

Inflation: Do Expectations Trump the Gap?*

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We measure the relative contribution of the deviation of real activity from its equilibrium (the gap), “supply-shock” variables, and long-horizon inflation forecasts for explaining the U.S. inflation rate in the post-war period. For alternative specifications for the inflation-driving process and measures of inflation and the gap, we reach a similar conclusion: the contribution of changes in long-horizon inflation forecasts dominates that for the gap and supply-shock variables. Put another way, variation in long-horizon inflation forecasts explains the bulk of the movement in realized inflation. Further, we find evidence that long-horizon forecasts have become substantially less volatile over the sample period, suggesting that permanent shocks to the inflation rate have moderated. Finally, we use our preferred specification for the inflation-driving process to compute a history of model-based forecasts of the inflation rate. For both short and long horizons, these forecasts are close to inflation expectations obtained from surveys.

JEL Codes: C32, E31.

1. Introduction

The Phillips curve is one of the most recognized concepts in modern macroeconomics and is widely used as both a theoretical construct and an empirical tool. At the core of the Phillips curve is a relationship between inflation and the real activity “gap,” defined as the

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deviation of real economic activity from its equilibrium level. The within-sample statistical support for such a relationship in U.S. data over the post-war period is well documented in a number of studies, primary among them the work of Robert Gordon over the past twenty years (Gordon 1982, 1997, 1998). In particular, the gap is strongly statistically significant as an explanatory variable for inflation, and this significance is robust to a broad range of specifications of the Phillips curve. More recently, a number of papers have evaluated the out-of-sample forecasting performance of the Phillips curve. Here the evidence in favor of the gap as a driver for inflation is more mixed, with some papers documenting a substantial out-of-sample relationship (e.g., Stock and Watson 1999), while others find that inflation forecasts from a Phillips curve are not better than those from simple benchmark models such as a random walk or an autoregression (e.g., Atkeson and Ohanian 2001; Orphanides and van Norden 2005). Clark and McCracken (2006) provide a thorough exploration of the in-sample versus out-of-sample performance of the Phillips curve.

In this paper we revisit the importance of the gap as an explanatory variable for U.S. inflation over the post-war period. However, rather than measure importance with statistical significance, we instead focus on the relative contribution of the gap and other potential inflation drivers, such as changes in long-horizon inflation forecasts and “supply-shock” variables, for explaining the realized inflation rate. The initial analysis uses a specification for the inflation-driving process similar to that espoused by Gordon (1982, 1997, 1998). Subsequently, we investigate a specification that replaces the distributed lag on the inflation rate present in the Gordon specification with a time-varying intercept (TVI) that follows a random-walk process. The results from both the Gordon and TVI specifications are clear: changes in long-horizon inflation forecasts dominate the gap and supply-shock variables in the determination of actual inflation.¹

¹This result is reminiscent of findings in the bond-pricing literature that suggest that changes in long-horizon inflation expectations are the dominant source of variation in long-horizon bond yields (e.g., Gürkaynak, Sack, and Swanson 2005; Rudebusch and Wu 2008).

We then turn to more detailed analysis of the TVI model-based inflation forecasts. To begin, we allow for a sequence of structural breaks in the variance of shocks to the random-walk intercept. The estimates display a hump-shaped pattern, with the variance rising substantially during the late 1960s and the 1970s from its value in the 1950s and early 1960s, falling substantially in the early 1980s, and falling again in the early 1990s to its lowest level observed over the post-war period. This suggests that the size of permanent shocks with the inflation rate has varied substantially over the sample period.² Next, we use the TVI specification to construct histories of one-quarter-ahead inflation forecasts and compare these to survey-based inflation forecasts. For both short and long horizons, these forecasts are close to inflation expectations obtained from surveys, suggesting that the TVI model provides a reasonable description of the evolution of expectations.

The remainder of the paper proceeds as follows. Section 2 presents results for the Gordon-type Phillips-curve specification, while section 3 describes the TVI model and presents results from this specification. Section 4 compares the measures of inflation forecasts from the TVI model with survey-based measures of expected inflation. Section 5 concludes.

2. Results from the Gordon-Type Specification

2.1 *Model Specification and Estimation*

We begin with the specification that is featured in various analyses conducted by Robert Gordon:

$$\pi_t = a(L)\pi_{t-1} + b(L)D_t + c(L)X_t + \varepsilon_t. \quad (1)$$

Equation (1) relates the quarterly rate of inflation to a long (typically twenty-four quarters) distributed lag on inflation; an index of excess demand, D_t , measured as either the unemployment rate or the deviation of the unemployment rate from a time-varying NAIRU; and a vector of supply shocks, X_t , including changes in relative import

²Using a model with stochastic volatility, Stock and Watson (2007) also find substantial variability in the variance of shocks to the stochastic trend of inflation.

prices, changes in the relative price of food and energy, deviations of productivity from trend, and dummy variables for the beginning and termination of the Nixon price controls in the early 1970s. The distributed lag on inflation, $a(L)\pi_{t-1}$, is generally interpreted as “reflecting the influence of several past years of inflation behavior on current price-setting, through some combination of expectation formation and overlapping wage and price contracts” (Gordon 1998, 303).

Our specification differs from that in Gordon (1998) in that (i) it measures the gap using the “output gap,” defined as the percentage deviation of real GDP from potential GDP as measured by the Congressional Budget Office (CBO); (ii) it uses four lags on all variables (in contrast to the twenty-four lags on inflation used by Gordon); and (iii) it does not include the productivity deviations present in the Gordon specification. To measure changes in relative import prices and the relative price of food and energy, we follow Gordon and use changes in import prices relative to the GDP price index and changes in the “core” PCE price index relative to the PCE price index. All the estimations follow Gordon and exclude a constant term.³ We construct parallel analyses for the CPI, the PCE price index, and the GDP price index, each of which is measured in quarterly percentage changes at annual rates.

For presentation purposes, we focus on estimation of a transformed version of equation (1), which allows for direct estimation of the sum of the distributed lag coefficients, $a(1)$, $b(1)$, and $c(1)$:

$$\begin{aligned}\pi_t = & a(1)\pi_{t-1} + a^*(L)\Delta\pi_{t-1} + b(1)D_t \\ & + b^*(L)\Delta D_t + c(1)X_t + c^*(L)\Delta X_t + \varepsilon_t.\end{aligned}\quad (2)$$

Our estimates for equation (2) over the same 1962:Q1–1998:Q2 sample period used in Gordon (1998) are shown in table 1. The estimates of the sum of the distributed lag coefficients appear in bold.

In each of the three regressions, the sum of the estimated coefficients on lagged inflation is very close to unity, equaling 1.00 for

³Some initial regressions were constructed that included the constant term. The estimated constant was insignificant, and the estimates of the parameters of interest were unaffected by its omission.

Table 1. Gordon-Type Regressions
Sample Period: 1962:Q1–1998:Q2

	CPI	PCE	GDP
π_{t-1}	1.01 (0.02)	1.00 (0.02)	1.00 (0.02)
$\Delta\pi_{t-1}$	-0.64 (0.09)	-0.67 (0.09)	-0.63 (0.09)
$\Delta\pi_{t-2}$	-0.58 (0.09)	-0.44 (0.10)	-0.49 (0.09)
$\Delta\pi_{t-3}$	-0.18 (0.08)	-0.27 (0.09)	-0.33 (0.09)
Gap_t	0.16 (0.04)	0.12 (0.03)	0.13 (0.04)
ΔGap_t	0.07 (0.11)	0.07 (0.08)	0.01 (0.10)
ΔGap_{t-1}	0.13 (0.11)	0.01 (0.08)	0.01 (0.10)
ΔGap_{t-2}	0.13 (0.11)	-0.01 (0.08)	0.08 (0.10)
ΔGap_{t-3}	0.06 (0.11)	-0.12 (0.08)	0.08 (0.10)
$\Delta Rel\ Import\ Prices_t$	0.15 (0.11)	0.19 (0.09)	0.28 (0.11)
$\Delta^2 Rel\ Import\ Prices_t$	-0.07 (0.11)	-0.05 (0.08)	-0.42 (0.10)
$\Delta^2 Rel\ Import\ Prices_{t-1}$	0.05 (0.09)	0.08 (0.07)	-0.17 (0.09)
$\Delta^2 Rel\ Import\ Prices_{t-2}$	0.08 (0.08)	0.10 (0.06)	-0.05 (0.08)
$\Delta^2 Rel\ Import\ Prices_{t-3}$	0.08 (0.06)	0.13 (0.05)	0.03 (0.06)
$\Delta Rel\ Fd\ \&\ Energy\ Prices_t$	-0.15 (0.90)	0.20 (0.71)	-0.41 (0.86)
$\Delta^2 Rel\ Fd\ \&\ Energy\ Prices_t$	4.43 (0.85)	2.95 (0.66)	2.28 (0.81)
$\Delta^2 Rel\ Fd\ \&\ Energy\ Prices_{t-1}$	3.36 (0.88)	2.08 (0.68)	1.68 (0.77)

