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19-6 Low Inflation Bends the Phillips Curve

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Abstract

The Phillips curve, which traces out a negative relationship between inflation and unemployment, has undergone tremendous changes over more than 100 years. Some researchers argue that the slope of the curve in the United States fell substantially around 20 years ago so that unemployment now has little or no effect on inflation. This paper shows that another hypothesis is equally consistent with the data: The Phillips curve may be nonlinear when inflation is low, with the economy having operated in the flat region of the curve for most of the past 20 years. The next few years may be decisive in the debate between these hypotheses, as unemployment has returned to a range in which a nonlinear curve ought to display significant steepness. A flat Phillips curve implies little change in inflation going forward, but a nonlinear curve implies moderate increases in inflation over the next few years.

JEL codes: E31

Keywords: Non-accelerating inflation rate of unemployment (NAIRU), unemployment rate

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INTRODUCTION

One of the most controversial issues in economics is the relationship between the rate of unemployment and the rate of inflation. According to some economists, inflation tends to increase when unemployment is low and decrease when unemployment is high, a relationship known as the Phillips curve. However, the Phillips curve has broken down so often that other economists question its usefulness as a guide to policymakers and forecasters. In particular, during the period of prolonged high unemployment after the Great Recession of 2008–09 the inflation rate declined only temporarily rather than continuously into deflation.

Many studies have sought to explain this puzzle of the "missing deflation." Some argued that the equilibrium rate of unemployment had risen for various reasons, so that there was not a large excess of unemployment above equilibrium. However, this explanation soon ran into problems as unemployment eventually fell below its prerecession rate and inflation remained stable. Others pointed to the increased success of central banks in achieving a sustained low rate of inflation, which leaves little scope for unemployment to have any effect. Such an explanation poses a deep challenge to our understanding of the fundamental principles of supply and demand.

This paper confirms that there indeed appears to have been a near-total collapse in prevailing versions of the Phillips curve starting in the 1990s. This breakdown is partly explained by the success of central banks in firmly anchoring inflation and expectations of future inflation at a fixed low rate. The anchoring of inflation expectations appears to be moving the Phillips curve away from the standard version that is cast in terms of changes in the inflation rate toward a version that is cast in terms of the level of the inflation rate.

Even after controlling for this shift in the dynamics of inflation, the slope of the Phillips curve appears to have flattened. Some researchers hypothesize that the anchoring of inflation expectations also reduced the slope of the Phillips curve. Another hypothesis, which this paper explores, is that the Phillips curve is not linear, as is commonly assumed, but instead bends so that excessively high unemployment has less effect on inflation than excessively low unemployment. Moreover, this bend becomes apparent only when inflation is very low. Indeed, Alban Phillips appealed to exactly this consideration when he proposed his original, highly nonlinear, curve in 1958.

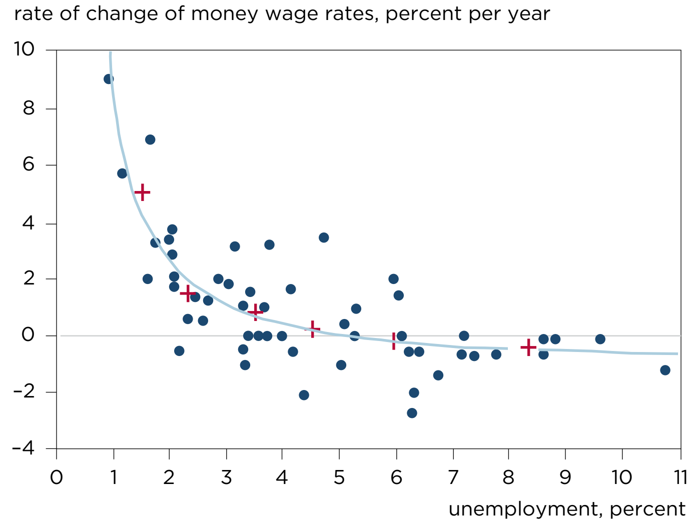
Although the two hypotheses explain inflation equally well over the past 60 years, we may be approaching a divergence. By most measures, unemployment is now below its equilibrium rate and is projected to remain there for the next few years. The hypothesis of a downward shift in a linear Phillips curve predicts little change in the inflation rate going forward. The hypothesis of a Phillips curve that bends when inflation is low predicts an increase in the inflation rate. Moreover, to the extent that inflation expectations are not fully anchored, the gap between the forecasts of the two hypotheses grows over time. We may therefore be on the cusp of one of the most important tests of macroeconomics in a generation.

A BRIEF HISTORY OF RESEARCH ON THE PHILLIPS CURVE

Alban Phillips's seminal 1958 paper explored a negative nonlinear correlation between the rate of growth of wages and the unemployment rate in the United Kingdom over nearly 100 years from 1861 through 1957. Figure 1 presents the original Phillips curve.[1] The curve is strikingly nonlinear, with wage rates rising steeply at low rates of unemployment and the change in wages flattening out near zero for high rates of unemployment.

1. Phillips based his curve on data from 1861 through 1913 and then showed that data after 1913 were broadly consistent with it.

Figure 1 Original Phillips (1958) curve, United Kingdom 1861–1913



Source: Phillips (1958), retrieved from Wiley Online Library.

Unfortunately for Phillips, his curve began to break down shortly after his paper was published. This breakdown almost surely reflects the gradual demise of the gold standard, which started in the 1930s, intensified in the 1960s, and concluded with President Richard Nixon shutting the gold window in 1971. Under the gold standard, inflation is expected to be close to zero on average over the long run, with only a small discrepancy related to any difference between the rate of gold production and the overall rate of economic growth. These conditions are ideal for the existence of a stable Phillips curve in terms of the level of inflation.

In the 1960s, before the breakdown of Phillips's original curve became apparent, a number of economists argued that it showed an exploitable tradeoff for policymakers, who could aim for a lower rate of unemployment as long as they were willing to tolerate a higher rate of wage (and price) inflation.[2] As the gold standard constraints became ever less important, it was possible to conceive of a world with permanent inflation. As early as 1960, however, Paul Samuelson and Robert Solow speculated that the Phillips curve tradeoff could be exploited only in the short run and that other factors would shift the curve over time, although they made no firm predictions about how it would shift.

Milton Friedman (1968), in his presidential address to the American Economic Association, was particularly influential in his argument that any attempt to exploit the Phillips curve to reduce unemployment permanently would cause workers to demand ever larger pay increases to keep ahead of ever higher rates of inflation. Robert Lucas (1976) went even further, arguing that monetary policy could not systematically influence unemployment, even temporarily, because workers would anticipate any systematic policy actions into their wage demands in order to keep unemployment at its equilibrium rate.

2. See the discussions in Blanchard (2017a, 157) or Fuhrer et al. (2009, 6).

While accepting the logic of Lucas's critique, most economists believed it was mainly relevant for extreme cases such as very high inflation and hyperinflation. Robert Gordon (1982) made the case for a stable accelerationist linear Phillips curve in the United States that does allow for effective countercyclical monetary policy. According to the accelerationist Phillips curve, inflation tends to remain where it has been in the recent past unless unemployment deviates from the equilibrium, or non-accelerating inflation, rate of unemployment (NAIRU). The accelerationist Phillips curve is thus expressed in terms of the *change* in the rate of inflation rather than simply the rate of inflation. The assumption of linearity was chosen for tractability and to make it possible to incorporate auxiliary variables and lagged adjustment.[3] John Taylor (1980) and Guillermo Calvo (1983) provided the theoretical underpinnings for an expectations-augmented version of an accelerationist linear Phillips curve that has become the workhorse of macroeconomic models to this day.

The 1980s and early 1990s were the golden age of the accelerationist linear Phillips curve. By the late 1990s, however, cracks began to appear. US unemployment fell to a 30-year low but inflation edged up only slightly. Katz and Krueger (1999) argued that the aging of the workforce, the rise of temporary employment, and a growing prison population were pushing down the NAIRU. Others argued that sustained declines in the unemployment rate could push down the NAIRU (and sustained increases in unemployment could push it up), an effect known as hysteresis (Blanchard and Summers 1986, Ball 2009). Still others argued that globalization was holding down US inflation by increasing foreign competition for US firms and workers.[4]

Some researchers put forward alternative hypotheses that focused on the growing credibility of monetary policy in achieving a low and stable rate of inflation. One result of this credibility was that wages and prices were becoming less responsive to past inflation, that is, less accelerationist. It was also argued that low and stable inflation might reduce the slope of the Phillips curve, for example, by reducing the frequency with which firms adjust wages and prices (Ball, Mankiw, and Romer 1988). Moreover, the unemployment gap was becoming a less useful predictor of future inflation, which would tend to reduce the apparent slope of the Phillips curves in models with imperfect controls for inflation expectations (Roberts 2006).

After the Great Recession of 2008–09, the problem of the "missing deflation" dramatized the breakdown of the accelerationist linear Phillips curve. In 2009 through 2014, unemployment rose and remained far above previous estimates of the NAIRU. Even after allowing for increased anchoring of long-run inflation expectations around the Federal Reserve's target of 2 percent, inflation fell less than existing Phillips curve models predicted. Early attempts to explain the missing deflation by appealing to a rise in the NAIRU failed soon after they were published, as unemployment fell below the estimated NAIRUs and inflation remained stable (Gordon 2013,

3. Phillips (1958) noted that his nonlinear form made it difficult to incorporate other factors that he felt were important, notably the change in the unemployment rate and the change in import prices.

4. Ihrig et al. (2007) found no support for this hypothesis. A larger proportion of a domestic demand shock spills over into the trade balance when an economy is more open, but the inflationary effect of the proportion that does not spill over, which is what determines the unemployment rate, remains unchanged. Import prices may have a larger direct effect on inflation in a globalized world. For this reason, our regressions include relative import price inflation scaled by the share of imports in GDP.

Watson 2014). Other studies proposed using alternative measures of inflation or unemployment that raised new issues.[5]

The past few years have cast doubt on the hysteresis hypothesis, as a prolonged episode of very high unemployment seemed to have little lasting effect on the NAIRU.[6] Greater attention has focused on the success of monetary policy in anchoring both inflation and inflation expectations at very low levels. New studies argued that increased monetary policy credibility has reduced both the slope of the Phillips curve and the persistence of inflation (Ball and Mazumder 2019b; Blanchard 2016, 2017b; Gordon 2018; Pfajfar and Roberts 2018).

Other studies have revisited the issue of nonlinearity in the Phillips curve and find that a nonlinear Phillips curve model can help to at least partly explain the missing deflation (Nalewaik 2016; Babb and Detmeister 2017; Doser et al. 2017; Hooper, Mishkin, and Sufi 2019). Effectively, the US economy was operating in the flatter region of the Phillips curve in 2009–14. Of these studies, Nalewaik (2016) comes closest to the approach in this paper, estimating a nonlinear Phillips curve that varies according to whether inflation appears to be stationary or nonstationary. Using aggregate data, Hooper, Mishkin, and Sufi (2019) obtain only limited success in estimating nonlinear Phillips curves that do not vary with the level of inflation. However, with US metropolitan area data during the post-1990 period of low inflation, they find differences in Phillips curve slopes that are strongly related to differences in unemployment rates, and this implied nonlinearity is similar to the nonlinearity found in this paper during periods of low inflation.

An important argument for a nonlinear Phillips curve is that downward nominal wage and price rigidity reduces the slope of the Phillips curve when unemployment exceeds the NAIRU and inflation is very low.[7] Given that individual prices do not move in lockstep, a very low average rate of inflation means that some prices must be falling to offset other prices that are rising. It is plausible that even a very high rate of excess unemployment may not succeed in pushing down many individual prices or wages, thus keeping the overall inflation rate from falling to zero or below. As shown in the next section, this hypothesis implies a significant interaction between the shape of the Phillips curve and the level of inflation. A couple of studies recently revisited the issue of downward wage and price rigidity but did not test the implications for a standard Phillips curve in macroeconomic data (Fuhrer, Olivei, and Tootell 2012; Daly and Hobijn 2014). That is the objective of this paper.

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5. Ball and Mazumder (2011, 2019a, 2019b) use median CPI and different measures of the unemployment gap. Their principal alternative measure, based on short-term unemployment, does not significantly improve the fit or change any of the main results of the regressions in this paper, a result also found by Kiley (2014). Median CPI is dominated by the price of housing, which is particularly slow to respond to the unemployment gap and distorts the picture of overall price trends. (To reduce the dominance of housing in the median CPI, the Federal Reserve Bank of Cleveland revised its methodology several years ago by breaking up the owner's equivalent rent component into four regional measures. However, housing remains the median component of the CPI in 57 percent of all observations. See www.clevelandfed.org/our-research/indicators-and-data/median-cpi/revised-methodology.aspx.) In the context of the regressions of this paper, median CPI reduces, but does not eliminate, the downward shift in a linear Phillips curve, in part because it leads to a lower estimated slope prior to the 1990s.

6. Leduc and Wilson (2017) suggest that reduced labor bargaining power and compositional shifts in labor supply have flattened the Phillips curve at least temporarily.

7. Phillips (1958) made this point. For evidence on downward wage and price rigidity, see Akerlof, Dickens, and Perry (1996) and Fallick, Lettau, and Wascher (2016).

