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DISCUSSION PAPER

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DISCUSSION PAPER

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ABSTRACT

This paper contrasts empirically four leading models of inflation dynamics – the accelerationist Phillips curve (APC), new Keynesian Phillips curve (NKPC), hybrid Phillips curve (HPC) and sticky information Phillips curve (SIPC). We employ an encompassing Phillips curve specification that allows us to derive tests for these models within a single framework. Using the generalized method of moments (GMM) estimator, the evidence suggests that the restrictions implied by the NKPC, HPC, and SIPC are rejected for the U.S. during the Great Moderation. Only the restrictions implied by the APC are not rejected. When we use methods that are robust to the issue of weak instruments in GMM, the confidence regions are so wide that it is not possible to reject any models' restrictions, meaning that the evidence is consistent with all four models of inflation dynamics.

Keywords: Phillips curves; weak instruments; fully robust confidence regions.

1 INTRODUCTION

The empirical evidence shows that inflation tends to be pro-cyclical: periods of above average inflation tend to be associated with above average economic activity. This statistical relationship is known as the Phillips curve. The Phillips curve was perceived in the 1960s as a menu for monetary policymakers: they could choose between high inflation and low unemployment or low inflation and high unemployment. But this interpretation of the Phillips curve assumed that the relationship between unemployment and inflation was stable and would not break down when a policymaker attempts to exploit the tradeoff. After Friedman's (1968) paper and the high inflation episodes experienced by many economies in the 1970s, this interpretation of the Phillips curve was discredited. After a period of low inflation in the 1980s and early 1990s, economists again worked on a theoretical framework for the Phillips curve. The new Keynesian Phillips curve (NKPC) provides an interpretation of the short-run inflation-unemployment trade-off by deriving it from an optimizing framework featuring rational expectations and nominal rigidities. This is a structural model, designed to be capable of explaining the behavior of inflation without being subject to the Lucas critique. The NKPC is part of the new Keynesian model which is the workhorse model for monetary analysis. However, to use the NKPC for policy analysis requires it to have a good econometric track record in describing inflation dynamics.

This paper contrasts empirically four leading models of inflation dynamics – the accelerationist Phillips curve (APC), NKPC, hybrid Phillips curve (HPC), and sticky information Phillips curve (SIPC).

Our method of testing Phillips curves is different from the approaches taken by previous studies (e.g., Kiley, 2007; Gordon, 2011; and Mavroeidis et al., 2014) because it is based on an alternative specification of this curve that encompasses the APC, NKPC, HPC and SIPC. This encompassing specification has the advantage of reducing part of the vast specification uncertainty surrounding the Phillips curve by making it possible to test each of these alternative specifications within a single framework. Using the generalized method of moments (GMM) estimator, the evidence suggests that the NKPC, HPC and SIPC are not consistent with data for the U.S. during the Great Moderation. Only the APC is consistent with these data. However, when we construct confidence regions that are robust to weak instruments in the sense that identification of the coefficients is not assumed (in contrast to the conventional GMM method, where the validity of tests of estimated coefficients requires the assumption that they are identified), our previous conclusions turn on their head and making it impossible to reject any of the Phillips curve specifications. This happens because the GMM confidence regions understate the sampling uncertainty, compared to regions that are robust to weak instruments. The results do not depend on the choice of the forcing variable (output gap or marginal cost) in the Phillips curve equation.

The paper is organized as follows: section 2 reviews briefly the history of the Phillips curve; section 3 presents the encompassing Phillips curve (EPC) and shows how different Phillips curve specifications considered in the literature can be seen as special cases of the EPC; section 4 tests the restrictions implied by different Phillips curve specifications for U.S. data using the GMM approach on a quarterly sample from 1985 to 2007, a period known as the Great Moderation; section 5 discusses the issue of weak instruments; finally, section 6 brings the concluding remarks.

2 A BRIEF HISTORY OF THE PHILLIPS CURVE

In a seminal paper, Phillips (1958) showed that there was a negative and relatively stable relationship between nominal wage inflation and unemployment in the United Kingdom over the previous century. This relationship was found to work well for price inflation and for other economies, receiving the name of "Phillips curve". It became a key part of the standard Keynesian textbook model of the 1960s and as Keynesian economists saw it, the Phillips curve provided an exploitable trade-off between inflation and unemployment: policymakers could use demand management policies to increase output and decrease unemployment, but this could only be done at the expense of higher inflation. The Phillips curve relationship can be represented as

$$\pi_t = \alpha - \gamma u_t,$$

where π_t is inflation, u_t is the unemployment rate, and $\gamma > 0$.

The theoretical foundations of these early formulations were not completely sound, with a particular weak point being their treatment of how expectations entered wage and price setting. This weakness was thoroughly criticized in the seminal contributions of Phelps

(1967, 1968) and Friedman (1968). Friedman predicted that attempts to keep unemployment low at the expense of higher inflation would just result in higher inflation expectations.

