deterministic trend forecast. Thus, the deterministic trend approach greatly understates the true uncertainty

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[15] *See Friedman and Schwartz (1963).*

associated with predicting future values of the price level.[16]

Of course, almost any type of model would have missed these episodes based on data up to 1929, but that is precisely the point. The uncertainty present in the long-term behavior of the GNP deflator is much more characteristic of a stochastic trend than a deterministic trend. The fact that there have been major shocks to the GNP deflator in the past suggests that future shocks may be possible. Indeed, if adopted in the future, a zero inflation rule would change the slope of the trend component of prices once more.

In summary, while annual real GNP data from 1869 to 1988 are, for the most part, consistent with a deterministic trend, the long-run behavior of the GNP deflator over this period is better characterized by a stochastic trend. However, only a few shocks account for most of the long-term variability of the price level. These shocks coincide with permanent changes in the inflation rate at the end of the nineteenth century, in the early and late 1970s, and in the early 1980s and with major permanent changes in the price level as a result of World War I, the Great Depression, and World War II.

Conclusion

In this article, I made the distinction between deterministic trends and stochastic trends and highlighted the implications of these alternative models of trend for business-cycle analysis and for characterizing forecast uncertainty. I suggested that stochastic trends with infrequent permanent shocks are plausible on economic grounds and are a possibility in the data as well. Indeed, most of the long-run variability in the aggregate price level can be traced to essentially six major events or breaks in a linear time trend.

One interesting result here is the very dramatic difference in the long-term variability of real GNP and of the GNP deflator: there is much more uncertainty concerning future long-run values of prices than of output. The aggregate price level almost certainly is characterized by a stochastic trend, so forecasting prices in the long term is extremely difficult. Much of this long-term volatility in the aggregate price level may actually be policy-induced. On the other hand, the fact that the trend component in real GNP is much more predictable than the price level suggests that long-term economic growth, at least in the aggregate, has been relatively stable over the past 100 years despite the numerous changes in economic structure and policy.

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[16] *In fact, using data up to 1929, a stochastic trend model with one unit root or a first-difference model of the deflator yields a forecast similar to the deterministic trend model. Furthermore, the actual price level in 1988 is far outside the confidence interval for this model. This result should not be surprising because the presence of infrequent shocks to the growth rate of prices or a segmented trend model for prices implies that, in effect, there are two unit roots in the price level.*

Appendix

Identifying Breaks in a Time Trend

In Balke and Fomby (1990), we essentially used two methods to help identify breaks in the time trend. One method was recursive analysis using the Dickey–Fuller regression. Recursive analysis starts with only a portion of the sample to estimate the model and then adds one observation to the sample at a time, reestimating the model each time. If a shifting or segmented trend is present, then the estimated model will look like a deterministic trend until the break occurs. After that, the Dickey–Fuller test should indicate the presence of a unit root. For a recent examination of the use of recursive analysis to search for breaks in a time trend, see Banerjee, Lumsdaine, and Stock (1990).

The second method is to look for outliers, or evidence of big shocks, in the time series. Here, we used the outlier identification method suggested by Tsay (1988). If the series is in levels (not first differences), then level-shift outliers would be evidence of a shifting trend. If the series is in first differences, then level-shift outliers would be evidence of a segmented trend, while temporary outliers (not offset by other temporary outliers of the opposite sign) would be consistent with a shifting trend model.

Using this outlier identification procedure and recursive analysis, we identified tentative dates for breaks in the trend. These dates were subsequently verified with intervention analyses, in which the effects of the breaks were captured with dummy variables.

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