HOW DOWNWARDLY RIGID WAGES (OR PRICES) BEND THE PHILLIPS CURVE

We assume that the economy is composed of many monopolistically competitive firms facing both aggregate and idiosyncratic demand shocks. Each firm is matched to a localized pool of workers.[8] We assume no productivity growth, so that, in the absence of shocks, wages increase at the same rate as expected price inflation. Lowercase Roman letters denote individual firm variables; uppercase Roman letters denote aggregate variables. Greek letters denote parameters. All parameters are nonnegative.

$$l_i^D = \left(\frac{1+\Delta w_i}{1+\Delta P^e}\right)^{-\alpha} \times u_i \times D \quad (1)$$

$$l_i^S = \left(\frac{1+\Delta w_i}{1+\Delta P^e}\right)^{\beta} \times z_i,\;\; z_i = 1 \; if \; \Delta w_i \geq 0 \; and \; z_i = \zeta < 1 \; if \; \Delta w_i < 0 \quad (2)$$

Equation 1 expresses the demand for labor of the i^{th} firm. It is downward-sloping in the ratio of firm-specific wages to aggregate expected prices. Wages and prices in the previous period are normalized at 1. Thus, current wages equal 1 plus the rate of wage inflation, Δw_i, and current expected prices equal 1 plus the expected rate of price inflation, ΔP^e. Firms are hit by idiosyncratic demand shocks, u_i, and aggregate demand shocks, D. These shocks are multiplicative and centered around 1. Equation 2 expresses the supply of labor to the i^{th} firm. It is upward-sloping in the ratio of wages to expected prices. There is another term, z_i, which plays no role when wages are constant or rising. However, workers reduce their labor supply by a discrete proportion, 1–ζ, when they are forced to take a nominal wage cut.

The discontinuity in labor supply creates three ranges for wage inflation. Equation 3a describes the normal range for wage inflation, which holds for positive values of expected inflation, ΔP^e, and values of $u_i \times D$ close to or greater than 1, as well as for negative values of expected inflation when $u_i \times D$ is sufficiently greater than 1. Equation 3b holds only when expected inflation is deeply negative and/or $u_i \times D$ is far below 1. In between the normal range and the extreme negative range for wage increases are various combinations of expected inflation and demand shocks that imply negative values of Δw_i in equation 3a and positive values of Δw_i in equation 3b. In this intermediate range, wage inflation is stuck at 0 and labor supply exceeds labor demand. In that case, we assume that labor is determined by the demand curve and there is notional excess supply of labor.

$$1+\Delta w_i = (1+\Delta P^e) \times (u_i \times D)^{1/(\alpha+\beta)} \;\; if \; \Delta w_i > 0 \quad (3a)$$

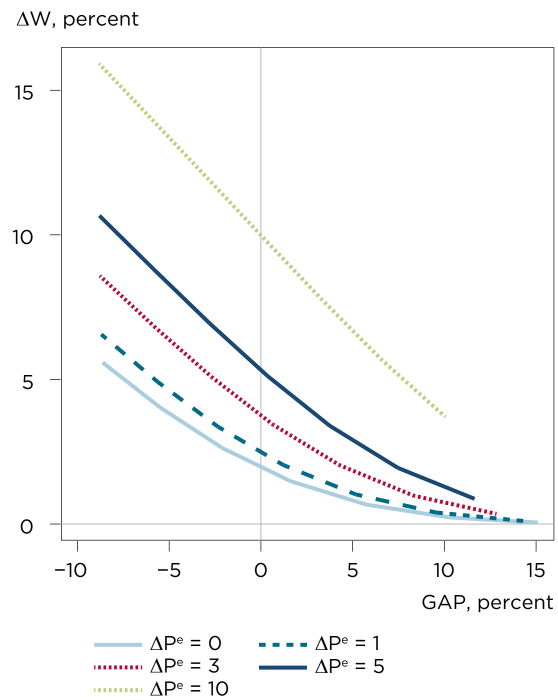
$$1+\Delta w_i = (1+\Delta P^e) \times \left(\frac{u_i \times D}{\zeta}\right)^{1/(\alpha+\beta)} \;\; if \; \Delta w_i < 0 \quad (3b)$$

$$else \; \Delta w_i = 0 \quad (3c)$$

Even when overall wage inflation is positive, some firms face negative demand shocks that may push them into the intermediate range of downward wage rigidity and excess unemployment. As more firms enter this range, the overall relationship between wage inflation and employment—in other words the slope of the Phillips curve—becomes flatter.

8. This model of a Phillips curve in wages and employment could also be specified in terms of prices and output. It is formally equivalent to a model in which monopolistically competitive entrepreneurs resist nominal price cuts.

Figure 2 Phillips curves for different rates of expected inflation



Source: Authors' calculations based on equations 1 to 7 and parameters in footnote 9.

The idiosyncratic shocks, u_i, are assumed to be normally distributed around 1. Without loss of generality, total labor in the economy is normalized around 1, so that economywide aggregates are averages across all firms and workers. For each combination of α, β, ζ, ΔP^e, D, and σ, it is possible to calculate overall wage inflation and employment, ΔW and L. In the absence of shocks and a nonnegative ΔP^e, the equilibrium level of employment is 1. The unemployment gap (GAP) is 1–L. We trace out Phillips curves in ΔW and GAP by solving the model for different values of the aggregate demand shock, D.

$$u_i \sim N(1, \sigma^2) \tag{4}$$

$$\Delta W = \int \Delta w_i(u_i, D, \Delta P^e)\, di \tag{5}$$

$$L = \int l_i(u_i, D, \Delta P^e)\ di \tag{6}$$

$$GAP = 1 - L \tag{7}$$

Figure 2 displays Phillips curves for different values of expected inflation.[9] When expected inflation is high, 0.10 or 10 percent, the curve is nearly linear with a slope of –0.6. As expected inflation declines, more and more

9. We assume α = 1, β = 1.6, ζ = 0.7, and σ = 0.1. Results are averaged over 10,000 random draws of u_i; nonpositive values of u_i, if any, are set equal to 0.01. The curves are traced out using D=0.85, 0.90, 0.95, 1.00, 1.05, 1.10, 1.15. Qualitative results are not sensitive to a wide range of parameter values.

firms encounter downward wage rigidity and the curve becomes flatter at high values of GAP. However, the slope for negative values of GAP is nearly unchanged. The curve becomes more nonlinear on the right side of the figure, while the left side declines roughly in proportion with the decline in expected inflation.

Overall, these results suggest that the Phillips curve shifts from linear to nonlinear as the expected rate of inflation declines and that most of the change in slope occurs at high rates of unemployment with little change at low rates of unemployment (negative values of GAP).

STATISTICAL ANALYSIS OF AN EVOLVING PHILLIPS CURVE

Equation 8 presents a simple version of an expectations-augmented linear Phillips curve. Inflation (ΔP) responds to the unemployment gap (GAP), which is defined as the unemployment rate minus its equilibrium rate, or NAIRU. The slope coefficient, γ, is negative, so that high unemployment reduces inflation. Inflation also moves one-for-one with long-run expected inflation, ΔP^e.

$$\Delta P_t = \gamma \, GAP_t + \Delta P_t^e \tag{8}$$

One approach to estimating equation 8 is to use a survey estimate of long-run inflation expectations. However, that approach raises several issues. First, surveys of long-run expectations are available only since 1981 and we wish to use a much longer sample that includes periods of low inflation in the 1950s and 1960s. Second, regressions show that lagged inflation still plays an important role in equation 8 even when survey expectations are included. This may reflect that surveys do not accurately capture expectations or that the inflation process has dynamic adjustment components independent of expectations. Third, survey expectations may respond to current inflation, thus raising the issue of endogeneity bias.[10]

The approach taken here is to model inflation expectations as a function of lagged inflation plus a constant, as shown in equation 9.[11] The accelerationist model implies that $\theta=0$ and $\Sigma\delta_i=1$, so that whenever the unemployment gap is zero, inflation remains constant at its average lagged value. The opposite extreme, strictly anchored expectations, implies that all $\delta_i=0$ so that θ is the inflation anchor; $\Delta P=\theta$ whenever $GAP=0$.

$$\Delta P_t^e = \theta + \sum_{i=1}^{n} \delta_i \, \Delta P_{t-i} \tag{9}$$

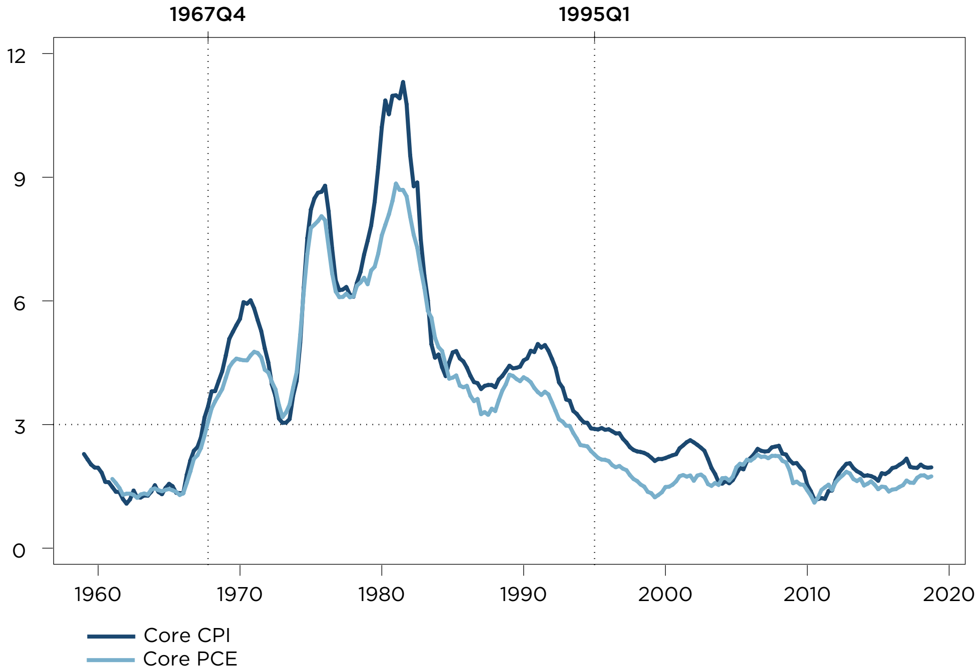
As discussed in Blanchard (2017a, chapter 8) and Ball and Mazumder (2019b), the parameters of equation 9 appear to have shifted over time, becoming more accelerationist in the late 1960s and less accelerationist in the middle or late 1990s. These changes were not marked by publicly announced policy changes at the Federal Reserve but instead reflect private-sector responses to inflation outcomes. To allow sufficient time for evidence of a change in inflation behavior to accumulate, we choose breakpoints using a lagged eight-quarter moving average of price inflation based on the consumer price index (CPI) excluding food and energy, also known as core

10. A few researchers use short-term inflation expectations in equation 8, but the problem of endogeneity bias is likely to be severe in that case.

11. As discussed below, our main results are robust to including long-run inflation expectations from the Survey of Professional Forecasters, which are available starting in 1981.

Figure 3 US price inflation, 1958Q2–2018Q4

8-quarter changes, percent annualized rates



Note: This figure displays 8-quarter annualized rates of change of the consumer price index (CPI) excluding food and energy and the personal consumption expenditures (PCE) deflator excluding food and energy.

Source: Authors' calculations using data defined in appendix B.

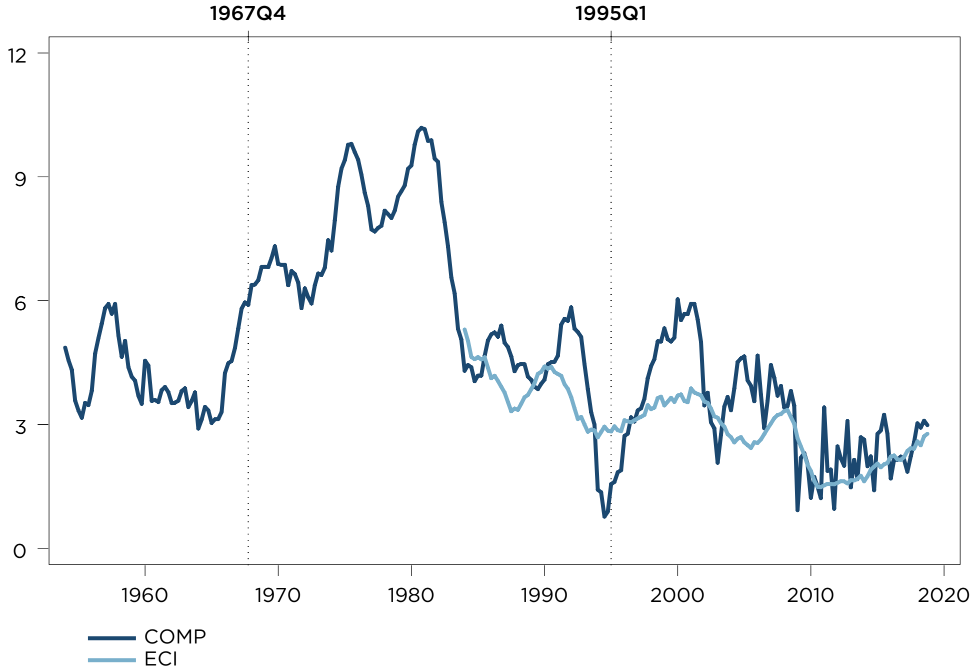
CPI inflation. Figure 3 displays core CPI inflation over the past 60 years along with core personal consumption expenditures (PCE) inflation. These "core" measures exclude much of the impact of commodity supply shocks that are outside the Phillips curve model (Gordon 1982). As marked by the vertical lines, the lagged moving average of core CPI inflation first rose above 3 percent in 1967Q4 and remained above 3 percent until 1995Q1. After 1995Q1, inflation remained consistently below 3 percent. Core PCE inflation is generally a bit lower than core CPI inflation.