(continued)

Table 1. (Continued)

	CPI	PCE	GDP
$\Delta^2 Rel\ Fd\ \&\ Energy\ Prices_{t-2}$	2.95 (0.81)	0.98 (0.63)	0.63 (0.66)
$\Delta^2 Rel\ Fd\ \&\ Energy\ Prices_{t-3}$	1.25 (0.63)	0.23 (0.47)	0.17 (0.51)
<i>NIXON_ON</i>	-1.50 (0.58)	-1.19 (0.46)	-1.00 (0.56)
<i>NIXON_OFF</i>	2.77 (0.63)	1.06 (0.51)	1.13 (0.60)
\overline{R}^2	0.90	0.91	0.86
<i>Std. Error of the Estimate</i>	0.97	0.77	0.93
<i>Durbin-Watson Statistic</i>	2.13	2.06	2.14
Notes: This table shows OLS coefficient estimates and standard errors (in parentheses) for the Gordon Phillips-curve specification in equation (2) over the sample period considered in Gordon (1998), 1962:Q1–1998:Q2. Items in bold indicate estimates of the sum of the distributed lag coefficients for π_{t-1} , <i>Gap</i> _{<i>t</i>} , $\Delta Rel\ Import\ Prices_t$, and $\Delta Rel\ Fd\ \&\ Energy\ Prices_t$. The “Gap” variable is measured using the estimate of the output gap produced by the CBO. All other variables are defined in section 2.			

PCE and GDP inflation, and 1.01 for CPI inflation. The estimated sum of the coefficients on the output gap ranges from 0.12 to 0.16 and, consistent with prior research, is highly significant for all three price indices. The estimated sum of the coefficients on changes in relative import prices ranges from 0.15 to 0.28 and is significant in two of the three equations. The sign of the sum of the estimated coefficients on changes in the relative price of food and energy is not consistent across the three equations and is not significant in any equation, though the impact effect of this variable is always large and significant.⁴

⁴We assume that the output-gap and supply-shock variables are covariance stationary, and thus statements regarding statistical significance are based on standard Gaussian limiting distributions for *t*-statistics.

2.2 *How Much Does the Gap Contribute to Explaining the Inflation Process?*

We turn now to the relative contribution of the output gap for explaining inflation variability. To measure this relative contribution, we compute the “marginal adjusted R^2 ,” defined as

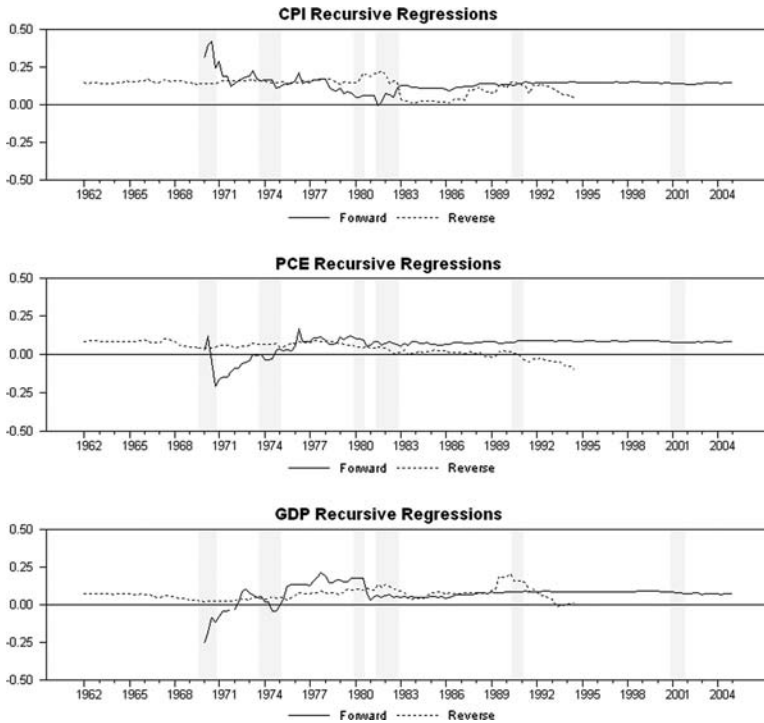
$$\bar{R}_m^2 = \frac{\bar{R}_{\text{with gap}}^2 - \bar{R}_{\text{without gap}}^2}{(1 - \bar{R}_{\text{without gap}}^2)}, \quad (3)$$

where $\bar{R}_{\text{with gap}}^2$ is the adjusted R^2 from a regression with all the regressors including the distributed lag on the output gap, and $\bar{R}_{\text{without gap}}^2$ is the adjusted R^2 from a regression that excludes the distributed lag on the output gap. \bar{R}_m^2 gives the additional (adjusted) proportion of inflation variance explained by the model with output-gap terms included, measured relative to the (adjusted) amount of inflation variance left unexplained by the model that excludes output-gap terms. An \bar{R}_m^2 close to zero or negative indicates that the model that includes the output gap explains quantitatively little over the model that excludes the output gap, while an \bar{R}_m^2 close to one indicates that the addition of output-gap terms explains most of the inflation variance not explained by the model that excludes output-gap terms.

To investigate both full-sample and subsample contributions of the output gap, we compute \bar{R}_m^2 for forward and backward recursive regressions. In the forward recursions the sample period always begins in 1962:Q1. Initially, the sample ends in 1970:Q1 and then is extended one quarter at a time through 2005:Q1. In the backward recursive regressions, the sample size increases from the most recent observations. In all cases the end of the sample is fixed at 2005:Q1, and the beginning of the sample is initially 1994:Q3 and then shifted backward one quarter at a time until 1962:Q1. Figure 1 displays \bar{R}_m^2 for the forward and backward recursive regressions for each of the three measures of inflation.

Taken as a whole, the results in figure 1 suggest that the marginal explanatory power of the output gap is quantitatively small. Beginning with the forward regressions, for the PCE and GDP measures of inflation, \bar{R}_m^2 never exceeds 0.25 and is often even negative,

Figure 1. Marginal Adjusted R^2 Squares of Recursive Regressions



Notes: This figure shows recursive estimates of the marginal adjusted R^2 measure defined in equation (3) for the Gordon Phillips-curve specification given in equation (1). The solid line indicates forward recursive regressions beginning with the sample period 1962:Q1–1970:Q1 and ending with 1962:Q1–2005:Q1. The dotted line indicates reverse recursive regressions beginning with the sample period 1994:Q3–2005:Q1 and ending with 1962:Q1–2005:Q1.

indicating that the other regressors have a higher adjusted R^2 in the absence of the gap terms than does the full regression specification that includes the gap terms. For the longer sample regressions using the PCE or GDP measures of inflation, \bar{R}_m^2 is quite low, on the order of 0.08 to 0.10. For the CPI measure of inflation, the highest marginal contribution of the gap terms occurs for the shorter sample periods (late 1960s and 1970s), where at times \bar{R}_m^2 exceeds 0.30. For the longer samples, \bar{R}_m^2 is generally around 0.14, larger than that

computed for the other two measures of inflation but still indicating relatively little marginal explanatory power for the output-gap terms.

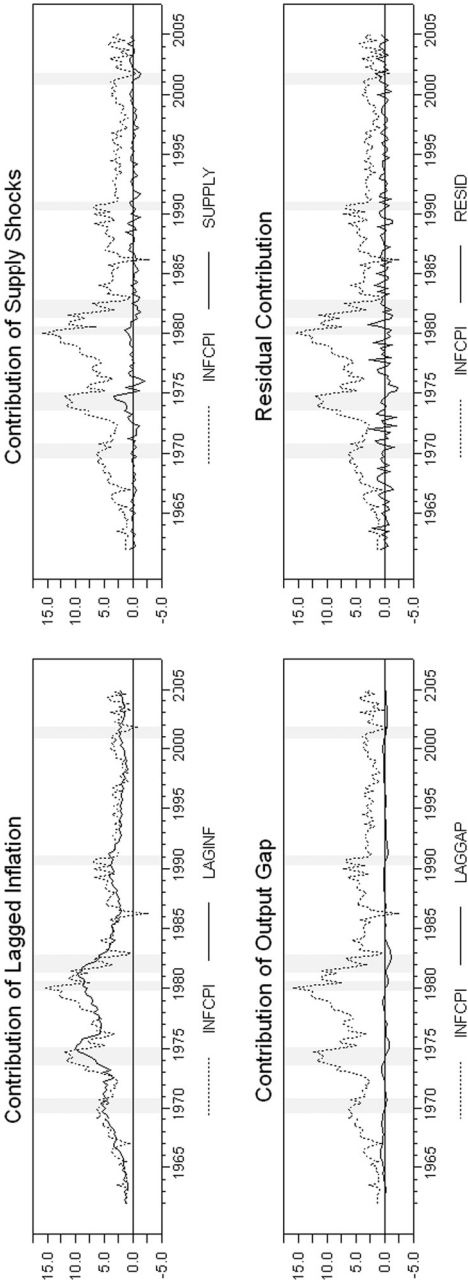
The marginal adjusted R^2 from the reverse recursive regressions does not alter the conclusions from the forward recursive regressions. Specifically, although \bar{R}_m^2 for the CPI and GDP measures of inflation is highly variable over recent sample periods, it never exceeds 0.25 and is usually much smaller. For the PCE measure of inflation, \bar{R}_m^2 is negative or close to zero for samples that include only recent years of data.