Thus, the economy would not be able to sustain the low unemployment and would end up with higher inflation. In the Friedman-Phelps framework, then, there is no permanent trade-off between the level of inflation and the unemployment rate. However, to the extent that agents' expectations were slow to catch up with reality, a policymaker could keep unemployment below the natural rate by constantly boosting the inflation rate. For this reason, the Friedman-Phelps characterization of the inflation process also came to be known as the "accelerationist hypothesis" since an acceleration in prices would occur should policymakers attempt to permanently keep unemployment below its natural rate. Phelps assumed that inflation expectations evolved over time as a result of actual past experience that is, that expectations were formed adaptively.[1]

Friedman argued that the correct formulation of the inflation-unemployment trade-off was a Phillips curve of the form:

$$\pi_t = E_{t-1}\pi_t - \gamma(u_t - \overline{u}),$$

where inflation, π_t, is negatively correlated with deviations of the unemployment rate from its natural rate $\overline{u}$ $(\gamma > 0)$ and where the entire curve is shifted up or down one-for-one with changes in the rate of inflation that agents expected at time *t-1* to prevail at time t, $E_{t-1}\pi_t$. A common variant of this equation replaces $u_t - \overline{u}$ with the gap between actual and potential output, $y_t - \overline{y} \equiv x_t$. There is a long tradition in applied work that assumes backward-looking expectations: expected inflation is determined by past inflation. In the special case where $E_{t-1}\pi_t = \pi_{t-1}$, the Phillips curve becomes.

$$\pi_t = \pi_{t-1} - \gamma(u_t - \overline{u}).$$

This so-called accelerationist Phillips curve in which the acceleration of prices is related to unemployment embodied two critical innovations in the literature. First, it eliminated the long-run trade-off between inflation and unemployment that was inherent in the original Phillips curve model. Second, it began to emphasize the

1. In Phelps (1967), the appeal to adaptive expectations is explicit. The term is not used by Friedman (1968), who provides an informal discussion of a gradual adjustment process.

importance of expectations in the price-setting process, a change that was to have dramatic implications on the evolution of inflation models.

In the decade following the publication of the Phelps and Friedman papers, the notion that the accelerationist view of the inflation process was correct gained wider acceptance. Several factors contributed to this attitude. The first, of course, was the strength of the theoretical arguments themselves. Second, it became apparent by the mid-1970s that the inflation-unemployment trade-off implied by the short-run Phillips curve had shifted. Finally, it became easier to find that the lags of inflation in empirical Phillips curves summed to one. In addition, the important contribution of "supply shocks" to price acceleration in the early 1970s led to food, energy, and/or import prices receiving special treatment in empirical descriptions of inflation. What emerged in this period, therefore, was a benchmark econometric model of inflation of the form:

$$\pi_t = \alpha - \gamma u_t + B(L)\pi_{t-1} + \lambda z_t + \varepsilon_t,$$

where B(L) is the distributed lag operator with B(1) = 1, z_t denotes a vector of supply shocks, and ε_t is an error term. In this specification, then, inflation dynamics are determined by three sources: real activity (as summarized by the unemployment rate), supply shocks, and "inertia" (as captured by the lagged inflation terms). For this reason, it is sometimes called the "triangle model". Taken literally, the characterization of inflation dynamics that the triangle model provides carries important implications for the conduct of macroeconomic policy. To the extent that lagged inflation captures true inertia in the price-setting process (resulting, for instance, from how expectations are formulated), the model implies that rapid reductions in inflation can only be produced at the cost of a substantial increase in unemployment. Hence, the model points to a gradualist approach as providing the best way to effect a large reduction in inflation. In addition, policymakers must be mindful of the presence of long time lags between macroeconomic shocks (including policy actions) and their full effects on inflation. Thus, this framework provides a strong argument in support of preemptive action to head off the full effect of an inflationary shock.

The introduction of rational expectations into the modeling of economic dynamics had a significant influence on the development of macroeconomic theory from the mid-1970s onwards. The "demise" of the traditional Phillips curve, and the sense that it was due to inadequate modeling of expectations, was a major impetus for the rational expectations school led by Robert Lucas and Thomas Sargent. Lucas and Sargent also rejected the "accelerationist" reformulation of the Phillips curve because it relied on the assumption of adaptive expectations, which do not allow for the idea that agents process information in an optimal manner. In addition to being more precise about expectations formation, this school of economists relied more heavily on neo-classical "microfoundations" for macroeconomic models. Often, as well as rejecting the Phillips curve, these economists also questioned the whole basis for Keynesian economics, i.e. the assumption that monetary policy could systematically affect output even in the short-run.

The principal response of Keynesian economists to these theoretical critiques has been to attempt to build models that incorporate rational expectations and that provide a microeconomic justification for monetary policy having, at least, short-run effects. To explain why monetary policy might have effects on the economy, one needs a theory of why inflation is not just determined by some nominal anchor such as the money supply. The most common microeconomic rationale put forward has been sticky prices. With sticky prices, an increase in the money stock can produce a short-run increase in real spending power and thus can boost real output. Many academic economists have become convinced that certain theoretical new Keynesian models can provide a good description of the empirical inflation process. In part, this development stemmed from the realization that a number of popular new Keynesian models of price-setting each implied a sort of Phillips curve relationship, known as the New Keynesian Phillips Curve (NKPC):

$$\pi_t = \beta E_t \pi_{t+1} + \gamma x_t,$$

where x_t is a measure of output gap.

In these models inflation is determined in a completely forward-looking manner. The idea that there is considerable inertia in inflation and hence that it is difficult to reduce inflation quickly, does not hold in this framework indeed, according to the NKPC, there is no "intrinsic" inertia in inflation, in the sense that there is no structural dependence of inflation on its own lagged values. Thus, the NKPC has very different implications for monetary policy. This model implies that there is no need for gradualist policies to reduce inflation. According to the NKPC, low inflation can be achieved immediately by the central bank announcing (and the public believing) that it is committing itself to eliminating positive output gaps in the future.