We allow the parameters of equation 9 to shift at each of the two vertical lines in figure 3. We expect the lag coefficients to increase after 1967 and to decrease beginning in 1995. We do not impose equality of coefficients across the periods before 1967 and after 1994 because we do not believe the Federal Reserve's interpretation of its mandate and the public's perception of Fed policy were identical across these periods, even though the average level of inflation was similar. Our results are not sensitive to using alternative break dates as described below.

Figure 4 displays two measures of wage inflation, based on compensation per hour (COMP) in the nonfarm business sector and the employment cost index (ECI). COMP includes commission and bonus payments, including stock options, which are volatile and for which declines from year to year are not likely to be resisted in the same way that cuts in hourly wages would be. COMP becomes especially volatile after the early 2000s

Figure 4 US wage inflation, 1954Q1–2018Q4

8-quarter changes, percent annualized rates



Note: This figure displays 8-quarter annualized rates of change of compensation per hour (COMP) for the nonfarm business sector and the employment cost index (ECI) for civilian worker wages and salaries.

Source: Authors' calculations using data defined in appendix B.

for reasons we do not understand. The main reason for including COMP in our analysis is that it is available back to the early 1950s.[12] ECI provides a much smoother measure of wage inflation, but it starts only in 1982.[13]

Equation 10 displays the generalized model of this paper. It is obtained by substituting equation 9 into equation 8, allowing inflation dynamics to differ across subsamples and allowing the Phillips curve to be kinked and to shift between periods of low and high inflation.[14] Unlike the data displayed in figures 3 and 4, the regressions are based on quarterly annualized rates of inflation. GAP is the unemployment rate minus the long-run NAIRU estimated by the Congressional Budget Office (CBO). Inflation is modeled as a function of GAP, lagged inflation, and some auxiliary variables (the change in the ratio of goods import prices to overall PCE goods prices

12. Indeed, COMP goes back to the late 1940s, but we do not include data before 1954 in our regressions owing to the relaxation of World War II price controls and the imposition and removal of price controls during the Korean War.

13. A third wage measure, hourly earnings of production and nonsupervisory employees, which we did not examine, covers only part of the labor force and starts in 1964, which is too late to obtain estimates for the pre-1967 period of low inflation.

14. Hooper, Mishkin, and Sufi (2019) experiment with different shapes of nonlinear Phillips curves and find greatest support for the piecewise linear form used here, although they do not allow the curve to vary with overall inflation. Box 1 explores a logarithmic specification similar to that in Phillips (1958).

and the Gordon (1982) measure of wage and price controls).[15] Greek letters denote coefficients to be estimated; Φ denotes a vector of coefficients.

$$\Delta P_t = \gamma_1 GAP_t + \gamma_2 GAP_t[\Delta CPI < 3] + \gamma_3 GAP_t[GAP > 0] + \gamma_4 GAP_t[GAP > 0, \Delta CPI < 3] \tag{10}$$

$$+ \sum_{i=1}^{3} \left\{ \left[\theta_i + \sum_{j=1}^{8} \delta_{ij} \, \Delta P_{t-j} \right] \times BREAK_{it} \right\} + \Phi \, AUX_t$$

Where $BREAK_{it} = 0$ except,
$BREAK_{1t} = 1 \; if \; t < 1967Q4$,
$BREAK_{2t} = 1 \; if \; t \geq 1967Q4 \; and \; t < 1995Q1$, and
$BREAK_{3t} = 1 \; if \; t \geq 1995Q1$.

In equation 10, the GAP effect is allowed to change when GAP changes from negative to positive.[16] It can also change as lagged eight-quarter core CPI inflation changes between low and high. As displayed in figure 3, core CPI inflation moved from below 3 percent to above 3 percent in 1967Q4 and back below 3 percent in 1995Q1. For comparability across regressions, these transition dates between ΔCPI<3 and ΔCPI≥3 are used for all regressions, even when the dependent variable is not core CPI. These are also the dates used to define the BREAK dummy variable for inflation dynamics. Applying a different threshold for low inflation, say 2.5 percent or 4 percent, effectively means setting different break dates.[17] A threshold of 2.5 percent implies a first break date of 1967Q2 and a second break date of 1997Q4.[18] A threshold of 4 percent implies a first break date of 1968Q3 and a second break date of 1993Q1. The results shown in table 1 are essentially unaffected by these alternative inflation thresholds.

The different GAP coefficients can be statistically identified only to the extent that there are observations in each of the four possible regimes. Figure 5 displays GAP with shading to denote these regimes. The red shading denotes quarters when inflation has been high and GAP is negative; in this region the Phillips curve slope is γ_1. Light blue shading denotes quarters when inflation has been high and GAP is positive; in this region the slope is $\gamma_1+\gamma_3$. Orange shading denotes quarters when inflation has been low and GAP is negative, including the most recent quarter, 2018Q4; in this region the slope is $\gamma_1+\gamma_2$. Dark blue shading denotes quarters when inflation has been low and GAP is positive; in this region the slope is $\gamma_1+\gamma_2+\gamma_3+\gamma_4$.

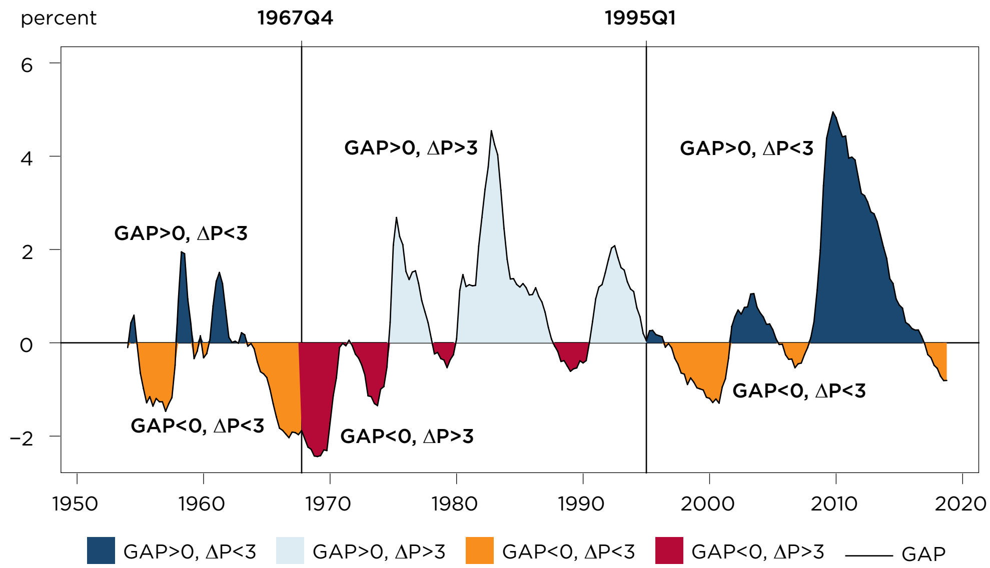
15. Results are not sensitive to dropping these auxiliary variables or to adding the change in the unemployment rate and the growth of smoothed labor productivity. Labor productivity growth, either raw or smoothed, is never statistically significant. The change in the unemployment rate is significant only for core CPI inflation. In his historical narrative, Phillips (1958) argued that changes in the unemployment rate and in relative import prices play an important role in wage inflation, but he did not include these variables in his regression.

16. Model fit and coefficient estimates are little changed when kinks are placed at values of –1 or +1 instead of 0.

17. Given that inflation never fell much below 2 percent in our sample, it does not make sense to apply a threshold lower than 2.5 percent. As shown in figure 3, an inflation threshold of 4 percent would also imply a brief shift in the slope coefficients and inflation dynamics in the mid-1970s. We do not believe it makes sense to model such short-lived shifts in behavior.

18. Blanchard (2017b) argues for a break in 1996 and Ball and Mazumder (2019b) argue for a break in 1998.

Figure 5 US unemployment GAP, 1954Q1–2018Q4



Note: GAP is the unemployment rate minus the Congressional Budget Office estimate of the equilibrium rate or NAIRU. Inflation thresholds are based on lagged 8-quarter core CPI inflation as shown in figure 3.
Source: Authors' calculations using data defined in appendix B.

The BREAK interaction terms allow the intercept and the coefficients on lagged inflation to change in 1967Q4 and again in 1995Q1. For parsimony, the first four lag coefficients (δ_{i1} through δ_{i4}) are constrained to be equal to each other and δ_{i5} through δ_{i8} are also constrained to be equal to each other (though possibly different from the first four). The tables display only the sums of all eight lag coefficients. Additional lags beyond eight quarters were almost never statistically significant.

Table 1 displays estimates of equation 10 for core CPI under various restrictions. The constant linear model (column 1) imposes the restrictions $\gamma_2=\gamma_3=\gamma_4=0$ relative to the unrestricted "shifting nonlinear" model of column 5. The p-values displayed in the "GAP restrict p-val" row at the bottom of the table show that these restrictions are very strongly rejected (0.1 percent level). The shifting linear model (column 2) imposes the restrictions $\gamma_3=\gamma_4=0$. These restrictions are rejected at the 1 percent level (but not the 0.1 percent level). The constant nonlinear model (column 3) allows for a bend in the Phillips curve but does not allow the curve to shift with overall inflation: $\gamma_2=\gamma_4=0$. These restrictions are very strongly rejected (0.1 percent level). The low inflation bend model (column 4) is inspired by figure 2, in which the Phillips curve is linear at high rates of inflation and retains roughly the same slope at low rates of inflation when *GAP* is negative but becomes flatter at low rates of inflation when *GAP* is positive: $\gamma_2=\gamma_3=0$. These restrictions are marginally rejected (5 percent level but not 1 percent level). An alternative version of the low inflation bend model would relax the restriction of equal slopes across high and low inflation periods when $GAP<0$ ($\gamma_2=0$). This restriction is never rejected at any significance level for core CPI, core PCE, and ECI, so we retain the restrictions inspired by figure 2.

Table 1 Core CPI Phillips curves, unconstrained dynamics allowing for breaks

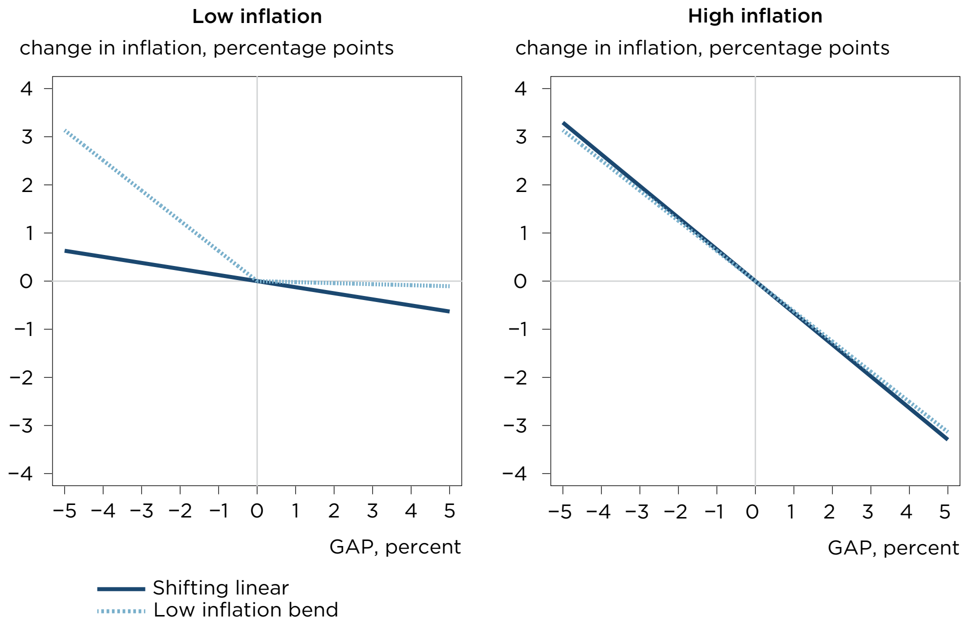
	(1) Constant linear	(2) Shifting linear	(3) Constant nonlinear	(4) Low inflation bend	(5) Shifting nonlinear
GAP	−0.35** (.07)	−0.66** (.12)	−0.32** (.12)	−0.63** (.11)	−0.13 (.16)
GAP [ΔP<3]		0.53** (.14)			−0.30 (.23)
GAP>0			−0.04 (.18)		−0.87** (.32)
GAP>0 [ΔP<3]				0.61** (.15)	1.25** (.38)
Price controls	−2.72** (.63)	−3.07** (.58)	−2.73** (.62)	−3.03** (.58)	−3.30** (.56)
Relative import price	0.40* (.17)	0.37* (.14)	0.39* (.16)	0.38** (.14)	0.32* (.13)
			Start–1967Q3		
Intercept	0.53 (.54)	0.48 (.58)	0.53 (.55)	0.53 (.53)	0.51 (.55)
Sum of lag ΔP	0.68* (.34)	0.76* (.36)	0.70* (.35)	0.54 (.33)	0.63 (.36)
			1967Q4–1994Q4		
Sum of lag ΔP	0.84** (.11)	0.93** (.11)	0.84** (.11)	0.92** (.11)	0.95** (.11)
			1995Q1–End		
Intercept	2.54** (.47)	1.34** (.38)	2.60** (.58)	0.86 (.46)	1.00* (.44)
Sum of lag ΔP	−0.10 (.21)	0.39* (.17)	−0.12 (.24)	0.51** (.20)	0.48* (.19)
R-squared	0.82	0.83	0.82	0.83	0.84
RMSE	1.146	1.101	1.148	1.099	1.073
GAP restrict p-value	0.000	0.005	0.000	0.022	
Long run ΔP, pre-1967	1.67 (.23)	2.01 (.87)	1.74 (.35)	1.16 (.18)	1.37 (.17)
Long run ΔP, 1967–94	6.34 (1.58)	9.42 (58.8)	6.47 (2.17)	8.76 (33.2)	20.60 (1250)
Long run ΔP, post-1994	2.31 (.00)	2.20 (.01)	2.32 (.01)	1.76 (.08)	1.93 (.05)
Observations	239	239	239	239	239
Start	1959Q2	1959Q2	1959Q2	1959Q2	1959Q2
End	2018Q4	2018Q4	2018Q4	2018Q4	2018Q4

Note: Robust standard errors in parentheses, * $p < 0.05$, ** $p < 0.01$.