Another way to address this question is to compare the estimated values of $a(L)\pi_{t-1}$, $b(L)D_t$, $c(L)X_t$, and ε_t for a regression over the entire sample period. These are shown in figures 2–4 for regressions constructed on the sample 1962:Q1–2005:Q1. Note that for all three measures of inflation, the contribution of the gap terms, $b(L)D_t$, and the supply-shock variables, $c(L)X_t$, is dominated by the contribution of lagged inflation, $a(L)\pi_{t-1}$. These results are consistent with the analysis above: the output gap accounts for only a minor portion of fluctuations in inflation regardless of the measure of inflation. By contrast, inflation expectations, as proxied by a distributed lag on inflation whose coefficients sum to 1.0, account for the bulk of fluctuations in inflation. These results present a preliminary answer to the question posed in the title. Based on the Phillips-curve specification considered here, expectations do appear to trump the gap.

3. Results from the Time-Varying Intercept Specification

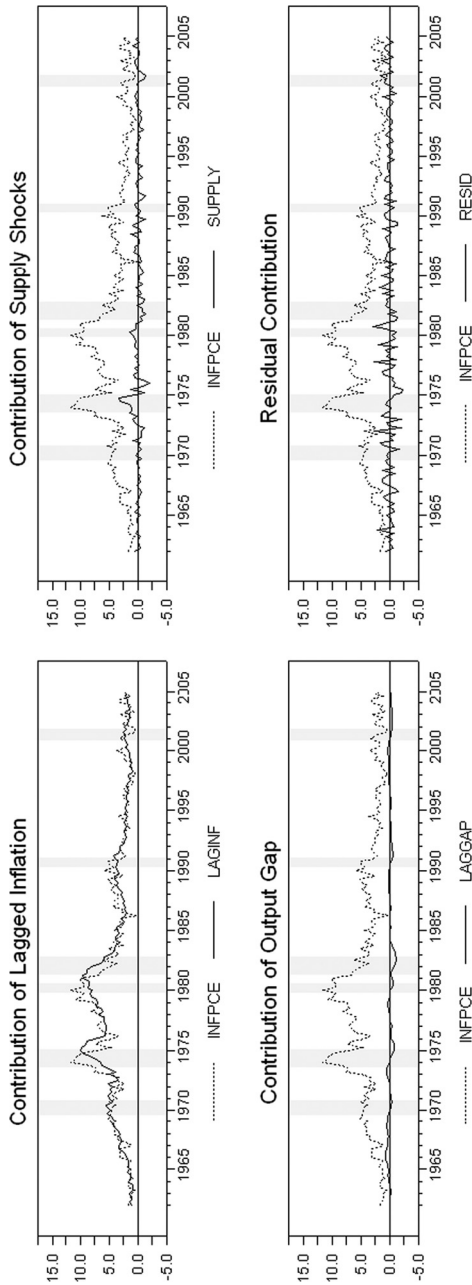
The results from the Phillips-curve specification in equation (1) indicate that inflation expectations are a dominant driver of realized inflation. In this section we refine this result using an alternative specification that allows us to focus more directly on the importance of movements in long-horizon inflation expectations. In particular, we extract a permanent random-walk component from the inflation process that can be interpreted as the long-horizon forecast of inflation. This allows us to directly assess the variability of changes in long-horizon inflation expectations as well as to investigate changes in this variability over time.

Figure 2. CPI Inflation: Gordon Equation, Sample Period 1962:Q1–2005:Q1



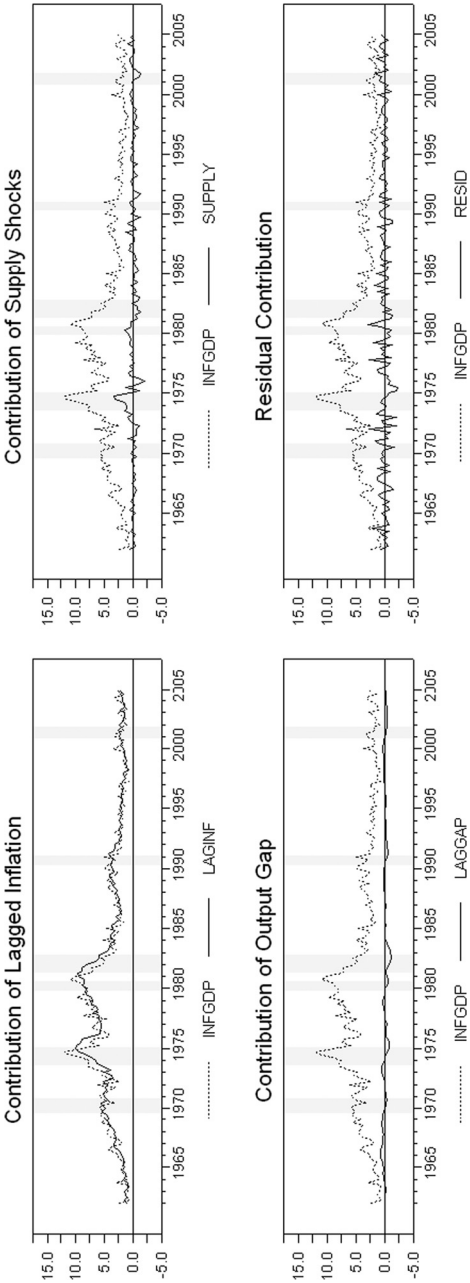
Notes: This figure plots the inflation rate (dotted line) against the estimated components of the Gordon Phillips-curve regression in equation (1), where parameter estimates were constructed using the sample period 1962:Q1–2005:Q1. The inflation measure is the CPI. The “Output Gap” variable is measured using the estimate of the output gap produced by the CBO. The “Supply Shock” variables are defined in section 2 above.

Figure 3. PCE Inflation: Gordon Equation, Sample Period 1962:Q1–2005:Q1



Notes: This figure plots the inflation rate (dotted line) against the estimated components of the Gordon Phillips-curve regression in equation (1), where parameter estimates were constructed using the sample period 1962:Q1–2005:Q1. The inflation measure is the PCE index. The “Output Gap” variable is measured using the estimate of the output gap produced by the CBO. The “Supply Shock” variables are defined in section 2 above.

Figure 4. GDP Inflation: Gordon Equation, Sample Period 1962:Q1–2005:Q1



Notes: This figure plots the inflation rate (dotted line) against the estimated components of the Gordon Phillips-curve regression in equation (1), where parameter estimates were constructed using the sample period 1962:Q1–2005:Q1. The inflation measure is the GDP index. The “Output Gap” variable is measured using the estimate of the output gap produced by the CBO. The “Supply Shock” variables are defined in section 2 above.

In particular, suppose that the distributed lag on inflation in the Gordon specification represents a proxy for long-horizon expected inflation that is specified to appear with a coefficient of 1.0 so that the long-run Phillips curve is vertical:

$$\pi_t = 1.0\pi_t^e + b(L)D_t + c(L)X_t + \varepsilon_t. \quad (4)$$

Alternatively, this equation can be thought of as specifying a time-varying intercept (TVI) on a vector of 1.0s:

$$\pi_t = 1.0z_t + b(L)D_t + c(L)X_t + \varepsilon_t. \quad (5)$$

We assume that z_t follows a random walk:⁵

$$z_t = z_{t-1} + \omega_t. \quad (6)$$

Equation (6) implies that, assuming stationarity of D_t and X_t , the infinite-horizon forecast of inflation is equal to z_t plus a constant term reflecting the unconditional mean of D_t and X_t (see Beveridge and Nelson 1981). Thus, variation in z_t has the interpretation of variation in the long-horizon inflation expectation.⁶

We estimate the model in equations (5)–(6) via maximum likelihood using the Kalman filter. The estimates of the model parameters are shown in table 2 for the sample period 1962:Q1–2005:Q1. Table 2 also shows the standard error of the estimate for the Gordon equation estimated over the same sample period, which demonstrates that the time-varying intercept specification is competitive with the Gordon specification.