Many estimates of the NKPC find that lagged inflation helps to explain current inflation. Galí and Gertler (1999) consider augmenting the NKPC with a backward-looking element that is motivated by the presence ofsome firms that follow a simple rule of thumb in setting prices. Christiano, Eichenbaum, and Evans (2005) derive a similar specification under the assumption that price-setters who are unable to reset prices instead index their prices to the last period inflation rate. All of these variants imply a so-called HPC of the form

$$\pi_t = \gamma_b \pi_{t-1} + \gamma_f E_t \pi_{t+1} + \kappa x_t.$$

The model of Mankiw and Reis (2002) was pioneer in the literature on sticky information. According to it, a Phillips curve with this rigidity is an adequate representation of the structural relationship between inflation and the real side of the economy. The model assumes that acquiring information is costly, and as a result information about macroeconomic conditions diffuses slowly through the population. Specifically, Mankiw and Reis assume that in each period a fraction of firms acquires complete (perfect) information about the current state of the economy, and these firm set prices optimally based on this information. The remaining firms continue to set prices based on outdated information. Mankiw and Reis posit that what matters now for current inflation is not current expectations about future economic conditions, but past expectations about current economic conditions. Because information constraints can apply to all economic agents, the sticky information model potentially provides a unifying framework for explaining the inertial behavior of different macroeconomic variables.

3 PHILLIPS CURVE: AN ENCOMPASSING SPECIFICATION

The Encompassing Phillips Curve (EPC), a model of inflation dynamics that encompasses the NKPC, APC, HPC and SIPC as special cases, takes the following form:

$$\Delta\pi_t = \alpha_1 \Delta\pi_{t-1} + \alpha_2 \Delta\pi_{t-2} + \beta_0 \Delta x_t + \gamma_1 x_{t-1} + \delta_1 \pi_{t-1} + \varepsilon_t, \tag{1}$$

where π is the inflation rate, x is a measure of inflation pressure (usually the output gap or, alternatively, the marginal cost), $\Delta z_t \equiv z_t - z_{t-1}$ is the rate of change of variable z and ε_t is an error term that can be correlated with the explanatory variables. This encompassing specification implies that the change of inflation depends on its lagged values, the change of the output gap (marginal cost), the lagged level of output gap (marginal cost) and the lagged level of the inflation rate. If the coefficient of this last variable is different from zero there is a long-run level trade-off between inflation and output gap (marginal cost).[2]

Let us show how each model is embedded in equation (1). For the case in which expected inflation depends on past inflation (we assume that expected inflation is the average of the last three periods), the APC is given by

$$\pi_t = \omega_1\pi_{t-1} + \omega_2\pi_{t-2} + \omega_3\pi_{t-3} + \kappa_0 x_t + \kappa_1 x_{t-1} + \varepsilon_t, \sum_{i=1}^{3}\omega_i = 1, \kappa_0 + \kappa_1 > 0.$$

This equation can be rewritten as

$$\Delta\pi_t = -\left(1-\omega_1\right)\Delta\pi_{t-1} - \left(1-\omega_1-\omega_2\right)\Delta\pi_{t-2} + \kappa_0\Delta x_t + \kappa_1 x_{t-1} + \varepsilon_t.$$

This specification is a particular case of equation (1) when:

$$\alpha_1 = -\left(1-\omega_1\right) < 0,\ \alpha_2 = -\left(1-\omega_1-\omega_2\right) < 0,\ \beta_0 = \kappa_0 > 0,\ \gamma_1 = \kappa_1 > 0,\ \delta_1 = 0.$$

The NKPC can be expressed as

$$\pi_t = \beta E_t\pi_{t+1} + \kappa x_t + \varepsilon_t,$$

where the rate of inflation depends on the rate of inflation that agents expect to prevail at time $t+1$, with the information available at time t. Assuming rational expectations, $E_t\pi_{t+1} = \pi_{t+1} + \mu_{t+1}$, where μ_{t+1} is a white noise error term, the NKPC can be written as

2. Rudd and Whelan (2006) report reduced form regressions for $\Delta\pi_t$ using the specification of equation (1). They have found negative coefficients on the lagged changes in inflation and positive coefficients for output gap and labor share. The coefficient of labor share is not significant. The main goal of Rudd and Whelan (2006) paper was to assess the empirical performance of HPC for the US inflation. They did not propose using equation (1) as a framework to test all Phillips curves specifications, which is our goal in this paper.

$$\Delta\pi_t = -\frac{\kappa}{\beta}x_{t-1} + \frac{1-\beta}{\beta}\pi_{t-1} + \eta,$$

The stochastic term η is given by: $\eta \equiv \mu_t - \varepsilon_{t-1}/\beta$, which is correlated with lagged inflation. This is a particular case of equation (1) when:

$$\alpha_1 = \alpha_2 = \beta_0 = 0, \gamma_1 = -\kappa/\beta < 0,\ \delta_1 = (1-\beta)/\beta > 0.$$

The HPC specification assumes that the inflation rate depends on the past inflation rate, the expected inflation rate for the next period and an inflation pressure variable according to:[3]

$$\pi_t = \gamma_b\pi_{t-1} + \gamma_f E_t\pi_{t+1} + \kappa x_t + \varepsilon_t.$$

We assume rational expectations, as with the NKPC, and after some algebra we obtain

$$\Delta\pi_t = \frac{\gamma_b}{\gamma_f}\Delta\pi_{t-1} - \frac{\kappa}{\gamma_f}x_{t-1} + \frac{(1-\gamma_b-\gamma_f)}{\gamma_f}\pi_{t-1} + \xi,$$

where $\xi \equiv \mu_t - \varepsilon_{t-1}/\gamma_f$, which is correlated with both lagged inflation and lagged change of inflation. This is a particular case of equation (1) when

$$\alpha_1 = \gamma_b/\gamma_f > 0, \alpha_2 = \beta_0 = 0, \gamma_1 = -k/\gamma_f < 0, \delta_1 = (1-\gamma_b-\gamma_f)/\gamma_f \geq 0.$$

The SIPC derived by Mankiw and Reis (2002) is given by[4]

$$\pi_t = \lambda\sum_{i=0}^{\infty}(1-\lambda)^j E_{t-1-j}(\pi_t + \alpha\Delta x_t) + \frac{\alpha\lambda}{1-\lambda}x_t + \varepsilon_t.$$

Inflation depends on the current output gap and on a geometric sum of past expectations of current inflation and output growth relative to potential.