Source: Authors' calculations based on equation 10 using data defined in appendix B.

We focus on the shifting linear and low inflation bend models (columns 2 and 4). Although the restrictions imposed in these models are marginally rejected in table 1, they are not rejected for core PCE (table 2) nor for headline CPI or PCE (tables A1 to A2 in appendix A) nor for a number of other specifications explored below. The unrestricted GAP coefficients in column 5 have relatively large standard errors and they differ markedly across inflation measures (tables 1 to 3), suggesting that these differences may be spurious. The shifting linear model displays a result that has been noted in other studies, that the slope of the Phillips curve appears to have

Figure 6 Phillips curves for core CPI inflation from table 1



Note: The curves depict the marginal effect of GAP on core CPI inflation conditional on the other variables in table 1. Low inflation is when lagged 8-quarter core CPI inflation is less than 3 percent.

Source: Authors' calculations based on the GAP coefficients from columns 2 and 4 of table 1.

flattened since the 1990s. The low inflation bend model reflects the theoretical model developed in this paper, which implies that the Phillips curve has become more nonlinear since the 1990s.[19]

The Phillips curves implied by columns 2 and 4 of table 1 are displayed in figure 6. In each panel, the horizontal axis displays the unemployment GAP and the vertical axis displays the marginal effect of GAP on core CPI inflation after conditioning on the other variables in the equation. (In other words, the panels display the relevant GAP coefficients times GAP.) The panel on the left refers to the periods of low inflation, 1959–67 and 1995–2018. The panel on the right refers to the period of high inflation, 1967–94. In the left panel, the Phillips curves from the two models are notably different. The shifting linear model has a relatively flat slope of –0.1 whereas the low inflation bend model has a slope of –0.6 for negative values of GAP and 0 for positive values of GAP. In the right panel, the two models are nearly identical, with linear slopes between –0.6 and –0.7 when inflation is high.

The effects of the auxiliary variables are nearly identical across all columns of table 1. Wage and price controls have a strong depressing effect on inflation, but these are limited to the early 1970s.[20] Relative import prices have a significant positive effect. The change in the relative goods import price is scaled by the share of goods imports in GDP, which has fluctuated in recent years between 10 and 15 percent of GDP. When goods imports are equivalent to 15 percent of GDP, a coefficient of 0.4 implies that a 10 percent increase in goods

19. Nalewaik (2016) finds a high probability of a regime switch to a nonlinear Phillips curve in 1995–96.

20. Wage and price controls are positive in 1971Q3–1972Q3 and negative in 1974Q2–1975Q1, with the sum of the positive and negative observations set at zero so that the overall effect on the price level is zero after 1975.

import prices relative to consumption goods prices would raise the core CPI by 0.6 percentage points. As shown in table A1, this effect is considerably larger for headline CPI, which includes food and energy prices.[21]

As expected, the effect of lagged inflation is greatest during the period of high inflation when expectations likely were not anchored. The sum of the lag coefficients in this period is around 0.9 and not significantly different from 1. Before 1967, the sum of the lag coefficients is noticeably smaller, especially in column 4 of table 1, but it has a large standard error and is not significantly different from 1 in any of the models. After 1994, the sum drops considerably, to around 0.4 to 0.5 in columns 2 and 4, and it is significantly less than 1.

It is possible to calculate the implied long-run inflation rate in each subsample by dividing the intercept by 1 minus the sum of the coefficients on lagged inflation. (GAP, relative import prices, and wage and price controls are assumed to be 0 in the long run.) These long-run estimates and their standard errors are displayed near the bottom of table 1. Prior to 1967, long-run implied inflation was generally below 2 percent. It jumps up substantially with large standard errors during the high inflation period, reflecting uncertainty and volatility in long-run inflation expectations. After 1994, the estimates are around 2 percent with very small standard errors.

The results for core PCE inflation (table 2) are broadly similar, except that the Phillips curve slopes under high inflation (γ_1) are somewhat flatter than those estimated for core CPI. The restrictions imposed in the shifting linear and low inflation bend models are not rejected at any significance level. In the shifting linear model, the Phillips curve under low inflation ($\gamma_1+\gamma_2$) is very flat. In the low inflation bend model, the slope with low inflation and a positive GAP ($\gamma_1+\gamma_4$) is equally flat. The sums of the coefficients on lagged inflation before 1967 are a bit larger than in table 1 but not significantly so. The total effect of lagged inflation in the high inflation period is close to 1, as in table 1. The sums of the coefficients on lagged inflation after 1994 are significantly less than 1. Long-run inflation is less precisely estimated before 1967, perhaps because the core PCE data start later than core CPI. As in table 1, long-run inflation is high with a large standard error in the high inflation period. After 1994, it is tightly estimated just below the Federal Reserve's target for PCE inflation of 2 percent.

Turning to the wage measures, similar regressions with compensation per hour (COMP) yield negative coefficients on lagged inflation during periods of low inflation. We believe this result reflects the high volatility of COMP arising from components that are not characterized by downward nominal rigidities. We believe results with such properties are not informative for our purposes and we do not show unrestricted estimates of equation 10 with COMP. When the accelerationist restriction is imposed, the results for COMP are more sensible and are displayed in table 4.

Table 3 displays results for the employment cost index (ECI). The ECI regressions start in 1984, so no coefficients may be estimated for the pre-1967 period. The restrictions in columns 2 and 4 relative to column 5 are only weakly rejected.[22] In both models, the Phillips curve slope is –0.55 when inflation is high and the slope is reduced by about half when inflation is low (shifting linear model) or when inflation is low and GAP is positive

21. Arguably, it would be more appropriate to use nonoil import prices in the relative import price control for core CPI inflation. However, nonoil import prices are available only after 1967. Hooper, Mishkin, and Sufi (2019) show that nonoil goods import prices are highly correlated with, and nearly as volatile as, total goods import prices.

22. In other regressions shown below, similar restrictions for ECI are not rejected at any significance level.

Table 2 Core PCE Phillips curves, unconstrained dynamics allowing for breaks

	(1) Constant linear	(2) Shifting linear	(3) Constant nonlinear	(4) Low inflation bend	(5) Shifting nonlinear
GAP	−0.17** (.04)	−0.33** (.08)	−0.22** (.08)	−0.32** (.07)	−0.21 (.11)
GAP [ΔP<3]		0.27** (.09)			0.03 (.18)
GAP>0			0.08 (.11)		−0.21 (.19)
GAP>0 [ΔP<3]				0.30** (.10)	0.35 (.26)
Price controls	−1.69** (.37)	−1.86** (.37)	−1.69** (.37)	−1.84** (.37)	−1.90** (.38)
Relative import price	0.45** (.10)	0.42** (.09)	0.45** (.10)	0.42** (.09)	0.41** (.09)
			Start–1967Q3		
Intercept	0.15 (.69)	0.22 (.73)	0.20 (.69)	0.39 (.68)	0.30 (.75)
Sum of lag ΔP	0.98* (.44)	0.97* (.47)	0.92* (.46)	0.73 (.46)	0.86 (.53)
			1967Q4–1994Q4		
Intercept	0.75** (.24)	0.52* (.24)	0.71** (.25)	0.54* (.24)	0.61* (.24)
Sum of lag ΔP	0.85** (.05)	0.92** (.05)	0.85** (.05)	0.91** (.05)	0.92** (.05)
			1995Q1–End		
Intercept	1.77** (.36)	1.39** (.32)	1.65** (.42)	1.02** (.39)	1.19** (.43)
Sum of lag ΔP	0.02 (.20)	0.20 (.19)	0.07 (.22)	0.35 (.21)	0.29 (.23)
R-squared	0.89	0.90	0.89	0.90	0.90
RMSE	0.736	0.717	0.737	0.717	0.716
GAP restrict p-value	0.021	0.415	0.016	0.410	
Long run ΔP, pre-1967	9.53 (51279)	6.56 (5156)	2.60 (48.2)	1.45 (.15)	2.09 (6.38)
Long run ΔP, 1967–94	5.08 (.34)	6.18 (2.33)	4.82 (.45)	6.00 (1.71)	7.79 (10.2)
Long run ΔP, post-1994	1.81 (.00)	1.74 (.00)	1.78 (.01)	1.57 (.02)	1.66 (.02)
Observations	231	231	231	231	231
Start	1961Q2	1961Q2	1961Q2	1961Q2	1961Q2
End	2018Q4	2018Q4	2018Q4	2018Q4	2018Q4

Note: Robust standard errors in parentheses, * $p < 0.05$, ** $p < 0.01$.

Source: Authors' calculations based on equation 10 using data defined in appendix B.

(low inflation bend model). The change in slope is almost significant in the latter model. Under high inflation, the sums of the coefficients on lagged inflation are somewhat less than 1, and the difference from 1 is marginally significant. After 1994, the lag coefficients on inflation decline further and their sum is significantly less than 1. The estimates of long-run wage inflation decline after 1994 and are uniformly close to 3 percent, consistent with an inflation target of 2 percent and productivity growth of 1 percent or so, which allows wages to rise faster than prices.

Table 3 ECI Phillips curves, unconstrained dynamics allowing for breaks

	(1) Constant linear	(2) Shifting linear	(3) Constant nonlinear	(4) Low inflation bend	(5) Shifting nonlinear
GAP	−0.35** (.05)	−0.54** (.16)	−0.72** (.21)	−0.55** (.13)	−1.99** (.60)
GAP [ΔP<3]		0.23 (.17)			1.40* (.64)
GAP>0			0.41 (.21)		1.71* (.71)
GAP>0 [ΔP<3]				0.26 (.13)	−1.42 (.75)
			Start–1994Q4		
Intercept	1.66* (.70)	1.77* (.69)	1.60* (.68)	1.78* (.69)	1.46* (.65)
Sum of lag ΔP	0.58** (.18)	0.57** (.18)	0.57** (.18)	0.57** (.18)	0.55** (.18)
			1995Q1–End		
Intercept	2.12** (.34)	1.95** (.35)	2.18** (.34)	1.99** (.34)	2.01** (.35)
Sum of lag ΔP	0.30* (.12)	0.36** (.12)	0.24 (.12)	0.31** (.12)	0.30* (.12)
R-squared	0.63	0.63	0.64	0.64	0.65
RMSE	0.613	0.611	0.606	0.607	0.601
GAP restrict p-value	0.015	0.026	0.069	0.059	
Long run ΔP, 1967-94	3.91 (.06)	4.15 (.10)	3.73 (.06)	4.17 (.09)	3.25 (.21)
Long run ΔP, post-1994	3.05 (.01)	3.04 (.01)	2.86 (.01)	2.90 (.01)	2.89 (.02)
Observations	139	139	139	139	139
Start	1984Q2	1984Q2	1984Q2	1984Q2	1984Q2
End	2018Q4	2018Q4	2018Q4	2018Q4	2018Q4

Note: Robust standard errors in parentheses, * $p < 0.05$, ** $p < 0.01$.

Source: Authors' calculations based on equation 10 using data defined in appendix B.

For each measure of wage or price inflation in tables 1 to 3, the shifting linear model and the low inflation bend model fit the data roughly equally well in terms of R^2 and root mean squared error (RMSE) of the regressions. There appears to be equal support to the hypotheses that either a linear Phillips curve has flattened with low inflation or a Phillips curve that was linear at high inflation has become nonlinear as inflation fell to a very low rate. The inability of the data to discriminate between these models may reflect several factors. First, positive GAPs have dominated the data over the past 20 years and both models have similar properties in this region. Second, ECI does not cover the periods of negative GAPs before 1967, and core CPI and core PCE have only limited coverage, with regressions starting in 1959 and 1961, respectively. Headline CPI and headline PCE regressions start in 1954 (tables A1 and A2), but these data are noisier and less informative for the model than core inflation measures. Third, the tendency of the low inflation bend model to predict higher inflation than the shifting linear model during periods of low inflation when GAP is negative is offset to some extent by a lower estimated long-run inflation rate during periods of low inflation.

Box 1 Phillips redux?