⁵This is similar to Gordon's specification of the time-varying NAIRU in his 1997 and 1998 papers.

⁶Equation (6) assumes that the shocks to long-horizon inflation expectations are frequent and continuous. An alternative is that shocks to long-horizon inflation expectations are infrequent and discrete. For an example of such a specification for modeling U.S. inflation, see Levin and Piger (2002, 2005).

Table 2. Time-Varying Intercept Model
Sample Period: 1962:Q1–2005:Q1

	CPI	PCE	GDP
<i>Standard Deviation of Intercept</i>	0.58 (0.08)	0.37 (0.05)	0.35 (0.05)
<i>Gap_t</i>	0.18 (0.10)	0.02 (0.06)	0.00 (0.00)
<i>Gap_{t-1}</i>	0.00 (0.00)	0.00 (0.00)	0.01 (0.07)
<i>Gap_{t-2}</i>	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
<i>Gap_{t-3}</i>	0.13 (0.12)	-0.12 (0.08)	0.07 (0.00)
<i>Gap_{t-4}</i>	0.04 (0.11)	0.25 (0.08)	0.07 (0.09)
<i>ΔRel Import Prices_t</i>	0.12 (0.06)	0.13 (0.04)	-0.20 (0.04)
<i>ΔRel Import Prices_{t-1}</i>	0.07 (0.06)	0.09 (0.04)	0.06 (0.05)
<i>ΔRel Import Prices_{t-2}</i>	0.07 (0.07)	0.02 (0.05)	0.07 (0.05)
<i>ΔRel Import Prices_{t-3}</i>	0.03 (0.06)	0.05 (0.04)	0.11 (0.05)
<i>ΔRel Import Prices_{t-4}</i>	0.00 (0.05)	0.04 (0.04)	0.05 (0.04)
<i>ΔRel Fd & Energy Prices_t</i>	2.83 (0.33)	1.97 (0.23)	1.30 (0.25)
<i>ΔRel Fd & Energy Prices_{t-1}</i>	0.35 (0.34)	0.40 (0.23)	0.68 (0.25)
<i>ΔRel Fd & Energy Prices_{t-2}</i>	0.19 (0.36)	0.21 (0.24)	0.01 (0.19)
<i>ΔRel Fd & Energy Prices_{t-3}</i>	0.19 (0.35)	0.03 (0.23)	-0.03 (0.24)
<i>ΔRel Fd & Energy Prices_{t-4}</i>	0.08 (0.27)	0.24 (0.22)	0.29 (0.25)
<i>NIXON_ON</i>	-0.84 (0.97)	-0.81 (0.65)	-1.27 (0.67)
<i>NIXON_OFF</i>	3.03 (0.79)	2.10 (0.50)	2.54 (0.59)

(continued)

Table 2. (Continued)

	CPI	PCE	GDP
<i>Log-Likelihood</i>	-276.16	-209.47	-225.91
<i>Std. Error of the Estimate</i>	0.90	0.64	0.78
<i>Std. Error of the Estimate</i> <i>(Gordon Equation)</i>	0.93	0.74	0.90
Notes: This table shows maximum likelihood coefficient estimates and standard errors (in parentheses) for the time-varying intercept Phillips-curve specification in equations (5)–(6) over the sample period 1962:Q1–2005:Q1. “Standard deviation of intercept” refers to the standard deviation of the innovation to the random-walk intercept term in equation (5). The “Gap” variable is measured using the estimate of the output gap produced by the CBO. All other variables are defined in section 2.			

We focus our analysis on an expanded version of the TVI specification, the results of which are presented in table 3. First, we extend the sample period to include data subsequent to the end of the Korean War. Since the core PCE data are not available before 1959, we recompute the relative change in food and energy prices using CPI data. The “core CPI” is available starting in 1957. Prior to 1957 we use the “all items CPI less food” rather than the “core CPI.” The two series are highly correlated in the late 1950s, since energy prices were not highly volatile until the early 1970s. Prior to 1987 we compute the relative change in food and energy prices using CPI data on a 1967 = 100 base, not seasonally adjusted, and apply the current seasonal factors for these years using the 1982–84 base-year data. We do this to avoid the truncation problems that affect the computation of CPI inflation rates in the early part of the sample period when the base year is 1982–84 = 100 (see Kozicki and Hoffman 2004).

Second, we allow for structural breaks in the variance of the innovations to the time-varying intercept process to occur at several points in the sample that align with well-known macroeconomic and monetary events. The first break is allowed to occur at the beginning of the Great Inflation, which we date to the first quarter of 1967. The second break is meant to capture the beginning of the large reduction in U.S. macroeconomic volatility that has been observed over the past two decades. Based on the findings of Kim and Nelson (1999)

Table 3. Time-Varying Intercept Model with Variance Breaks, Sample Period: 1953:Q1–2005:Q1

	CPI	PCE	GDP
<i>Standard Deviation of Intercept 53–66</i>	0.79 (0.15)	0.47 (0.12)	0.52 (0.15)
<i>Standard Deviation of Intercept 67–83</i>	1.92 (0.19)	1.06 (0.16)	0.75 (0.21)
<i>Standard Deviation of Intercept 84–93</i>	0.36 (0.09)	0.26 (0.06)	0.22 (0.08)
<i>Standard Deviation of Intercept 94–05</i>	0.15 (0.05)	0.12 (0.06)	0.09 (0.08)
<i>Gap_t</i>	−0.01 (0.07)	−0.09 (0.07)	−0.10 (0.09)
<i>Gap_{t−1}</i>	0.10 (0.09)	0.22 (0.09)	0.13 (0.10)
<i>Gap_{t−2}</i>	0.03 (0.10)	0.03 (0.09)	−0.03 (0.11)
<i>Gap_{t−3}</i>	0.10 (0.10)	−0.11 (0.09)	0.03 (0.12)
<i>Gap_{t−4}</i>	−0.07 (0.08)	0.06 (0.07)	0.01 (0.09)
<i>ΔRel Import Prices_t</i>	0.10 (0.04)	0.07 (0.04)	−0.23 (0.05)
<i>ΔRel Import Prices_{t−1}</i>	−0.002 (0.04)	0.08 (0.04)	0.11 (0.05)
<i>ΔRel Import Prices_{t−2}</i>	0.04 (0.04)	−0.03 (0.05)	0.01 (0.05)
<i>ΔRel Import Prices_{t−3}</i>	−0.06 (0.04)	0.04 (0.04)	0.09 (0.05)
<i>ΔRel Import Prices_{t−4}</i>	0.03 (0.04)	−0.01 (0.04)	0.02 (0.05)
<i>ΔRel Fd & Energy Prices_t</i>	3.26 (0.21)	2.14 (0.18)	1.36 (0.22)
<i>ΔRel Fd & Energy Prices_{t−1}</i>	0.21 (0.21)	0.01 (0.13)	0.17 (0.23)
<i>ΔRel Fd & Energy Prices_{t−2}</i>	−0.07 (0.21)	0.01 (0.32)	0.20 (0.22)
<i>ΔRel Fd & Energy Prices_{t−3}</i>	0.32 (0.21)	−0.21 (0.19)	0.03 (0.33)

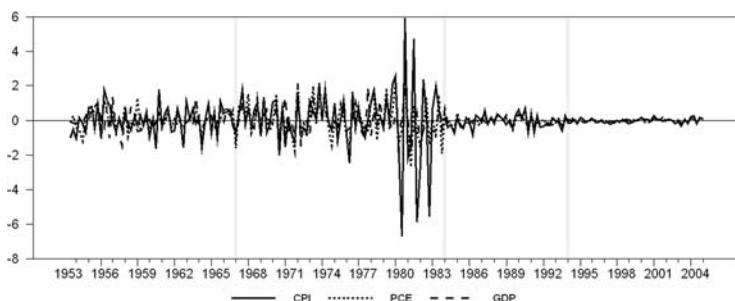
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Table 3. (Continued)

	CPI	PCE	GDP
$\Delta Rel\ Fd\ \&\ Energy\ Prices_{t-4}$	-0.18 (0.21)	0.30 (0.18)	0.41 (0.22)
<i>NIXON_ON</i>	-0.36 (1.75)	-0.31 (1.08)	-1.51 (0.96)
<i>NIXON_OFF</i>	3.37 (1.16)	2.20 (0.73)	2.46 (0.71)
<i>Log-Likelihood</i>	-290.16	-249.08	-277.11
<i>Std. Error of the Estimate</i>	0.40	0.47	0.66
Notes: This table shows maximum likelihood coefficient estimates and standard errors (in parentheses) for the time-varying intercept Phillips-curve specification in equations (5)–(6) over the sample period 1953:Q1–2005:Q1, where the standard deviation of the innovation to the random-walk intercept term (denoted “Standard Deviation of Intercept”) is allowed to change in 1967, 1984, and 1994. The “Gap” variable is measured using the estimate of the output gap produced by the CBO. All other variables are defined in section 2.			

and McConnell and Pérez-Quirós (2000), we date the beginning of this “Great Moderation” to the first quarter of 1984. We date the third break at the first quarter of 1994, when the Federal Open Market Committee (FOMC) started releasing information on changes in the intended federal funds rate at the close of FOMC meetings.