3. Woodford [(2003), equation (2.23), p.568] specifies an hybrid Phillips curve in the presence of habit persistence, that takes the form: $\pi_t = \beta E_t\pi_{t+1} + \kappa\left[(x_t - \delta x_{t-1}) - \beta\delta E_t\left(x_{t+1} - \delta x_t\right)\right] + u_t$. This can be written as an EPC when: $\alpha_1 = \alpha_2 = 0,\ \beta_0 = \kappa\delta,\ \beta_1 = -\kappa\delta/\beta,\ \gamma_1 = \kappa\left(1-\delta\right)\left(1-\beta\delta\right)/\beta$ Notice that a lagged change of output (marginal cost) was added as an explanatory variable. The error term of this specification is given by: $\mu_t + \kappa\delta v_t - u_{t-1}/\beta$.
4. We follow the same notation used in their paper.

Assuming rational expectations and using the lag operator $L^j E_{t-1} = E_{t-1-j}$ we obtain, after some algebra, the following expression for the acceleration of inflation

$$\Delta\pi_t = \frac{\alpha\lambda(2-\lambda)}{(1-\lambda)^2}\Delta x_t + \frac{\alpha\lambda^2}{(1-\lambda)^2}x_{t-1} + \varsigma,$$

where $\varsigma \equiv \frac{1}{1-\lambda}\left[\varepsilon_t - (1-\lambda)\varepsilon_{t-1} + (\pi_t - E_{t-1}\pi_t)\right]$. Thus, the change of inflation depends on the change of output gap (marginal cost) and it's lagged level. This expression is a particular case of equation (1) when

$$\alpha_1 = \alpha_2 = \delta_1 = 0, \beta_0 = \alpha\lambda(2-\lambda)/(1-\lambda)^2 > 0,\ \gamma_1 = \alpha\lambda^2/(1-\lambda) > 0.$$

The EPC provides a simple set-up to test competing specifications of the Phillips curve. Table 1 shows the signs of the coefficients of the EPC resulting from each Phillips curve model considered. For example, suppose that one estimates equation (1) and finds out that $\beta_0 > 0,\ \gamma_1 > 0$, and $\delta_1 = 0$. Then, based on this information one can reject both the NKPC and HPC, but not the APC or SIPC. If in addition one has that $\alpha_1 = \alpha_2 = 0$, then the only model consistent with data would be the SIPC.

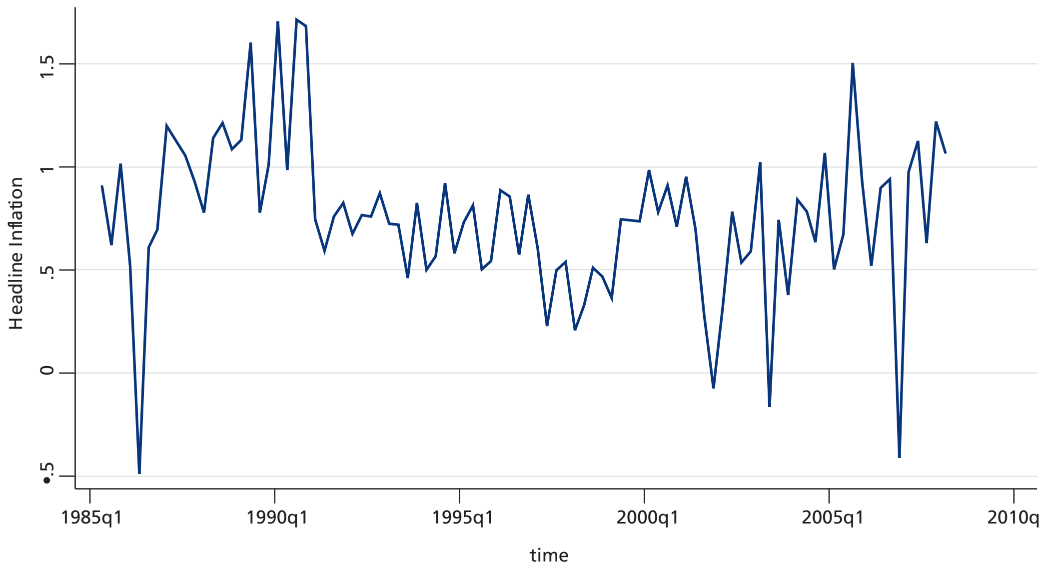
TABLE 1
Model typology

Model	Parameters				
	$\boldsymbol{\alpha}_1$	$\boldsymbol{\alpha}_2$	$\boldsymbol{\beta}_0$	$\boldsymbol{\gamma}_1$	$\boldsymbol{\delta}_1$
APC	-	-	+	+	0
NKPC	0	0	0	-	+
HPC	+	0	0	-	+ or 0
SIPC	0	0	+	+	0