Table B1 displays the coefficients in Phillips (1958) and those from regressions of the four measures of US inflation since 1995Q1 using Phillips's logarithmic form displayed in equation 11:[1]

$$log(\Delta P_t) = \theta + \gamma \, log(GAP_{t-2} + 5) \tag{11}$$

where ΔP is an 8-quarter average of inflation at an annual rate and *GAP* is a 4-quarter average of the difference between the unemployment rate and the CBO NAIRU. Phillips's original regression was based on UK wages. The US wage inflation regressions in table B1 (columns 4 and 5) display GAP coefficients quite similar to that found by Phillips. The price inflation regressions (columns 2 and 3) display a somewhat smaller effect, but the effect is highly significant for core CPI. Figure B1 displays scatter plots of the US inflation and unemployment data used in table B1. The curved lines are the fitted values from the regressions in table B1 and the straight lines are fitted values from a linear regression on the same data. The scatter plots and curved lines for COMP and ECI strongly resemble the original Phillips curve shown in figure 1.

Table B1 Original Phillips curve specification

	(1) logΔWAGE	(2) logΔCPI	(3) logΔPCE	(4) logΔCOMP	(5) logΔECI
logGAP	–1.39	–0.58** (.11)	–0.19 (.14)	–1.19** (.16)	–1.03** (.05)
Intercept	0.98	1.73** (.19)	0.86** (.27)	3.13** (.30)	2.73** (.10)
R-squared		0.45	0.08	0.56	0.86
Observations	53	96	96	96	96
Start	1861	1995Q1	1995Q1	1995Q1	1995Q1
End	1913	2018Q4	2018Q4	2018Q4	2018Q4
Country	UK	US	US	US	US

Note: ΔP are 8-quarter annualized rates of inflation, using core measures for CPI and PCE, and GAP is 4-quarter average value, defined as the unemployment rate minus the Congressional Budget Office estimate of the equilibrium rate, lagged by two quarters. Newey-West standard errors with 8 lags in parentheses, * $p < 0.05$, ** $p < 0.01$.

Source: Column (1) is from Phillips (1958) and columns (2) to (5) are authors' calculations based on equation 11 using data described in appendix B.

(box continues)

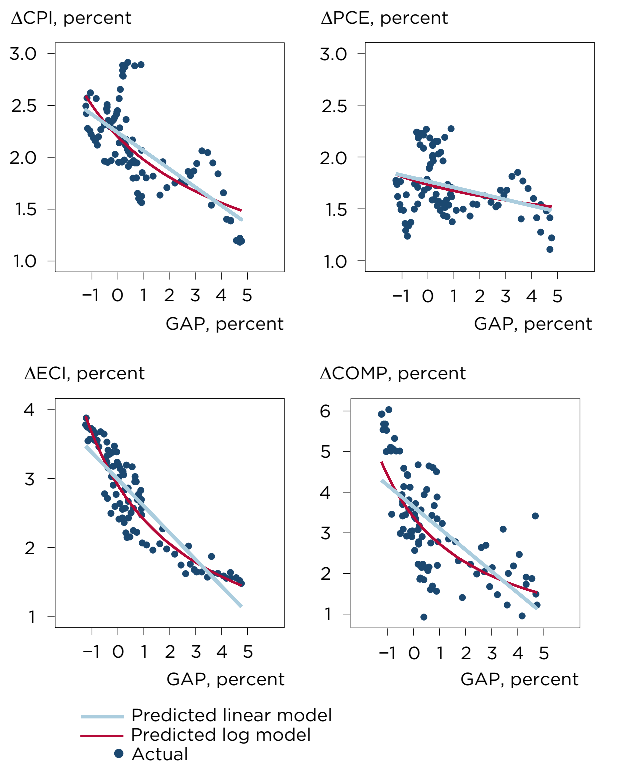
1. Phillips estimated his curve with six data points (shown as crosses in figure 1) constructed by averaging wage inflation and the unemployment rate over six bins of the unemployment distribution from 1861 through 1913. His wage and unemployment data were annual averages. Wage inflation is the annualized change from *t*–1 to *t*+1 and unemployment is the value in period *t*. He added 0.9 to inflation within the logarithmic function to avoid the undefined value of a logarithm of a negative number. With inflation now centered around 2 percent, it is no longer necessary to add a constant to the inflation rate. To make our GAP term more comparable to the unemployment rate in Phillips's regression, we add the average value of the CBO NAIRU inside the logarithm of the GAP.

Tables A1 and A2 in appendix A show that similar results hold for regressions based on headline CPI and headline PCE inflation, albeit with larger coefficient standard errors. The slopes under low inflation (shifting linear model) and under low inflation when GAP is positive (low inflation bend model) are somewhat less flat than for core inflation, but the differences are not statistically significant. Table A3 shows that adding survey expectations of long-term inflation (which limits the sample to 1981–2018) has only modest effects.[23] For core CPI and core PCE, the shorter sample leads to larger standard errors on the GAP coefficients, but no coefficient changes by more than one standard deviation. For ECI, the sample is unchanged and the GAP coefficients are

23. We do not allow the coefficient on expectations to shift in 1995 because expectations become almost completely constant after 1997 and there is almost no information with which to identify such a shift given that the intercept is allowed to shift.

Box 1 Phillips redux? (continued)

Figure B1 Logarithmic and linear model comparisons, 1995Q1–2018Q4



Note: The dots display the data used in the regressions of table B1. Panels display 8-quarter annualized rates of inflation, using core measures for CPI and PCE, and 4-quarter average GAP, defined as the unemployment rate minus the Congressional Budget Office estimate of the equilibrium rate, lagged by two quarters.The curved lines are fitted values of the regressions in table B1. The straight lines are fitted values of a linear regression (estimates not shown) over the same period.

Source: Authors' calculations based on table B1 using data defined in appendix B.

nearly unchanged. Table A4 shows that eliminating the first period of low inflation and starting the regression in 1970Q1, by which time inflation expectations had clearly become unanchored, leads to slightly higher estimates of the slope of the Phillips curve when inflation is high for core CPI and core PCE inflation. (The ECI regression is not affected by this change in sample because ECI regressions begin in 1984.) The slopes when inflation is low (shifting linear model) or when inflation is low and GAP is positive (low inflation bend model) are essentially the same as in tables 1 and 2.

The decline of the coefficients on lagged inflation and the relative success of the low inflation bend model raise the possibility that the original nonlinear Phillips curve in the level of inflation may have reemerged. Box 1 explores this possibility.

It is common in other studies of the Phillips curve to reduce the occurrence of spurious results by restricting the coefficients on lagged inflation to sum to 1, thus enforcing the accelerationist model of inflation expectations. Table 4 shows results when a strict accelerationist constraint is imposed across the entire sample with no

Table 4 Accelerationist Phillips curves

	Shifting linear model				Low inflation bend model			
	(1) ΔCPI	(2) ΔPCE	(3) ΔECI	(4) ΔCOMP	(5) ΔCPI	(6) ΔPCE	(7) ΔECI	(8) ΔCOMP
GAP	−0.67** (.12)	−0.39** (.07)	−0.43** (.13)	−0.59** (.13)	−0.58** (.10)	−0.35** (.06)	−0.31** (.11)	−0.59** (.13)
GAP [ΔP<3]	0.59** (.12)	0.35** (.08)	0.34** (.12)	0.45 (.28)				
GAP>0 [ΔP<3]					0.55** (.12)	0.35** (.08)	0.25* (.11)	0.57 (.33)
Price controls	−3.00** (.56)	−1.95** (.36)		−1.67* (.70)	−2.93** (.59)	−1.93** (.36)		−1.70* (.72)
Relative import price	0.39** (.14)	0.37** (.10)			0.42** (.14)	0.39** (.10)		
Intercept	0.15* (.07)	0.09 (.05)	0.08 (.07)	0.12 (.16)	0.02 (.08)	0.00 (.05)	−0.00 (.07)	−0.04 (.16)
Sum of lag ΔP 1-4	0.69** (.11)	0.75** (.09)	0.66** (.12)	0.52** (.12)	0.70** (.11)	0.75** (.09)	0.70** (.12)	0.50** (.12)
Sum of lag ΔP 5-8	0.31** (.11)	0.25** (.09)	0.34** (.12)	0.48** (.12)	0.30** (.11)	0.25** (.09)	0.30* (.12)	0.50** (.12)
R-squared	0.83	0.89	0.54	0.28	0.82	0.89	0.53	0.29
RMSE	1.106	0.740	0.672	2.852	1.120	0.741	0.678	2.840
GAP restrict p-value	0.410	0.461	0.411	0.248	0.027	0.315	0.114	0.723
Observations	239	231	139	260	239	231	139	260
Start	1959Q2	1961Q2	1984Q2	1954Q1	1959Q2	1961Q2	1984Q2	1954Q1
End	2018Q4	2018Q4	2018Q4	2018Q4	2018Q4	2018Q4	2018Q4	2018Q4

Note: Columns 1, 2, 5, and 6 are for core CPI and core PCE. Robust standard errors in parentheses, * $p < 0.05$, ** $p < 0.01$.

Source: Authors' calculations based on equation 10 with constraints on inflation dynamics using data defined in appendix B.

allowance for a shift in either lags or intercept.[24] Table 4 presents results only for the shifting linear and low inflation bend models; when the accelerationist constraint is imposed, the GAP coefficient restrictions implied by these models are never strongly rejected.

The Phillips curve coefficients for core CPI and core PCE in table 4 are little changed from those in tables 1 and 2. The Phillips curves for ECI are broadly similar to those in table 3 except for a modest decline in slope under high inflation for both models. The Phillips curves for COMP are quite similar to those for core CPI. For all inflation measures, table 4 provides roughly equal support (in terms of R^2 and RMSE) to the hypotheses that either a linear Phillips curve has flattened with low inflation or a Phillips curve that was linear at high inflation has become nonlinear as inflation fell.

ALTERNATIVE GAP MEASURES

The previous section focused on Phillips curves with a commonly used measure of GAP, the overall unemployment rate minus the CBO NAIRU. This section explores whether using a different measure of GAP would change the results of the previous section.

24. The restrictions on lag coefficients and intercepts across subsamples are generally not statistically significant and they never have a significant effect on the GAP coefficients as long as the lags within each subsample are constrained to sum to 1.

Table 5 Married male Phillips curves, unconstrained dynamics allowing for breaks, constant NAIRU of 3.5 percent

	Shifting linear model			Low inflation bend model		
	(1) ΔCPI	(2) ΔPCE	(3) ΔECI	(4) ΔCPI	(5) ΔPCE	(6) ΔECI
GAP	−0.79** (.14)	−0.38** (.09)	−0.77** (.22)	−0.71** (.12)	−0.35** (.08)	−0.58** (.14)
GAP [ΔP<3]	0.64** (.16)	0.30** (.10)	0.46* (.23)			
GAP>0 [ΔP<3]				0.81** (.20)	0.39** (.13)	0.36* (.17)
Price controls	−3.07** (.57)	−1.86** (.37)		−2.99** (.58)	−1.83** (.37)	
Relative import price	0.35* (.14)	0.41** (.09)		0.37** (.14)	0.42** (.09)	
Start–1967Q3						
Intercept	0.42 (.58)	0.18 (.73)		0.29 (.52)	0.32 (.70)	
Sum of lag ΔP	0.79* (.36)	0.99* (.47)		0.65* (.33)	0.75 (.47)	
1967Q4–1994Q4						
Intercept	0.63 (.51)	0.55* (.24)	1.54* (.69)	0.72 (.51)	0.59* (.24)	1.52* (.69)
Sum of lag ΔP	0.91** (.11)	0.89** (.05)	0.63** (.18)	0.89** (.10)	0.89** (.05)	0.62** (.18)
1995Q1–End						
Intercept	1.10** (.32)	1.32** (.31)	1.19** (.27)	0.40 (.43)	0.88* (.37)	1.08** (.30)
Sum of lag ΔP	0.45** (.15)	0.21 (.19)	0.54** (.11)	0.58** (.19)	0.34 (.20)	0.51** (.11)
R-squared	0.84	0.90	0.62	0.84	0.90	0.62
RMSE	1.086	0.715	0.621	1.089	0.716	0.621
GAP restrict p-value	0.073	0.599	0.189	0.085	0.395	0.216
Long run ΔP, pre-1967	2.05 (1.26)	12.30 (118978)		0.83 (.64)	1.29 (.31)	
Long run ΔP, 1967–94	7.08 (9.00)	5.22 (.70)	4.19 (.15)	6.66 (4.42)	5.14 (.57)	4.00 (.09)
Long run ΔP, post-1994	2.01 (.01)	1.67 (.00)	2.61 (.02)	0.93 (.39)	1.33 (.03)	2.21 (.06)
Observations	239	231	139	239	231	139
Start	1959Q2	1961Q2	1984Q2	1959Q2	1961Q2	1984Q2
End	2018Q4	2018Q4	2018Q4	2018Q4	2018Q4	2018Q4

Note: Columns 1, 2, 4, and 5 are for core CPI and core PCE. Robust standard errors in parentheses, * $p < 0.05$, ** $p < 0.01$.

Source: Authors' calculations based on equation 10 using data defined in appendix B.

Many papers have examined different measures of the unemployment gap (or output gap) in search of one that might lead to a stable linear Phillips curve (Ball 2009, Ball and Mazumder 2019b, Gordon 2013, Stock and Watson 2010, Watson 2014). There are three broad approaches: (1) choose a measure of unemployment for which the NAIRU is likely to be constant; (2) model the NAIRU as a function of demographic and institutional variables; and (3) construct a GAP that can explain the behavior of inflation. These approaches are not mutually inconsistent; some papers employ a mixture of them.