As table 3 demonstrates, for all three measures of inflation the estimated variance of the innovations to the time-varying intercept increases sharply during the Great Inflation, falls to 40–50 percent of its 1953–66 value during the first decade of the Great Moderation, and then declines by roughly 50 percent of the value in the 1984–93 period during the most recent decade (see figure 5 for a plot of the estimated innovations). This pattern for the volatility of shocks to the random-walk intercept suggests that the size of permanent shocks to the inflation rate has varied substantially over the sample period, and that such shocks are now quite small from a historical perspective. The latest decline in volatility is consistent with

Figure 5. Shocks to Permanent Inflation

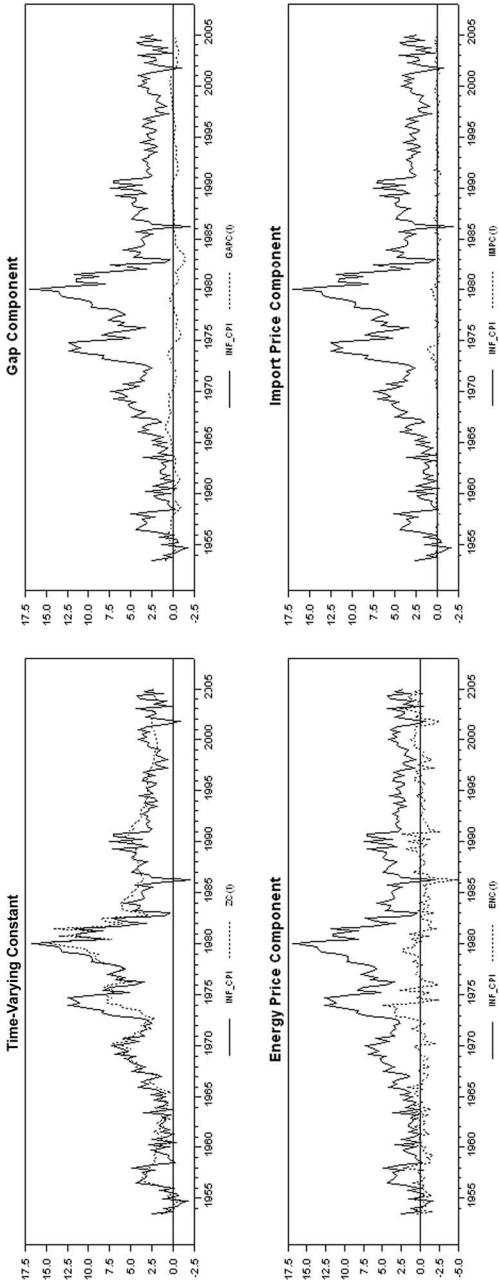
Notes: This figure plots the estimated innovations to the random-walk intercept of the time-varying intercept Phillips-curve specification in equations (5)–(6), where estimation is based on the sample period 1953:Q1–2005:Q1.

the notion that long-horizon inflation expectations have become better “anchored” during the period of increasing FOMC transparency, although this is not necessarily evidence of a causal relationship between increased transparency and lower volatility of long-term inflation expectations.

The estimates of the time-varying intercept and the contributions of the gap and supply shocks from the estimates in table 3 are shown in figures 6–8 for the three measures of inflation. These graphs indicate that the time-varying intercept term dominates the variation in all three measures of inflation. The only cases where the distributed lags on the output-gap and the supply-shock terms account for a substantial portion of the inflation rates are in 1973–74 and, to a lesser extent, in 1979–80.

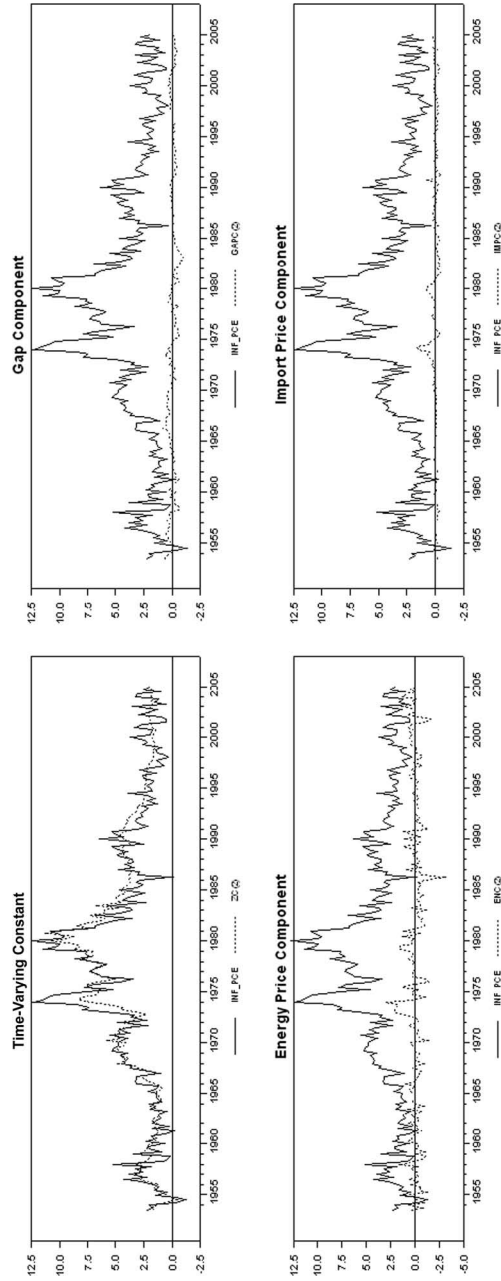
Finally, we have also estimated a version of the TVI specification in which the CBO measure of the output gap is replaced by the difference between the unemployment rate and a time-varying estimate of the NAIRU. We follow Gordon (1997) and model the NAIRU as a random walk and constrain the standard deviation of the error term in this process to 0.2. Results from this specification (not reported here) are substantially the same as those obtained with the CBO output gap, suggesting that our conclusions about the contribution of the gap are not sensitive to whether it is measured as an output or unemployment gap.

Figure 6. One-Period-Ahead CPI Inflation Components



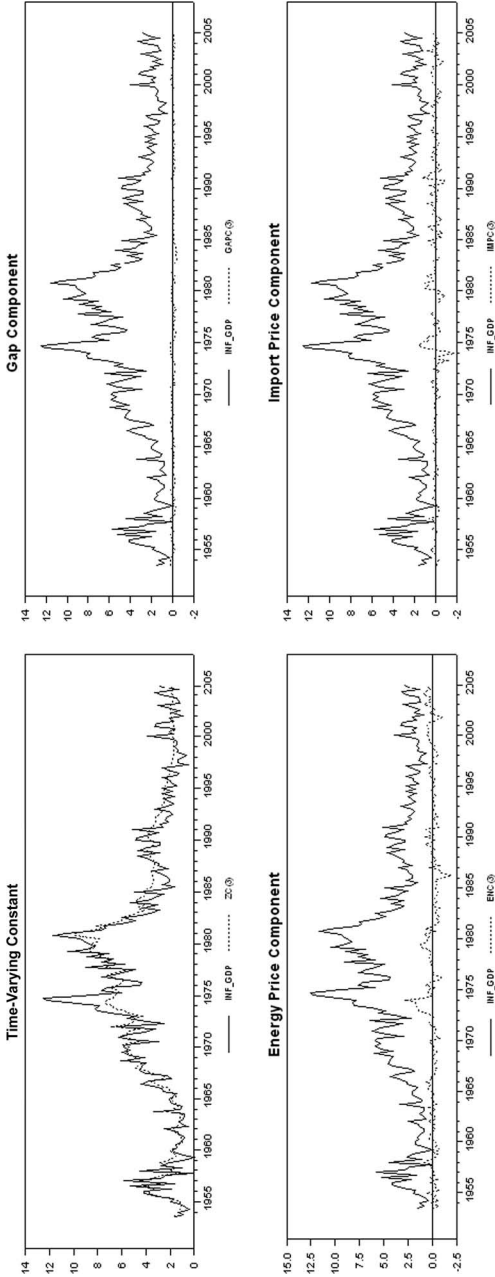
Notes: This figure plots the inflation rate (solid line) against the estimated components of the time-varying intercept Phillips-curve specification in equations (5)–(6), where parameter estimates were constructed using the sample period 1953:Q1–2005:Q1. The inflation measure is the CPI. The “Gap” variable is measured using the estimate of the output gap produced by the CBO. The “Energy Price” and “Import Price” variables are defined in section 2 above.