4 EMPIRICAL EVIDENCE: UNITED STATES (1985Q1- 2OO7Q4)

The U.S. sample extends from 1985Q1 to 2007Q4, the period known as the "Great Moderation" due to the decline in the variability of both output and inflation.[5] Graph 1 plots the inflation rate and graph 2 exhibits the output gap.[6]

GRAPH 1
Headline inflation



Our empirical analysis starts with the EPC [equation (1)]. Given the presence of current output gap change (Δx_t) as a regressor, one may suspect that the ordinary least square (OLS) assumption of orthogonality between regressors and the error term (ε_t) may not hold. If Δx_t is correlated with ε_t, then the OLS estimates will be inconsistent. Furthermore, when the EPC has forward-looking elements as in the case of the NKPC, HPC, and SIPC, the error term becomes a function of ε_{t-1}, which makes the error term correlated with π_{t-1} and $\Delta\pi_t$, by construction. A solution to the endogeneity problem lies in the use of generalized method of moments (GMM) estimators. In this article we

5. Given that we estimate reduced-form models, the choice of the sample is motivated by the attempt of avoiding the Lucas critique by selecting periods of economic regime stability. James Stock and Mark Watson coined the phrase the great moderation while writing a research paper in 2002 (Has the Business Cycle Changed and Why?). It was brought to the attention of the wider public by Ben Bernanke (then member and chairman of the Board of Governors of the Federal Reserve - from January 2006 to January 2014) in a speech titled The Great Moderation in 2004.The results do not change significantly when we start or finish the sample one year earlier.
6. The Data Appendix gives details on the definitions of the variables employed in the estimations.

use the continuously updated (CU) GMM estimator whose estimates are independent of any normalization applied to the data.

GRAPH 2
Output gap

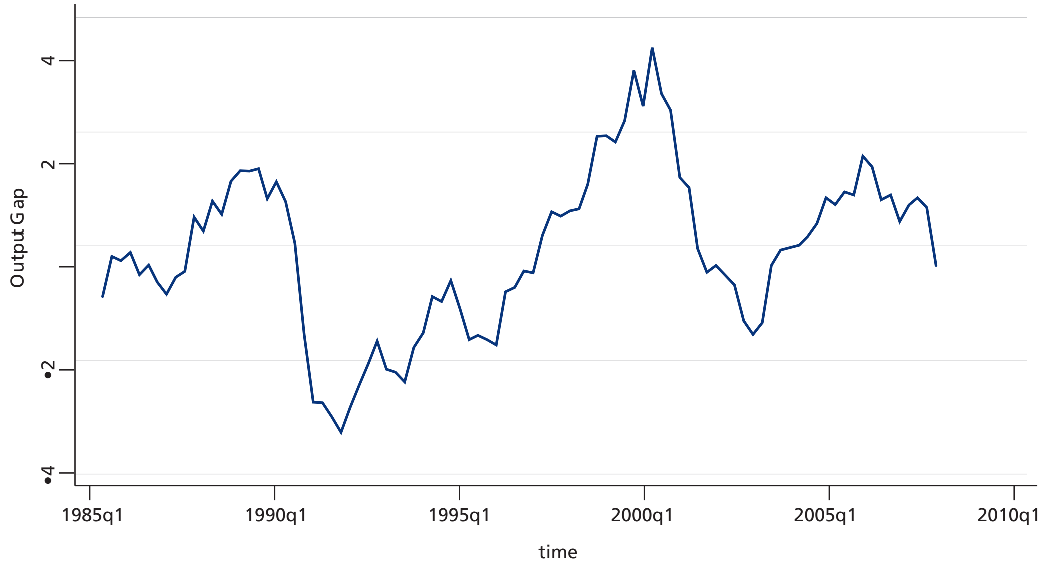


Table 2 reports CU-GMM estimates of the EPC in the 1985Q1-2007Q4 sample. According to table 2 the coefficients of both lagged inflation acceleration terms are negative within the 95% confidence interval, while the coefficients of the change in output gap and the output gap lag are positive. The coefficient of the inflation lag is not significantly different from zero. Using equation (1) and comparing the signs of tables 1 and 2 we observe that none of the restrictions implied by the NKPC is verified. Only one restriction implied by the HPC is valid $(\delta_1 = 0)$. Three of the restrictions implied by the SIPC are accepted $(\beta_0, \gamma_1 > 0$ and $\delta_1 = 0)$ and two are not $(\alpha_1, \alpha_2 = 0)$. All restrictions implied by the APC are accepted $(\alpha_1, \alpha_2 < 0, \beta_0, \gamma_1 > 0$ and $\delta_1 = 0)$. Only the APC model appears to be consistent with inflation dynamics in the U.S. from 1985Q1-2007Q4.

TABLE 2
Encompassing Phillips curve: GMM estimates

Dependent variable: $\Delta\pi_t$ Estimation method: CU-GMM sample: 1985Q1-2007Q4				
Variable	Coefficient	Standard error	P-value	95% confidence interval
$\Delta\pi_{t-1}$	-0.725	0.149	0.000	[-1.018,-0.431]
$\Delta\pi_{t-2}$	-0.531	0.137	0.000	[-0.801,-0.261]
Δx_t	0.593	0.155	0.000	[0.288,0.898]
x_{t-1}	0.070	0.015	0.000	[0.040,0.100]
π_{t-1}	-0.005	0.042	0.888	[-0.089,0.077]

Hansen J statistic (overidentification test of all instruments): 0.808 Chi-sq(2) P-value = 0.667.
Instrumented variables: $\pi_{t-1}, \Delta\pi_{t-1}, \Delta x_t$.
Included instruments: $\Delta\pi_{t-2}, x_{t-1}$.
Excluded instruments: $\pi_{t-2}, \Delta\pi_{t-3}, \Delta x_{t-1}, \Delta x_{t-3}, x_{t-3}$.