We eschew the third approach because of its fundamental circularity. A Phillips curve with a highly variable NAIRU (or some other measure of the output gap) may fit past inflation well, but only because it was designed to do so. Such models generally have little to say about the future evolution of the NAIRU (or potential output) and thus they provide little guidance to policymakers and forecasters of inflation.

Following the first approach mentioned above, table 5 replicates results for the shifting linear and low inflation bend models of tables 1 to 3 using a GAP defined as the married male unemployment rate minus its historical average value. Among the available demographic groups, married men are likely to be most strongly attached to the labor force and least affected by demographic and institutional changes. Allowing a time-varying NAIRU is likely to be least important for this group. The fit of both models is slightly better in table 5 than in tables 1 to 3 for core CPI and core PCE and slightly worse for ECI. The Phillips curve slopes under high inflation (γ_1) are a bit steeper for core CPI and core PCE and noticeably steeper for ECI under the shifting linear model, but none of these changes are statistically significant. The slopes under low inflation (shifting linear model) or under low inflation with positive GAP (low inflation bend model) are similar to those in tables 1 to 3.

The implied long-run inflation rates after 1994 in table 5 are lower than those in tables 1 to 3 for the low inflation bend model. This may reflect that the true NAIRU is lower than the historical average of married male unemployment. Such a result arises with a nonlinear model, in which periods of positive GAPs tend to have smaller effects on inflation than periods of negative GAPs and positive GAPs are larger and/or more frequent than negative GAPs. It is interesting to note that the CBO NAIRU averaged 5.5 percent over the 1959–2018 sample, whereas the overall unemployment rate averaged 6.0 percent. When the regressions in table 5 are rerun under the assumption of a NAIRU that is 0.5 percentage point below the average value of married male unemployment, only the intercepts change noticeably and the implied long-run inflation rates after 1994 increase to values similar to those shown in tables 1 to 3.

The second approach described above involves modeling the NAIRU as a function of demographic and/or institutional variables. The Phillips curve is most useful to policymakers and forecasters when it relies on a NAIRU that moves only slowly over time in a predictable fashion. In many countries, important institutional changes in labor markets have influenced the NAIRU, such as changes in the terms of unemployment benefits, in protections against firing existing workers, and in rates of union membership. It is generally believed that such changes are less important in the United States than elsewhere, though they still may be significant. Other factors mentioned in past research include the age distribution of the labor force, educational attainment, female labor force participation, shares of the population in military service or in prison or in long-term disability status, the rise of temporary employment services, and other technologies that affect the efficiency of job matching.

We regressed the rate of unemployment (UN) on several variables, both separately and in combination, to see which best explains long-term swings in UN.[25] Consistent with the findings of Katz and Krueger (1999),

25. We tested union membership density (Bureau of Labor Statistics and Freeman [1998]), the incarcerated population rate (Bureau of Justice Statistics, Maguire and Pastore [1996]), the military population rate (Department of Defense), the Social Security disability insurance beneficiary rate (Social Security Administration), the female labor force participation rate (Bureau of Labor Statistics), the youth labor force participation rate (Bureau of Labor Statistics), the "part time for economic reasons" rate (Bureau of Labor Statistics), the temporary help agency

Table 6 Unemployment on the median age of the labor force (AGE)

	(1) UN	(2) UN	(3) UN
AGE	−0.22 (.14)	−0.44** (.10)	−0.28** (.05)
Intercept	14.13** (5.21)	22.36** (3.85)	16.37** (1.91)
R-squared	0.09	0.38	0.08
RMSE	1.559	1.175	1.573
Observations	284	244	284
Start	1948Q1	1948Q1	1948Q1
End	2018Q4	2008Q4	2018Q4

Note: This table presents regressions of the unemployment rate (UN) on the median age of the labor force (AGE). The first column is based on all available data. The second column drops data after 2008Q4. The third column uses a least absolute deviations regression over all available data. Columns (1) and (2): Newey-West standard errors with 12 lags in parentheses. Column (3): robust standard errors in parentheses, * p < 0.05, ** p < 0.01.

Source: Authors' calculations using data defined in appendix B.

the most important variable is the median age of the labor force (AGE). Other variables are insignificant or have coefficients with an implausible sign or magnitude or lead to implied NAIRUs that fluctuate at a business cycle (or higher) frequency.

Table 6 displays results from a regression of the unemployment rate (UN) on AGE. Column 1 uses all available data back to 1948. An increase in AGE of 1 year reduces UN by 0.2 percentage point. Column 2 shows that this estimate is highly sensitive to the sample period. Dropping the last 10 years from the sample doubles the estimated effect of AGE. The very long period of high unemployment in 2009–16 apparently has an outsized effect on the estimated AGE effect. One way to minimize the effect of outliers is to use a regression technique that minimizes absolute residuals instead of squared residuals. Column 3 displays the results of a "least absolute deviations" regression over the entire sample.[26] The effect of AGE lies between those of the first two columns, perhaps reflecting a reasonable compromise that uses all available data but downweights the influence of the Great Recession.

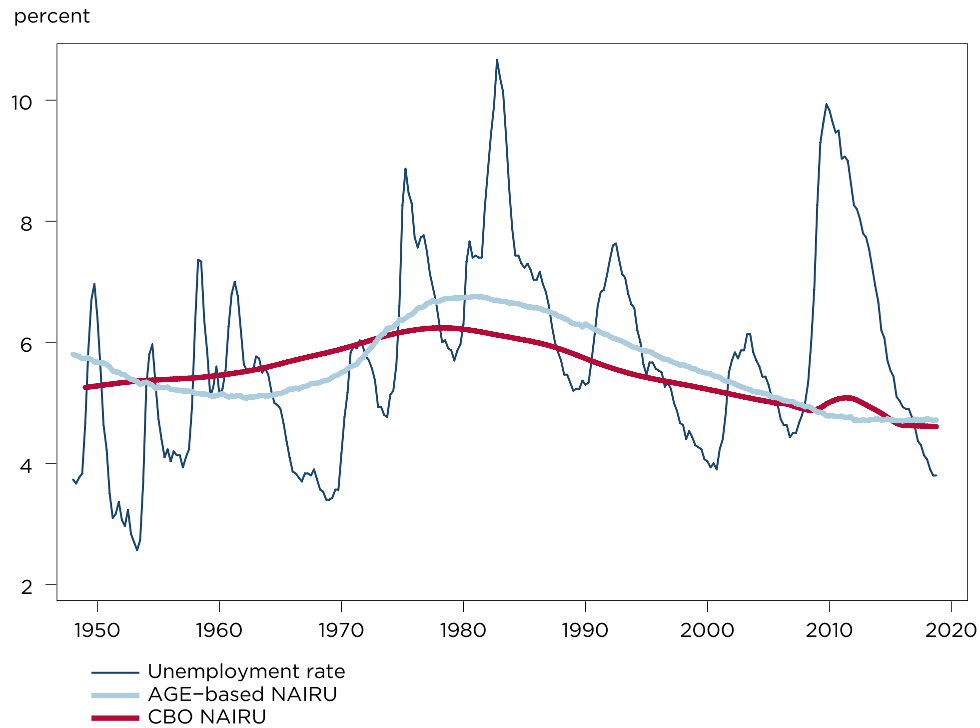
Figure 7 displays the unemployment rate, the CBO NAIRU, and an estimated NAIRU based on AGE (the fitted value of column 3 of table 6). The two NAIRU estimates have broadly similar contours except for a modest divergence in direction in the 1950s and a small bump in the CBO NAIRU around 2010. The CBO NAIRU is somewhat flatter than the AGE-based NAIRU.[27] The two NAIRU estimates are nearly identical in 2018Q4, at 4.6

employment share (Bureau of Labor Statistics), and the sum of the rates of private sector gross job gains and job losses (Bureau of Labor Statistics).

26. The reported coefficient standard deviations in column 3 are robust to heteroskedasticity but not to autocorrelation in residuals. They are likely to overstate the significance of the GAP coefficient.

27. Brauer (2007) discusses structural factors that influence the CBO's NAIRU, of which the most important is the age distribution of the labor force. He does not provide an explicit statistical model, but inflation is not one of the factors mentioned. Nevertheless, one cannot exclude the possibility that factors are chosen in part to deliver a NAIRU that helps to explain historical inflation.

Figure 7 Unemployment and the NAIRU, 1948Q1–2018Q4



Note: The CBO NAIRU is the long-run estimate from the Congressional Budget Office. The AGE-based NAIRU is the fitted value from the regression in column 3 of table 6.
Source: Authors' calculations using data defined in appendix B.

percent (CBO) and 4.7 percent (AGE-based) and are moderately above the unemployment rate of 3.8 percent. It is worth noting, however, that other estimates of the current NAIRU are rather different. For example, the implied AGE-based NAIRUs in 2018Q4 from columns 1 and 2 of table 6 are 5.1 and 4.0 percent, respectively.

Table 7 replicates results for the shifting linear and low inflation bend models of tables 1 to 3 using a GAP defined as the difference between the unemployment rate and the AGE-based NAIRU shown in figure 7. The equation RMSEs are slightly better in table 7 than in tables 1 to 3. The slopes under high inflation are steeper for core CPI and core PCE and about the same for ECI. The slopes under low inflation (shifting linear model) or under low inflation with positive GAP (low inflation bend model) are similar to those in tables 1 to 3. The implied long-run inflation rates after 1994 are similar to those in tables 1 to 3.[28] Overall, it seems a NAIRU based on AGE may explain inflation slightly better than the CBO NAIRU, but the differences are small. The main conclusions are not affected.

Table A5 replicates table 7 using a GAP defined as manufacturing capacity utilization minus its historical average multiplied by –1 to be consistent with a GAP based on unemployment, which is positive when the economy is running below potential. The GAP coefficients are uniformly smaller in magnitude than those in tables 1 to 3, reflecting the fact that capacity utilization fluctuates much more than unemployment over the

28. We note that the AGE-based NAIRU shares the asymmetric property of the CBO NAIRU, in that it averaged 5.6 percent over 1959–2018 compared with 6.0 percent for the unemployment rate.

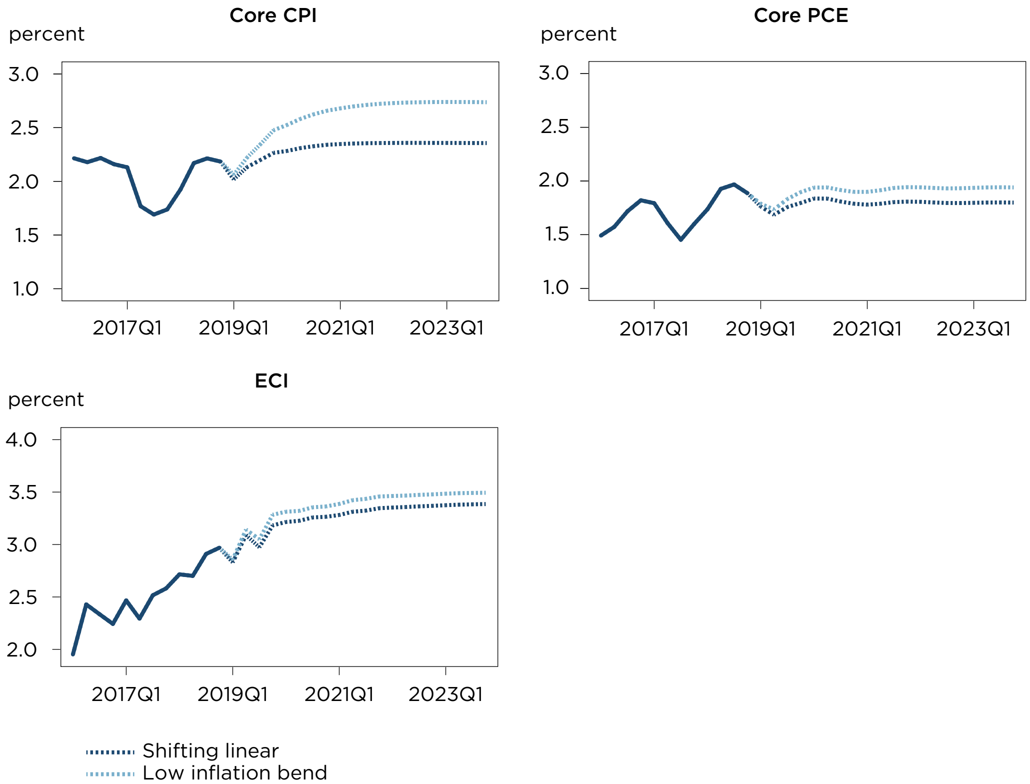
Table 7 Phillips curves, unconstrained dynamics allowing for breaks, AGE-based GAP