Figure 7. One-Period-Ahead PCE Inflation Components



Notes: This figure plots the inflation rate (solid line) against the estimated components of the time-varying intercept Phillips-curve specification in equations (5)–(6), where parameter estimates were constructed using the sample period 1953:Q1–2005:Q1. The inflation measure is the PCE index. The “Gap” variable is measured using the estimate of the output gap produced by the CBO. The “Energy Price” and “Import Price” variables are defined in section 2 above.

Figure 8. One-Period-Ahead GDP Inflation Components



Notes: This figure plots the inflation rate (solid line) against the estimated components of the time-varying intercept Phillips-curve specification in equations (5)–(6), where parameter estimates were constructed using the sample period 1953:Q1–2005:Q1. The inflation measure is the GDP index. The “Gap” variable is measured using the estimate of the output gap produced by the CBO. The “Energy Price” and “Import Price” variables are defined in section 2 above.

4. TVI Model-Based Inflation Forecasts

The econometric evidence from the Gordon and TVI Phillips-curve specifications suggests that the output gap is not an important driver of inflation dynamics. Of course, the validity of this conclusion is conditioned on the appropriateness of the models used for describing the inflation process. In this section we provide an external check of this appropriateness for the TVI specification. Specifically, we compute inflation forecasts from the TVI specification and compare these forecasts with measures obtained from surveys of professional forecasters. To the extent that the TVI model-based forecasts are close to those obtained from surveys, it suggests that the TVI specification is a reasonable description of the evolution of inflation expectations.

We first describe how forecasts are generated from the TVI specification in equations (5)–(6). To begin, rewrite equation (5) as

$$\pi_t = z_t + \sum_{i=0}^N \alpha_i \begin{bmatrix} D_{t-i} \\ X_{t-i} \end{bmatrix} + \varepsilon_t, \quad (7)$$

where α_i is a vector of coefficients taken from the lag polynomials $b(L)$ and $c(L)$, and N is the lag order of these lag polynomials. Incrementing the time index in equation (7) by one quarter and taking conditional expectations yields

$$E_t[\pi_{t+1}] = E_t[z_{t+1}] + \alpha_0 E_t \begin{bmatrix} D_{t+1} \\ X_{t+1} \end{bmatrix} + \sum_{i=1}^N \alpha_i \begin{bmatrix} D_{t+1-i} \\ X_{t+1-i} \end{bmatrix}. \quad (8)$$

Assume that $\begin{bmatrix} D_{t+1} \\ X_{t+1} \end{bmatrix}$ can be modeled as a stationary VAR process:⁷

$$\begin{bmatrix} D_{t+1} \\ X_{t+1} \end{bmatrix} = \sum_{i=0}^J \beta_i \begin{bmatrix} D_{t-i} \\ X_{t-i} \end{bmatrix} + v_{t+1}. \quad (9)$$

⁷Our forecasting model for $(D_{t+1}, X_{t+1})'$ is a restricted VAR with four lags. Estimates of an unrestricted VAR, $(I - \beta(L))(D_{t+1}, X_{t+1})' = v_{t+1}$, indicated a lower triangular structure for $\beta(L)$ when the three variables are ordered as follows: (i) relative food and energy price changes, (ii) relative import price changes, and (iii) the output gap. This structure was imposed to generate our forecasts.

Then

$$E_t[\pi_{t+1}] = z_t + \alpha_0 \sum_{i=0}^J \beta_i \begin{bmatrix} D_{t-i} \\ X_{t-i} \end{bmatrix} + \sum_{i=1}^N \alpha_i \begin{bmatrix} D_{t+1-i} \\ X_{t+1-i} \end{bmatrix}. \quad (10)$$

Since $\begin{bmatrix} D_t \\ X_t \end{bmatrix}$ is assumed to be stationary, $\lim_{M \rightarrow \infty} E_t \pi_{t+M} = z_t$.⁸ Thus z_t represents the long-horizon inflation forecast from the model and, in the sense of Beveridge and Nelson (1981), represents the long-run or permanent component of inflation. Likewise, $\alpha_0 \sum_{i=0}^J \beta_i \begin{bmatrix} D_{t-i} \\ X_{t-i} \end{bmatrix} + \sum_{i=1}^N \alpha_i \begin{bmatrix} D_{t+1-i} \\ X_{t+1-i} \end{bmatrix}$ is then the one-period-ahead transitory component of expected inflation.⁹

The inflation forecast error from the TVI specification is given by

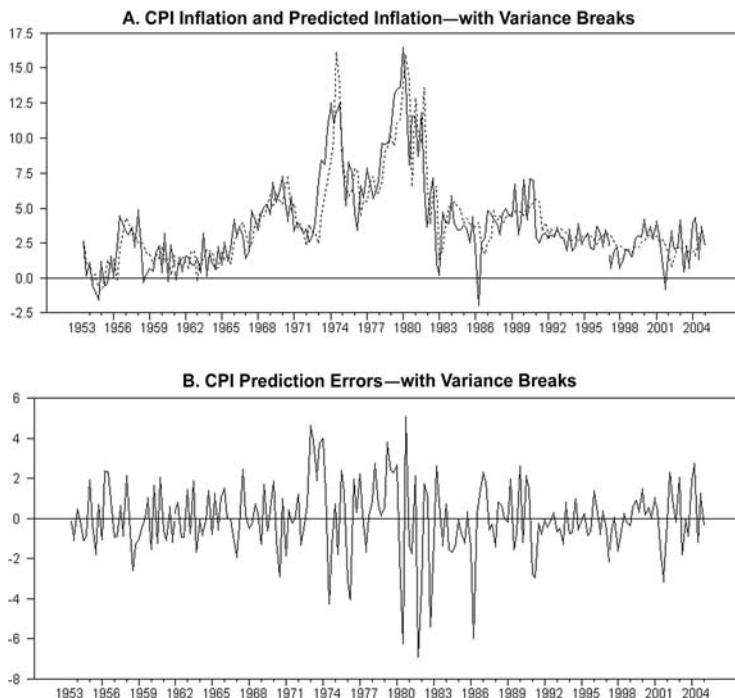
$$\begin{aligned} \pi_{t+1} - E_t[\pi_{t+1}] &= \omega_{t+1} + \alpha_0 \left[\begin{bmatrix} D_{t+1} \\ X_{t+1} \end{bmatrix} - \sum_{i=0}^J \beta_i \begin{bmatrix} D_{t-i} \\ X_{t-i} \end{bmatrix} \right] \\ &+ \varepsilon_{t+1} = \omega_{t+1} + \alpha_0 v_{t+1} + \varepsilon_{t+1}. \end{aligned} \quad (11)$$

Thus unpredicted inflation is the sum of three terms: (i) the innovation to long-horizon inflation expectations, given by ω_{t+1} ; (ii) the one-period-ahead forecast error for $\begin{bmatrix} D_{t+1} \\ X_{t+1} \end{bmatrix}$, given by $\alpha_0 v_{t+1}$; and (iii) the residual of the Phillips curve, given by ε_{t+1} . When $\alpha_0 = 0$ the one-period-ahead unexpected inflation is just $\pi_{t+1} - E_t[\pi_{t+1}] = \omega_{t+1} + \varepsilon_{t+1}$.

In figures 9A–11A the actual inflation rates are plotted against the one-quarter-ahead projections, $E_{t-1}[\pi_t]$, using the estimated coefficients from table 3. The lower panels of each figure (9B–11B) show the differences in the series from the

⁸This limit assumes that both D_t and X_t are mean zero, an assumption we have imposed by omitting intercepts in the VAR specification in (7). Preliminary analysis that included intercepts in (9) suggested they were statistically insignificant.

⁹By constructing multistep dynamic forecasts of $(D_{t+i}X_{t+i})'$, the entire path of the transitory component of expected inflation can be estimated.