5 WEAK INSTRUMENTS

However, in order to be valid, the set of instruments chosen must satisfy two statistical conditions. First, each instrument must be uncorrelated with the error term (instrument exogeneity). Second, an instrument must be highly correlated with that portion of the endogenous regressors that cannot be explained by the other instruments (instrument relevance). Despite the fact that both criteria are necessary for an instrument to be valid, most of the empirical literature on the NKPC has ignored the issue of instrument relevance and has focused solely on instrument exogeneity.[7] When the instruments are only weakly correlated with the endogenous regressors, we have what is known as weak instruments or weak identification. Weak instruments pose considerable challenges to inference with GMM methods. If instruments are weak, then the sampling distributions of GMM statistics are in general non normal, and standard GMM point estimates, hypothesis tests, and confidence intervals are unreliable.

7. Exceptions include Ma (2002), Dufour et al. (2006), Mavroeidis (2005), and Nason and Smith (2008).

5.1 Approaches to inference with weak instruments: detecting weak instruments

One approach to dealing with weak instruments is to conduct tests of underidentification and weak identification.[8] The first diagnostic tool for assessing the strength of identification is based on a Lagrange-Multiplier (LM) test for underidentification using the Kleibergen and Paap (2006) *rk* statistic, see table 3. We cannot reject the hypothesis that the model is underidentified. The second set of diagnostics is based on the Stock and Yogo (2005) characterization of weak instruments using the Kleibergen-Paap Wald statistic, see table 4.[9] As the test statistics exceed the critical values tabulated by Stock and Yogo, we reject the hypothesis that the instruments used are weak.

TABLE 3
Underidentification test

Underidentification test
Kleibergen-Paap rk LM statistic: 3.484 Chi-sq(3) P-value = 0.322 (underidentified)

TABLE 4
Weak identification test

Weak identification test
Kleibergen-Paap rk Wald statistic: 5.970 (equation is not weakly identified)

5.2 Approaches to inference with weak instruments: fully robust confidence regions

The weak instruments literature (e.g., Andrews and Stock, 2005; and Kleiberger and Mavroeidis, 2009) has shown that using conventional inference methods after pretesting for identification is both unreliable and unnecessary. A better approach is to construct confidence regions that are fully robust to weak instruments.

In order to conduct inference on the parameters of the EPC we use methods that are robust to weak instruments in the sense that identification of the coefficients is not assumed. This is in contrast to the traditional IV/GMM method, where the validity of tests on estimated coefficients requires the assumption that they are identified. We construct

8. See Baum et al. (2007).
9. The Kleibergen-Paap Wald statistic correspond to the heteroscedasticity-robust multivariate analogue to the first-stage F statistic.

fully robust confidence regions by inverting the conditional likelihood ratio (CLR) test of Moreira (2003). Moreira's test overcomes the distortions of standard tests by adjusting the critical values for hypothesis tests from sample to sample so that, for given data, the critical values used yield a correct significance level. Thus, his critical values are "conditioned" on the data in hand, not constant. The projection-based confidence regions are obtained by grid search over the parameter space and are centered around the point estimates from the continuously updated GMM estimator, with width set as a multiple of the Wald confidence interval.[10]

Table 5 shows the projection-based CLR confidence sets for the baseline EPC model where there are three endogenous regressors $(\pi_{t-1}, \Delta\pi_{t-1}$ and $\Delta x_t)$ and two exogenous regressors $\Delta\pi_{t-2}$ and x_{t-1}, with inflation represented by headline inflation and the output gap as the forcing variable. Graphs 3-5 display the scatter plots for the 2-dimension confidence regions.[11] The results are consistent both with the view that price setting is purely backward-looking, as well as with the view that forward-looking expectations are very important in price setting. Furthermore, they are consistent with the view that prices are sticky as well as the view that information disseminates slowly through the economy. We also constructed robust confidence regions using median inflation, instead of headline inflation, and the gap of labor share of income, instead of output gap. In all cases they gave very similar results to the baseline model, so we do not display their graphs here.[12]

TABLE 5
Projection-based inference

	95% CLR Confidence set
π_{t-1}	[-0.960,0.913]
$\Delta\pi_{t-1}$	[-4.524,3.105]
Δx_t	[-3.352,4.379]
$\Delta\pi_{t-2}$	[-3.314,2.243]
x_{t-1}	[-0.423,0.559]

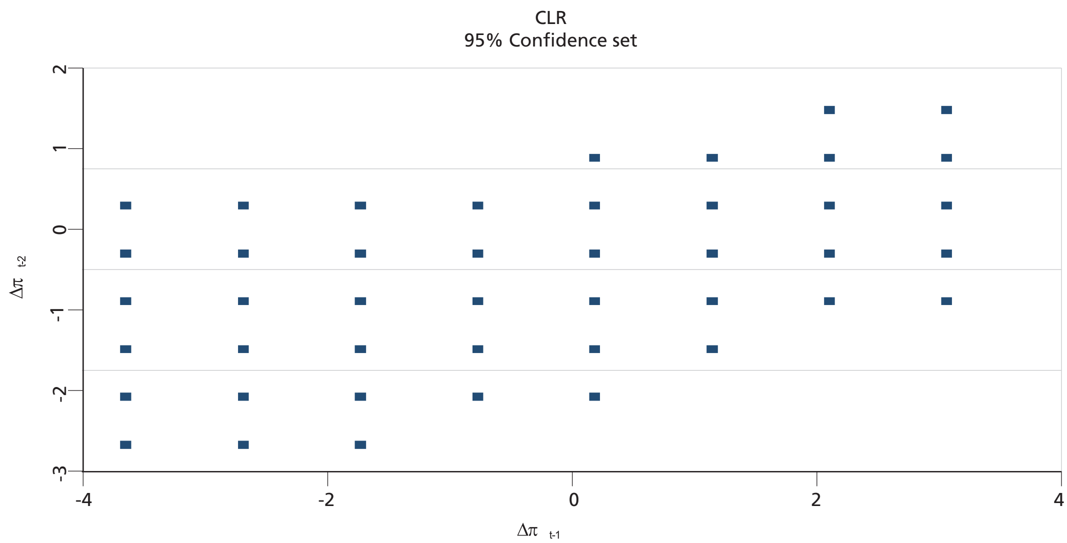
10. To construct the fully robust confidence regions we employ the routine weakiv that can estimate models with any number of endogenous regressors. See Finlay, Magnusson, and Schaffer (2013).