	Shifting linear model			Low inflation bend model		
	(1) ΔCPI	(2) ΔPCE	(3) ΔECI	(4) ΔCPI	(5) ΔPCE	(6) ΔECI
GAP	−0.87** (.14)	−0.41** (.09)	−0.53** (.16)	−0.79** (.12)	−0.37** (.08)	−0.56** (.12)
GAP [ΔP<3]	0.75** (.15)	0.35** (.10)	0.24 (.17)			
GAP>0 [ΔP<3]				0.79** (.15)	0.37** (.11)	0.30* (.13)
Price controls	−3.05** (.56)	−1.79** (.36)		−2.97** (.57)	−1.77** (.36)	
Relative import price	0.35* (.14)	0.41** (.09)		0.37** (.14)	0.42** (.09)	
Start–1967Q3						
Intercept	0.54 (.59)	0.25 (.74)		0.57 (.51)	0.47 (.68)	
Sum of lag ΔP	0.76* (.36)	0.96* (.48)		0.56 (.32)	0.71 (.45)	
1967Q4–1994Q4						
Intercept	0.32 (.54)	0.38 (.25)	1.59* (.68)	0.43 (.53)	0.44 (.24)	1.60* (.67)
Sum of lag ΔP	0.96** (.11)	0.93** (.05)	0.55** (.18)	0.94** (.11)	0.91** (.05)	0.54** (.18)
1995Q1–End						
Intercept	1.39** (.38)	1.37** (.32)	2.01** (.35)	0.97* (.47)	0.90* (.41)	2.07** (.35)
Sum of lag ΔP	0.36* (.18)	0.20 (.19)	0.32** (.12)	0.40 (.20)	0.39 (.22)	0.25* (.12)
R-squared	0.84	0.90	0.63	0.84	0.90	0.64
RMSE	1.068	0.711	0.610	1.070	0.715	0.603
GAP restrict p-value	0.034	0.835	0.130	0.069	0.217	0.561
Long run ΔP, pre-1967	2.22 (1.29)	6.67 (4164)		1.31 (.14)	1.62 (.16)	
Long run ΔP, 1967–94	8.31 (107)	5.14 (1.35)	3.51 (.06)	7.09 (20.3)	5.02 (.91)	3.51 (.05)
Long run ΔP, post-1994	2.17 (.01)	1.72 (.00)	2.96 (.01)	1.61 (.08)	1.46 (.03)	2.78 (.01)
Observations	239	231	139	239	231	139
Start	1959Q2	1961Q2	1984Q2	1959Q2	1961Q2	1984Q2
End	2018Q4	2018Q4	2018Q4	2018Q4	2018Q4	2018Q4

Note: Columns 1, 2, 4, and 5 are for core CPI and core PCE. Robust standard errors in parentheses, * $p < 0.05$, ** $p < 0.01$.

Source: Authors' calculations based on equation 10 using GAP from column 3 of table 6 and data defined in appendix B.

Figure 8 Forecast comparisons for unconstrained models with regime breaks, 2016Q1–2023Q4



Note: Solid lines are historical values through 2018Q4. Dashed lines are forecasts of 4-quarter inflation based on regressions in tables 1 to 3. The unemployment rate is assumed to remain constant at its 2018Q4 value. The NAIRU is projected by the Congressional Budget Office in January 2019.
Source: Authors' calculations using data defined in appendix B.

business cycle. Nevertheless, the overall conclusions concerning the differences between the shifting linear and low inflation bend models and their similar ability to explain the data remain the same.[29]

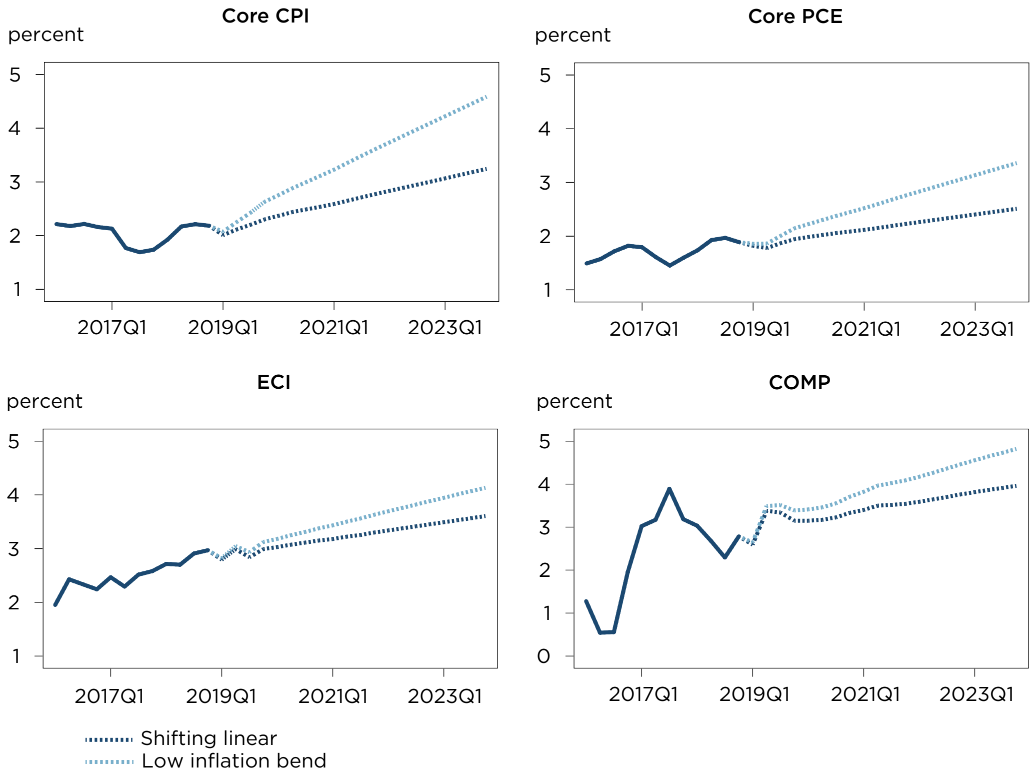
PROJECTIONS

Regardless of whether inflation dynamics are unrestricted (tables 1 to 3) or modeled as strictly accelerationist (table 4), the shifting linear and low inflation bend models fit the historical data roughly equally well. But what do they predict for the future? Is there any interesting difference between their predictions?

Figure 8 displays dynamic predictions of inflation over the next 5 years using the regressions of tables 1 to 3. Unemployment is assumed to remain constant at its 2018Q4 value of 3.8 percent and the CBO NAIRU edges down very slightly from 4.6 to 4.5 percent by 2023. The low inflation bend model projects a gradual rise in core CPI inflation to 2.7 percent, whereas the shifting linear model shows only a small increase in core CPI inflation to 2.4 percent. The low inflation bend model has core PCE inflation stabilizing around its 2 percent target,

29. Similar results also obtain for a gap based on short-term unemployment minus a NAIRU based on median age of all workers, for a gap based on GDP minus the CBO estimate of potential GDP, and for a gap based on capacity utilization in mining, manufacturing, and utilities.

Figure 9 Forecast comparisons for accelerationist models, 2016Q1–2023Q4



Note: Solid lines are historical values through 2018Q4. Dashed lines are forecasts of 4-quarter inflation based on regressions in table 4. The unemployment rate is assumed to remain constant at its 2018Q4 value. The NAIRU is projected by the Congressional Budget Office in January 2019.
Source: Authors' calculations using data defined in appendix B.

while the shifting linear model has it remaining below target continuously. ECI inflation trends up to almost 3.5 percent in the low inflation bend model and slightly less in the shifting linear model.

Figure 9 displays projections under the assumption of accelerationist inflation expectations (table 4). Core CPI inflation rises steadily to 4.6 percent by late 2023 under the low inflation bend model but reaches only 3.2 percent under the shifting linear model. Core PCE rises to 3.4 percent under the low inflation bend model but only 2.5 percent under the shifting linear model. COMP and ECI display similar sustained rises that are notably larger under the low inflation bend model than under the shifting linear model.

It should be noted that there is considerable uncertainty concerning the value of GAP used in these projections. The median projection of participants in the Federal Reserve's Federal Open Market Committee (FOMC) is for the unemployment rate to step down to 3.7 percent by late 2019 and then to rise gradually to 3.9 percent by late 2021. The FOMC's estimate of the NAIRU is likely equal to its "longer run" projection of unemployment at 4.3 percent.[30] The consensus of private forecasters in the March 2019 issue of *Blue Chip Economic Indicators* projects a slight drop in the unemployment rate to 3.7 percent in 2019 and 2020 before rising steadily to the long-run value of 4.3 percent by 2023. These projections imply somewhat smaller unemployment gaps than are

30. FOMC projections are from the March 2019 meeting and are available at www.federalreserve.gov.

assumed in figures 8 and 9. However, the FOMC and Blue Chip projections of a rising unemployment rate may be motivated by the default preference of many forecasters to project a return toward perceived equilibrium. We note that married male unemployment, at 2 percent, is far below its historical average of 3.5 percent. Even if the associated NAIRU is less than 3.5 percent, the implied GAP is almost surely large and negative.

Overall, the formation of inflation expectations is critical to the projections. The relatively low lags estimated in the period after 1994 imply only a limited effect of GAP on inflation, as shown in figure 8. Moreover, the long-run inflation estimates suggest that core PCE inflation may be anchored even lower than the Federal Reserve's official target of 2 percent, especially in the low inflation bend model. On the other hand, if expectations were to become unanchored and GAP were to remain negative, the projections in figure 9 suggest that inflation could rise substantially.

CONCLUSION

The Phillips curve remains a useful model of inflation that may be returning to its original form. The evolution of the curve over the past 60 years reflects two major developments. First, inflation became unanchored as the monetary link to gold broke down in the late 1960s, and it was reanchored in the late 1990s with the advent of inflation-targeting monetary policy. The Phillips curve transitioned from a level form to an accelerationist form and has since moved at least partly back to a level form. Second, either the Phillips curve is highly nonlinear when inflation is very low or its slope has declined substantially. Although both hypotheses can explain inflation roughly equally well over the past 60 years, the evidence originally presented by Phillips (1958) supports the hypothesis of nonlinearity. Indeed, with the return of very low and stable inflation rates over the past 20 years, the original nonlinear Phillips curve may be returning.

These developments have opposing implications for inflation over the medium term. On the one hand, a nonlinear Phillips curve implies that the current low level of unemployment is likely to push inflation up more than most linear models would suggest. On the other hand, the move from an accelerationist Phillips curve to a level Phillips curve, or somewhere in between, implies that inflation will be slower to rise than it would under a strict accelerationist model. A further complication is that the NAIRU, and hence the GAP in the Phillips curve, is not estimated with great precision. Plausible values of the NAIRU range from 4 to 5 percent, implying a GAP range of roughly 0 to –1 percent.

Olivier Blanchard (2017b) noted that the anchoring of inflation expectations may pose a temptation for central banks to trade off a little more inflation for less unemployment. One lesson of the 1960s is that an extended attempt to make such a trade may result in the detachment of the inflation anchor and a shift to accelerating inflation. Because inflation in the United States has been somewhat below target for the past 10 years, there may be scope to enjoy this tradeoff for a few years. Indeed, it may be desirable to push inflation above target temporarily to correct the apparent anchoring of expectations slightly below target. But it would be a mistake to believe that a strong economy and low unemployment are no longer capable of generating inflation.

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APPENDIX A ALTERNATIVE REGRESSIONS

Table A1 Headline CPI Phillips curves, unconstrained dynamics allowing for breaks

	(1) Constant linear	(2) Shifting linear	(3) Constant nonlinear	(4) Low inflation bend	(5) Shifting nonlinear
GAP	−0.37** (.10)	−0.55** (.15)	−0.43** (.14)	−0.54** (.13)	−0.32 (.19)
GAP [ΔP<3]		0.27 (.20)			−0.2 (.28)
GAP>0			0.09 (.23)		−0.41 (.41)
GAP>0 [ΔP<3]				0.33 (.22)	0.70 (.50)
Price controls	−0.69 (.54)	−0.88 (.58)	−0.68 (.54)	−0.87 (.57)	−0.99 (.62)
Relative import price	0.87** (.17)	0.86** (.17)	0.88** (.17)	0.86** (.17)	0.84** (.17)
			Start–1967Q3		
Intercept	0.60 (.35)	0.66 (.36)	0.56 (.35)	0.51 (.35)	0.53 (.37)
Sum of lag ΔP	0.56* (.23)	0.54* (.23)	0.56* (.23)	0.53* (.24)	0.53* (.24)
			1967Q4–1994Q4		
Intercept	1.38** (.42)	1.30** (.41)	1.33** (.44)	1.30** (.41)	1.50** (.46)
Sum of lag ΔP	0.77** (.08)	0.80** (.08)	0.77** (.08)	0.80** (.08)	0.81** (.08)
			1995Q1–End		
Intercept	2.98** (.85)	2.79** (.91)	2.91** (.91)	2.62** (.97)	2.62** (.97)
Sum of lag ΔP	−0.24 (.40)	−0.19 (.42)	−0.23 (.40)	−0.17 (.42)	−0.16 (.42)
R-squared	0.71	0.71	0.71	0.71	0.71
RMSE	1.678	1.674	1.681	1.671	1.675
GAP restrict p-value	0.462	0.359	0.309	0.594	
Long run ΔP, pre-1967	1.38 (.13)	1.45 (.13)	1.28 (.17)	1.08 (.15)	1.12 (.20)
Long run ΔP, 1967–94	5.97 (.63)	6.50 (1.08)	5.77 (.96)	6.47 (1.02)	7.74 (4.28)
Long run ΔP, post-1994	2.40 (.03)	2.35 (.02)	2.36 (.03)	2.24 (.02)	2.25 (.03)
Observations	260	260	260	260	260
Start	1954Q1	1954Q1	1954Q1	1954Q1	1954Q1
End	2018Q4	2018Q4	2018Q4	2018Q4	2018Q4

Note: Robust standard errors in parentheses, * $p < 0.05$, ** $p < 0.01$

Source: Authors' calculations based on equation 10 using data defined in appendix B.