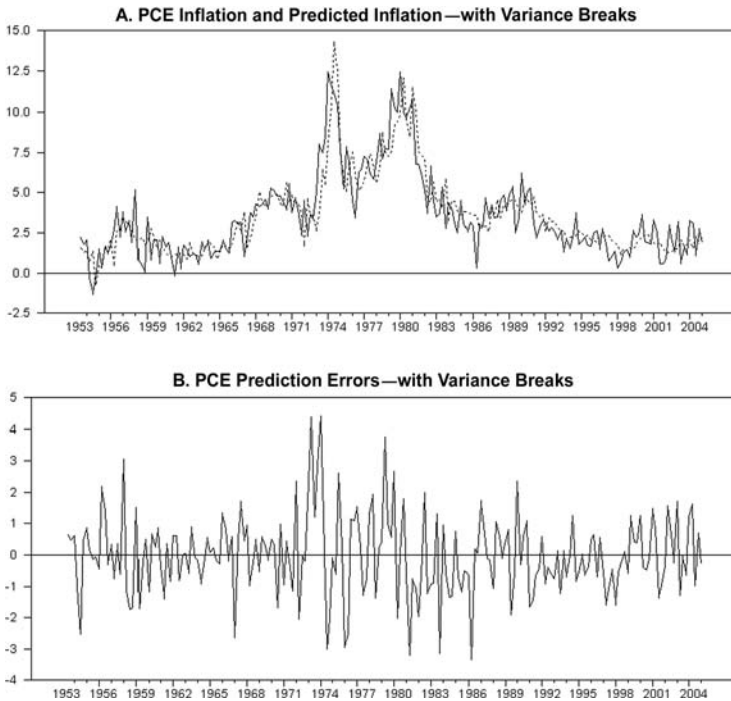
Figure 9. CPI Inflation Predictions from TVI Model

Notes: This figure contains information regarding the one-quarter-ahead inflation predictions generated by the time-varying intercept Phillips-curve specification in equations (5)–(6), where estimation was based on the sample period 1953:Q1–2005:Q1. The inflation rate is measured using the CPI. Panel A plots the actual inflation rate (solid line) against the prediction (dotted line). Panel B plots the prediction errors.

upper panels—the one-quarter-ahead inflation forecast errors.¹⁰ The estimated autocorrelations of the computed one-quarter-ahead inflation forecast errors (not shown) are very small, indicating that there is little predictive content in the history of the forecast errors for future forecast errors.

¹⁰For purposes of these graphs, we incorporate the effects of the Nixon price-control dummy variables, *Nixon_On* and *Nixon_Off*. While these variables were constructed by Gordon ex post, we believe it is reasonable to assume that, at the time, individuals expected some impact on inflation in the short run of the implementation and removal of the controls.

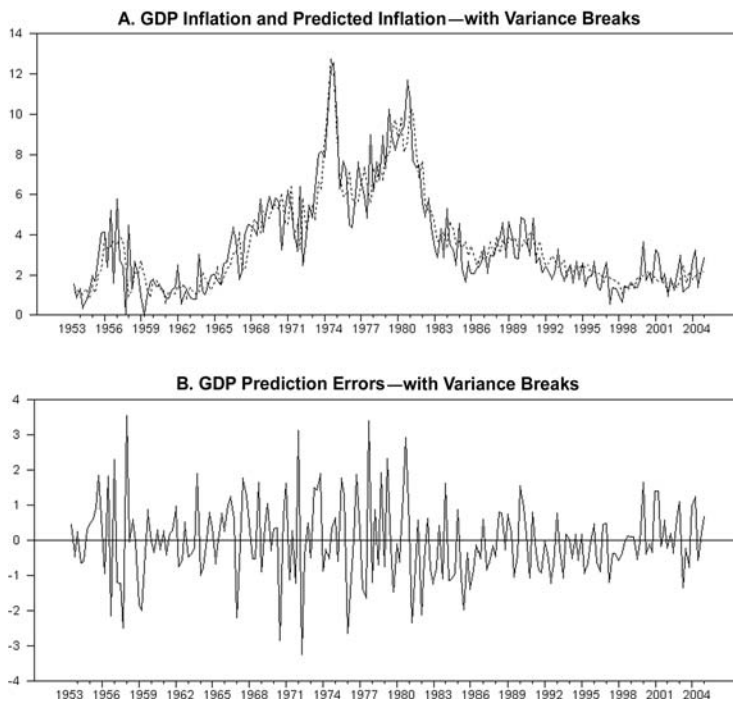
Figure 10. PCE Deflator Inflation Predictions from TVI Model



Notes: This figure contains information regarding the one-quarter-ahead inflation predictions generated by the time-varying intercept Phillips-curve specification in equations (5)–(6), where estimation was based on the sample period 1953:Q1–2005:Q1. The inflation rate is measured using the PCE index. Panel A plots the actual inflation rate (solid line) against the prediction (dotted line). Panel B plots the prediction errors.

In figure 12 we compare our estimates of the model-based one-quarter-ahead inflation forecasts with various survey measures of expected CPI and GDP deflator inflation. The inflation-forecast measure from the TVI model is indicated by the solid line in both panels of figure 12. There are two surveys that are available for CPI and GDP inflation: the one-quarter-ahead inflation forecast from the Survey of Professional Forecasters (available since 1981:Q3 for CPI inflation and 1968:Q4 for GDP inflation) and the one-quarter-ahead inflation forecast from the Blue Chip Survey (available since

Figure 11. GDP Deflator Inflation Predictions from TVI Model

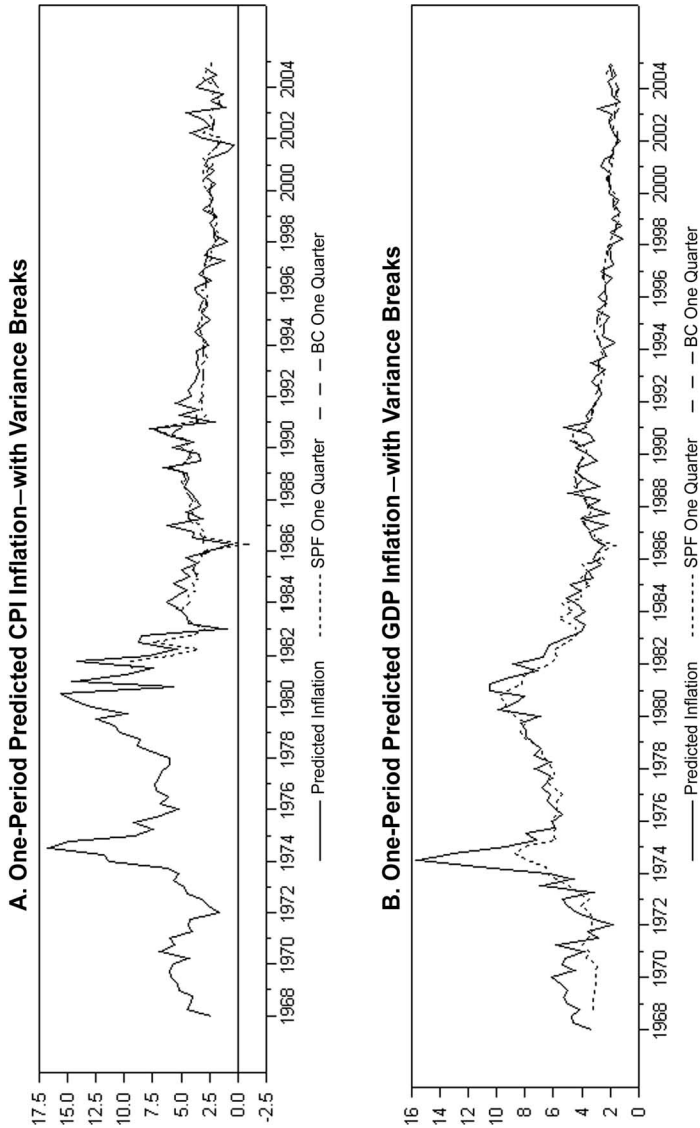


Notes: This figure contains information regarding the one-quarter-ahead inflation predictions generated by the time-varying intercept Phillips-curve specification in equations (5)–(6), where estimation was based on the sample period 1953:Q1–2005:Q1. The inflation rate is measured using the GDP index. Panel A plots the actual inflation rate (solid line) against the prediction (dotted line). Panel B plots the prediction errors.

1985:Q1 for both CPI and GDP inflation). The forecasts from the Survey of Professional Forecasters are indicated by the short-dashed line (SPF One Quarter) and the forecasts from the Blue Chip Survey are indicated by the long-dashed line (BC One Quarter) in figure 12.