11. The confidence regions are estimated over 8^5=32768 grid points.

12. All results are available upon request to the authors.

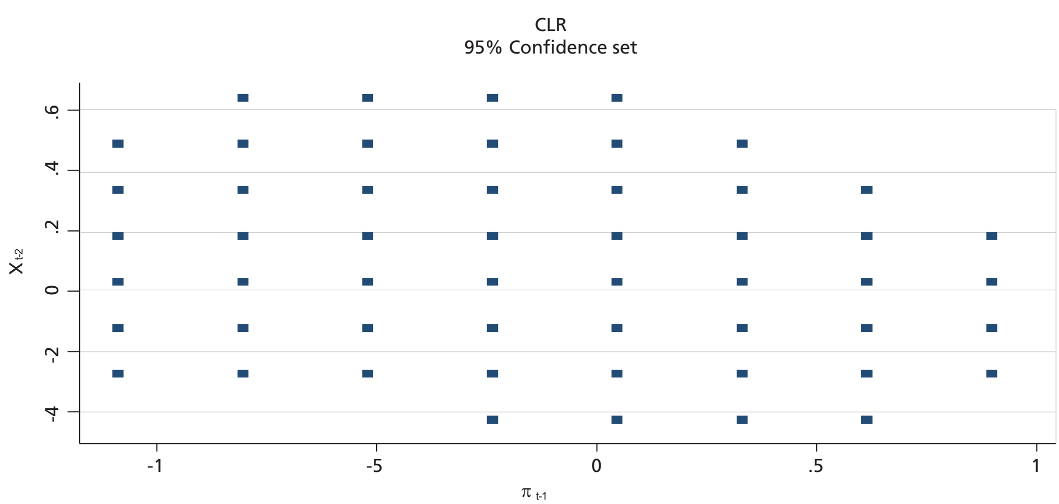
GRAPH 3

CLR robust confidence region for $\Delta\pi_{t-1}$ and $\Delta\pi_{t-2}$.

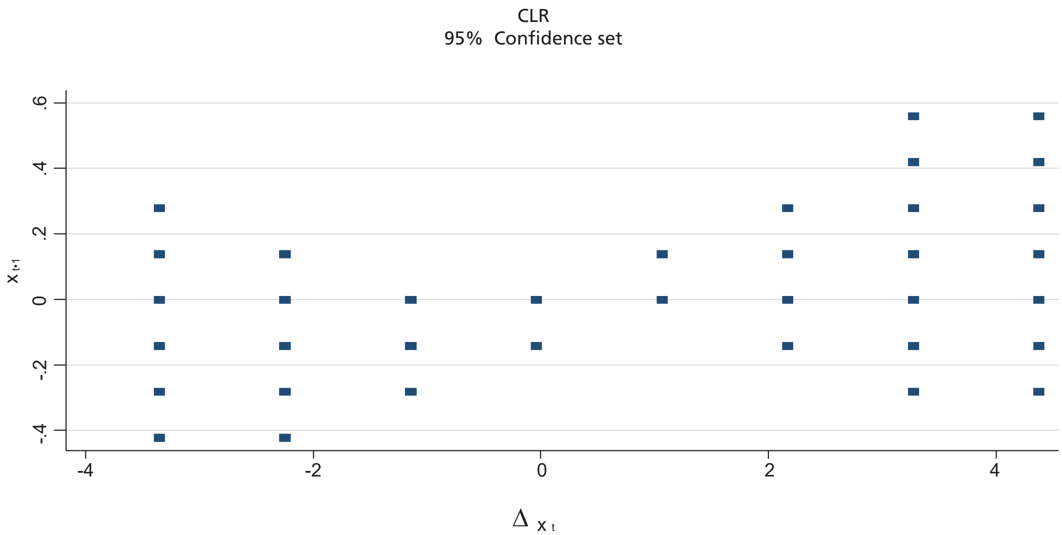


GRAPH 4

CLR robust confidence region for π_{t-1} and x_{t-1}.