Table A2 Headline PCE Phillips curves, unconstrained dynamics allowing for breaks

	(1) Constant linear	(2) Shifting linear	(3) Constant nonlinear	(4) Low inflation bend	(5) Shifting nonlinear
GAP	−0.23** (.07)	−0.37** (.11)	−0.40** (.12)	−0.38** (.10)	−0.36* (.15)
GAP [ΔP<3]		0.20 (.14)			−0.07 (.23)
GAP>0			0.24 (.16)		−0.03 (.28)
GAP>0 [ΔP<3]				0.28 (.15)	0.35 (.36)
Price controls	−0.40 (.44)	−0.55 (.47)	−0.37 (.43)	−0.56 (.46)	−0.56 (.49)
Relative import price	0.82** (.13)	0.81** (.13)	0.83** (.13)	0.81** (.13)	0.80** (.13)
			Start–1967Q3		
Intercept	0.77 (.40)	0.83* (.41)	0.68 (.40)	0.72 (.40)	0.70 (.40)
Sum of lag ΔP	0.50 (.28)	0.47 (.28)	0.48 (.28)	0.45 (.28)	0.45 (.29)
			1967Q4–1994Q4		
Intercept	1.05** (.30)	0.97** (.30)	0.92** (.32)	0.96** (.30)	0.98** (.33)
Sum of lag ΔP	0.79** (.06)	0.83** (.07)	0.80** (.06)	0.83** (.06)	0.83** (.07)
			1995Q1–End		
Intercept	2.20** (.58)	2.10** (.60)	2.04** (.62)	1.93** (.64)	1.90** (.65)
Sum of lag ΔP	−0.14 (.34)	−0.11 (.35)	−0.11 (.35)	−0.08 (.35)	−0.08 (.36)
R-squared	0.76	0.76	0.76	0.76	0.76
RMSE	1.269	1.265	1.267	1.261	1.266
GAP restrict p-value	0.296	0.353	0.436	0.959	
Long run ΔP, pre-1967	1.54 (.08)	1.58 (.08)	1.31 (.09)	1.31 (.07)	1.27 (.11)
Long run ΔP, 1967-94	5.13 (.41)	5.55 (.76)	4.54 (.55)	5.58 (.76)	5.64 (1.79)
Long run ΔP, post-1994	1.93 (.02)	1.88 (.01)	1.83 (.02)	1.78 (.02)	1.77 (.02)
Observations	260	260	260	260	260
Start	1954Q1	1954Q1	1954Q1	1954Q1	1954Q1
End	2018Q4	2018Q4	2018Q4	2018Q4	2018Q4

Note: Robust standard errors in parentheses, * $p < 0.05$, ** $p < 0.01$.

Source: Authors' calculations based on equation 10 using data defined in appendix B.

Table A3 Phillips curves, unconstrained dynamics allowing for breaks, with survey-based inflation expectations

	Shifting linear model			Low inflation bend model		
	(1) ΔCPI	(2) ΔPCE	(3) ΔECI	(4) ΔCPI	(5) ΔPCE	(6) ΔECI
GAP	−0.80* (.33)	−0.23 (.15)	−0.50** (.17)	−0.64* (.27)	−0.15 (.12)	−0.54** (.13)
GAP [ΔP<3]	0.66* (.33)	0.19 (.15)	0.19 (.17)			
GAP>0 [ΔP<3]				0.56 (.30)	0.12 (.15)	0.25 (.14)
Relative import price	0.00 (.07)	0.19** (.06)		0.01 (.07)	0.19** (.06)	
Survey ΔP^e	0.45** (.14)	0.18 (.14)	0.11 (.15)	0.47** (.13)	0.19 (.14)	0.13 (.15)
Start–1994Q4						
Intercept	0.20 (.47)	0.24 (.30)	1.67* (.74)	0.15 (.49)	0.26 (.30)	1.68* (.72)
Sum of lag ΔP	0.60** (.18)	0.73** (.12)	0.47* (.20)	0.57** (.17)	0.70** (.12)	0.46* (.20)
1995Q1–End						
Intercept	0.88* (.36)	0.89* (.36)	1.75** (.43)	0.64 (.43)	0.77 (.39)	1.74** (.43)
Sum of lag ΔP	0.16 (.16)	0.26 (.19)	0.34** (.12)	0.18 (.17)	0.30 (.23)	0.31* (.12)
R-squared	0.81	0.86	0.63	0.80	0.85	0.64
RMSE	0.791	0.583	0.612	0.808	0.586	0.607
GAP restrict p-value	0.258	0.505	0.012	0.105	0.213	0.034
Observations	152	152	139	152	152	139
Start	1981Q1	1981Q1	1984Q2	1981Q1	1981Q1	1984Q2
End	2018Q4	2018Q4	2018Q4	2018Q4	2018Q4	2018Q4

Note: Columns 1, 2, 4, and 5 are for core CPI and core PCE. Robust standard errors in parentheses, * $p < 0.05$, ** $p < 0.01$.

Source: Authors' calculations based on equation 10 using data defined in appendix B.

Table A4 Phillips curves, unconstrained dynamics allowing for breaks, starting in 1970Q1

	Shifting linear model			Low inflation bend model		
	(1) ΔCPI	(2) ΔPCE	(3) ΔECI	(4) ΔCPI	(5) ΔPCE	(6) ΔECI
GAP	−0.86** (.15)	−0.41** (.10)	−0.54** (.16)	−0.78** (.14)	−0.36** (.10)	−0.55** (.13)
GAP [ΔP<3]	0.76** (.16)	0.36** (.11)	0.23 (.17)			
GAP>0 [ΔP<3]				0.76** (.18)	0.35** (.12)	0.26 (.13)
Price controls	−3.19** (.55)	−1.87** (.37)		−3.11** (.56)	−1.84** (.37)	
Relative import price	0.30* (.13)	0.39** (.09)		0.32* (.13)	0.40** (.09)	
	Start–1994Q4					
Intercept	0.76 (.53)	0.53* (.24)	1.77* (.69)	0.81 (.53)	0.56* (.24)	1.78* (.69)
Sum of lag ΔP	0.95** (.11)	0.93** (.05)	0.57** (.18)	0.93** (.11)	0.92** (.05)	0.57** (.18)
	1995Q1–End					
Intercept	1.20** (.37)	1.31** (.32)	1.95** (.35)	0.88 (.47)	0.95* (.40)	1.99** (.34)
Sum of lag ΔP	0.45** (.17)	0.24 (.19)	0.36** (.12)	0.48* (.20)	0.38 (.22)	0.31** (.12)
R-squared	0.84	0.90	0.63	0.83	0.90	0.64
RMSE	1.118	0.731	0.611	1.132	0.740	0.607
GAP restrict p-value	0.605	0.455	0.026	0.000	0.010	0.059
Observations	196	196	139	196	196	139
Start	1970Q1	1970Q1	1984Q2	1970Q1	1970Q1	1984Q2
End	2018Q4	2018Q4	2018Q4	2018Q4	2018Q4	2018Q4

Note: Columns 1, 2, 4, and 5 are for core CPI and core PCE. Robust standard errors in parentheses, * $p < 0.05$, ** $p < 0.01$.

Source: Authors' calculations based on equation 10 using data defined in appendix B.

Table A5 Phillips curves, unconstrained dynamics allowing for breaks, manufacturing capacity utilization GAP

	Shifting linear model			Low inflation bend model		
	(1) ΔCPI	(2) ΔPCE	(3) ΔECI	(4) ΔCPI	(5) ΔPCE	(6) ΔECI
GAP	−0.28** (.04)	−0.13** (.03)	−0.16* (.08)	−0.23** (.03)	−0.11** (.02)	−0.07 (.06)
GAP [ΔP<3]	0.23** (.05)	0.11** (.03)	0.07 (.08)			
GAP>0 [ΔP<3]				0.22** (.05)	0.11** (.04)	−0.04 (.07)
Price controls	−2.69** (.55)	1.64** .34)		−2.60** (.56)	−1.62** (.34)	
Relative import price	0.29* (.13)	0.38** (.08)		0.36** (.13)	0.41** (.08)	
Start–1967Q3						
Intercept	0.13 (.54)	−0.02 (.72)		−0.83 (.66)	−0.68 (.72)	
Sum of lag ΔP	0.88* (.34)	1.06* (.47)		0.98* (.40)	1.20* (.48)	
1967Q4–1994Q4						
Intercept	−0.47 (.58)	0.04 (.28)	0.41 (.97)	−0.11 (.56)	0.18 (.26)	1.00 (.87)
Sum of lag ΔP	1.04** (.11)	0.96** (.05)	0.81** (.24)	0.98** (.11)	0.94** (.05)	0.68** (.22)
1995Q1–End						
Intercept	1.43** (.38)	1.48** (.38)	1.24** (.26)	1.31** (.40)	1.41** (.41)	1.36** (.27)
Sum of lag ΔP	0.40* (.16)	0.18 (.21)	0.66** (.09)	0.33* (.16)	0.15 (.21)	0.64** (.09)
R-squared	0.85	0.90	0.61	0.84	0.90	0.60
RMSE	1.042	0.699	0.632	1.061	0.705	0.633
GAP restrict p-value	0.029	0.693	0.020	0.004	0.113	0.025
Long run ΔP, pre-1967	1.09 (3.27)	0.34 (97.7)		−42.94 (833197)	3.50 (25.6)	
Long run ΔP, 1967–94	11.51 (319)	1.11 (32.8)	2.13 (5.91)	−6.51 (5357)	2.78 (4.31)	3.13 (.46)
Long run ΔP, post-1994	2.36 (.01)	1.80 (.01)	3.62 (.14)	1.94 (.04)	1.65 (.01)	3.77 (.21)
Observations	239	231	139	239	231	139
Start	1959Q2	1961Q2	1984Q2	1959Q2	1961Q2	1984Q2
End	2018Q4	2018Q4	2018Q4	2018Q4	2018Q4	2018Q4

Note: Columns 1, 2, 4, and 5 are for core CPI and core PCE. Robust standard errors in parentheses, * $p < 0.05$, ** $p < 0.01$

Source: Authors' calculations based on equation 10 using data defined in appendix B.

APPENDIX B DESCRIPTION OF VARIABLES AND DATA SOURCES

Variable	Description	Source	Retrieved from
AGE	Median age of the labor force	US Bureau of Labor Statistics (BLS)	BLS website: www.bls.gov/data/
COMP	Compensation per hour, nonfarm business sector	US Bureau of Labor Statistics	Federal Reserve Economic Data (FRED), Federal Reserve Bank of St. Louis, https://fred.stlouisfed.org/
Core CPI	Consumer price index for all urban consumers: All items less food and energy	US Bureau of Labor Statistics	FRED, Federal Reserve Bank of St. Louis
Core PCE	Personal consumption expenditures excluding food and energy (chain-type price index)	US Bureau of Economic Analysis	FRED, Federal Reserve Bank of St. Louis
ECI	Employment cost index, wages and salaries for all civilian workers in all industries and occupations	US Bureau of Labor Statistics	FRED, Federal Reserve Bank of St. Louis
Headline CPI	Consumer price index for all urban consumers: All items	US Bureau of Labor Statistics	FRED, Federal Reserve Bank of St. Louis
Headline PCE	Personal consumption expenditures: All items (chain-type price index)	US Bureau of Economic Analysis	FRED, Federal Reserve Bank of St. Louis
Manufacturing capacity utilization	Capacity utilization: Manufacturing (North American Industry Classification System [NAICS])	Board of Governors of the Federal Reserve System	FRED, Federal Reserve Bank of St. Louis
Married male UN	Unemployment rate for married men	US Bureau of Labor Statistics	FRED, Federal Reserve Bank of St. Louis
NAIRU	Non-accelerating inflation rate of unemployment (NAIRU). The NAIRU is the January 2019 estimate of the underlying long-term rate of unemployment from the Congressional Budget Office.	US Congressional Budget Office	FRED, Federal Reserve Bank of St. Louis
UN	Civilian unemployment rate	US Bureau of Labor Statistics	FRED, Federal Reserve Bank of St. Louis
Price controls	Dummy variable for President Richard Nixon's wage and price controls. This variable is equal to 0.8 for the five quarters 1971Q3 to 1972Q3, –0.4 in 1974Q2 and 1975Q1, –1.6 in 1974Q3 and 1974Q4, and 0 otherwise.	Gordon (1982)	
Relative import price	Annualized 1-quarter growth rate of the ratio of imports of goods price index to personal consumption expenditures (PCE) goods price index, scaled by total goods imports as a percentage of gross domestic product.	US Bureau of Economic Analysis	FRED, Federal Reserve Bank of St. Louis
Survey ΔP^e	Long-term (10-year) inflation expectation from the Federal Reserve Board's FRB/US model. Since 1991Q4, the source has been the Survey of Professional Forecasters (SPF), first for expected CPI inflation and then, when it becomes available in 2007, for expected PCE price inflation. Data from 1981Q1 to 1991Q3 are primarily from a survey conducted by Richard Hoey. The Hoey and SPF CPI observations are reduced by 0.4 percentage point to account for the average difference between CPI and PCE inflation.	Federal Reserve Board FRB/US model dataset	Federal Reserve Board website: www.federalreserve.gov/econres/us-models-package.htm