For the CPI, the TVI inflation forecasts are reasonably successful at tracking the survey measures. In particular, the major spikes in the TVI inflation forecasts are mirrored in the timing, and in many

Figure 12. Inflation Predictions from TVI Model and Surveys



Notes: This figure plots the one-quarter-ahead inflation prediction generated by the time-varying intercept Phillips-curve specification in equations (5)–(6) against survey measures of inflation expectations taken from the Survey of Professional Forecasters (SPF) and Blue Chip Survey (BC). Estimation is based on the sample period 1953:Q1–2005:Q1.

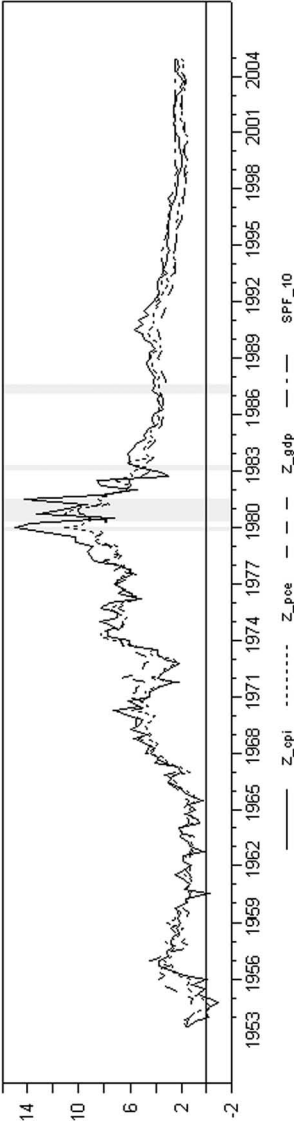
cases in the amplitude, by spikes in the SPF one-quarter measure. The BC one-quarter inflation forecasts are less volatile than the other two measures, but again the major spikes in this series mirror the timing of the major spikes in the series derived from the TVI model. The TVI inflation forecasts are less successful at tracking the survey forecasts for GDP inflation. In particular, there are substantial differences in the TVI forecast and the SPF survey forecast in the late 1960s and again in 1973. The latter period is strongly influenced by our decision to include the estimated effect of the removal of the price controls in the TVI measure of expected inflation. After 1973 the two measures track more closely, though the spikes in the TVI forecasts are not as well aligned with the survey data as is the case with the CPI inflation rate. The TVI model has the worst success at mimicking the BC survey forecast for GDP inflation. The BC survey forecast is substantially less volatile than the TVI inflation forecast, and the spikes between the two series are not particularly well aligned.¹¹

The estimated time series of the time-varying intercept (the permanent component of inflation) are shown in figure 13. The series for all three inflation rates are quite similar, though the one derived from the CPI is more volatile than the other two up to the Great Moderation period. The estimates suggest that long-term expected inflation rose sharply in the late 1960s from less than 2 percent in 1964 to over 4 percent in 1968. All three series level off in the late 1960s and decline a bit in the early 1970s before the first energy shock. From 1973 until 1982 all the series trend up. From 1982 to 1985 the trend is reversed, and the series level out at around 4 percent for the remainder of the 1980s. After 1990 all the series again trend down through the mid-1990s, after which they level out at around 2 percent.

The final line (SPF_10) plotted in figure 13 is the ten-year-ahead CPI inflation forecast from the Survey of Professional Forecasters. The general trend in the long-term expected CPI inflation from the

¹¹For CPI inflation, the correlation between the change in the TVI inflation forecast and the change in the survey measures is 0.56 for the SPF and 0.39 for the BC Survey. For GDP inflation, this correlation is 0.16 for the SPF and -0.11 for the BC Survey.

Figure 13. Expected Long-Term Inflation—Z and SPF



Notes: This figure plots the estimate of the time-varying intercept from the time-varying intercept Phillips-curve specification in equations (5)–(6), where estimation is based on the sample period 1953:Q1–2005:Q1. The solid, dashed, and long-dashed lines indicate estimation using CPI, PCE deflator, and GDP deflator measures of inflation, respectively. The dash-dotted line indicates a survey measure of long-horizon (ten years ahead) CPI inflation expectations taken from the Survey of Professional Forecasters (SPF).

TVI model tracks that in the survey data quite well for the period for which the latter series are available, 1991:Q4 through 2005:Q1.

5. Conclusion

We have presented evidence regarding the relative contribution of the real activity “gap” and other potential inflation drivers, such as changes in long-horizon inflation expectations and supply-shock variables, for explaining the U.S. inflation rate over the post-war period. Our results suggest that realized inflation is dominated by variation in long-horizon expected inflation, while the gap and supply-shock variables play only a very limited role. These results are robust to alternative specifications for the inflation-driving process and measures of inflation and the gap.

Our preferred model specification is one in which inflation is determined by a random-walk permanent component (which represents the long-horizon inflation expectation), a distributed lag on the real activity gap, and a distributed lag on supply-shock variables. Model-based inflation forecasts have reasonable success at tracking forecasts obtained from surveys. This suggests that our model of the inflation-driving process does a relatively good job of reproducing whatever process is driving survey measures of future inflation. Results from this model also suggest that the variance of the process that generates changes in long-horizon expected inflation has changed over time. Interestingly, this variance has become very small over the last ten years of the sample, suggesting that long-horizon expected inflation has become much better “anchored” in the past decade.

Taken together, the evidence presented here suggests that the key to understanding the inflation process is to understand what drives changes in long-horizon inflation expectations. To this end, further research focused on attempting to relate these changes to “news” could prove especially fruitful.

References

- Atkeson, A., and L. E. Ohanian. 2001. “Are Phillips Curves Useful for Forecasting Inflation?” *Quarterly Review* (Federal Reserve Bank of Minneapolis) 25 (1): 2–11.

- Beveridge, S., and C. R. Nelson. 1981. "A New Approach to Decomposition of Economic Time Series into Permanent and Transitory Components with Particular Attention to Measurement of the Business Cycle." *Journal of Monetary Economics* 7 (2): 151–74.
- Clark, T. E., and M. W. McCracken. 2006. "The Predictive Content of the Output Gap for Inflation: Resolving In-Sample and Out-of-Sample Evidence." *Journal of Money, Credit, and Banking* 38 (5): 1127–48.
- Gordon, R. J. 1982. "Inflation, Flexible Exchange Rates and the Natural Rate of Unemployment." In *Workers, Jobs and Inflation*, ed. M. N. Baily, 88–152. Washington, DC: Brookings Institution.
- . 1997. "The Time-Varying NAIRU and Its Implications for Economic Policy." *Journal of Economic Perspectives* 11 (1): 11–32.
- . 1998. "Foundations of the Goldilocks Economy: Supply Shocks and the Time-Varying NAIRU." *Brookings Papers on Economic Activity* 29 (2): 297–346.
- Gürkaynak, R. S., B. Sack, and E. Swanson. 2005. "The Sensitivity of Long-Term Interest Rates to Economic News: Evidence and Implications for Macroeconomic Models." *American Economic Review* 95 (1): 425–36.
- Kim, C.-J., and C. R. Nelson. 1999. "Has the U.S. Economy Become More Stable? A Bayesian Approach Based on a Markov-Switching Model of the Business Cycle." *The Review of Economics and Statistics* 81 (4): 608–16.
- Kozicki, S., and B. Hoffman. 2004. "Rounding Error: A Distorting Influence on Index Data." *Journal of Money, Credit, and Banking* 36 (3): 319–38.
- Levin, A., and J. Piger. 2002. "Is Inflation Persistence Intrinsic in Industrial Economies?" Federal Reserve Bank of St. Louis Working Paper No. 2002–023.
- . 2005. "Bayesian Model Selection for Structural Break Models." Mimeo.
- McConnell, M. M., and G. Pérez-Quirós. 2000. "Output Fluctuations in the United States: What Has Changed Since the Early 1980s?" *American Economic Review* 90 (5): 1464–76.

- Orphanides, A., and S. van Norden. 2005. "The Reliability of Inflation Forecasts Based on Output Gap Estimates in Real Time." *Journal of Money, Credit, and Banking* 37 (3): 583–601.
- Rudebusch, G. D., and T. Wu. 2008. "A Macro-Finance Model of the Term Structure, Monetary Policy and the Economy." *Economic Journal* 118 (530): 906–26.
- Stock, J. H., and M. W. Watson. 1999. "Forecasting Inflation." *Journal of Monetary Economics* 44 (2): 293–335.
- . 2007. "Why Has U.S. Inflation Become Harder to Forecast?" *Journal of Money, Credit, and Banking* 39 (s1): 3–33.