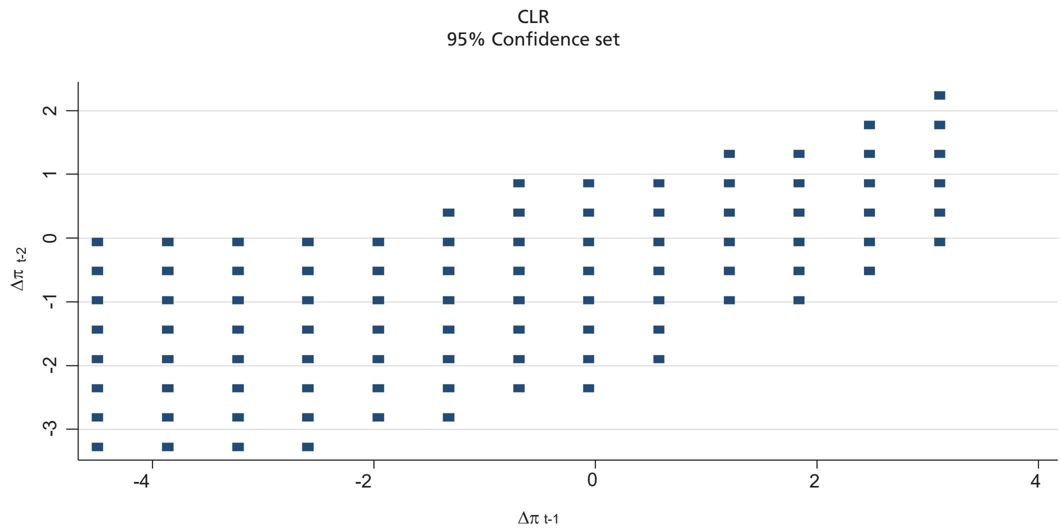


GRAPH 5
CLR robust confidence region for Δx_t and x_{t-1}.

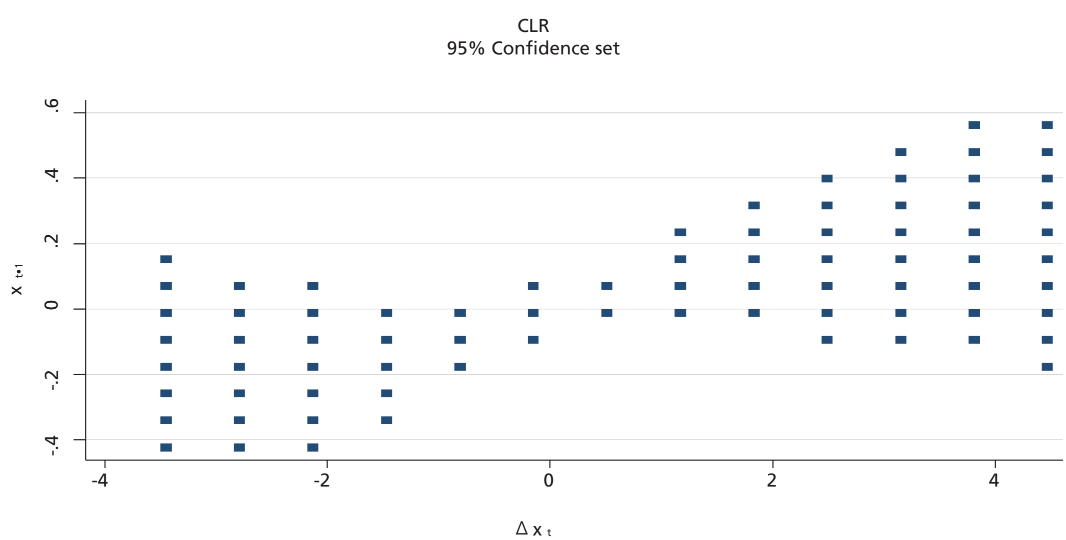


A number of investigators suggest restricting the reduced-form, hybrid NKPC parameters so that the sum of the coefficients of lagged inflation and expected inflation is equal to one (in the NKPC, $\gamma_f + \gamma_b = 1$). Imposing this restriction helps with identification by reducing the number of coefficients to be estimated by one. In the EPC model this restriction implies that the coefficient of lagged inflation in equation (1) is equal to zero. It turns out, though, that this restriction does not change our conclusions, as can be seen on graphs 6 and 7.

GRAPH 6
CLR robust confidence region for $\Delta\pi_{t-1}$ and $\Delta\pi_{t-2}$ for the restricted model where $\delta_1 = 0.$



GRAPH 7
CLR robust confidence region for Δx_t and x_{t-1} for the restricted model where $\delta_1 = 0.$



6 CONCLUDING REMARKS

This paper contrasted empirically four leading models of inflation dynamics using an encompassing specification that allowed us to derive tests for each model within a single framework. When we used the GMM estimator, only the restrictions implied by the APC were not rejected. However, when we used methods that are robust to the issue of weak instruments in GMM, the confidence regions were so wide that it was not possible to reject any models' restrictions, meaning that the evidence is consistent with all four models of inflation dynamics. These confidence regions were constructed using projection-based methods, which are very conservative, especially when many dimensions of the structural parameter vector are projected out.[13] To the best of our knowledge, there is currently no alternative way of making fully robust inference to weak instruments having more than one endogenous variable, as in our case. As pointed out by Mikusheva (2010), this seems extremely difficult to do. Nonetheless, we hope that this becomes a topic of research for those working at the frontier of inference with weak instruments.

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13. It is conservative in the sense that it has asymptotic size less than or equal to nominal size. Intuitively, whereas a standard correctly-sized test will commit a Type I error 5% of the time, a conservative projection-based test will commit a Type I error at most 5% of the time.

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DATA APPENDIX

- The inflation rate (π_t) is measured as the quarter-to-quarter change in the Consumer Price Index, where the quarterly inflation rates are calculated by the arithmetic average of the monthly series.
- The output gap (x_t) is measured as the real per capita GDP minus the real per capita potential GDP, as estimated by the Congressional Budget Office.
- The labor share of income gap is given by the log of the labor share of income, detrended by the Hodrick-Prescott filter.

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