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Research Article

A new measure of the output gap, inflation dynamics, and the New Keynesian Phillips Curve

Çıktı açığının yeni ölçüsü, enflasyon dinamikleri ve Yeni Keynesyen Phillips Eğrisi

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Abstract

Literature suggests that measures of slack such as unemployment, output, labour share, and inflation have been separated in recent years, particularly after the global crisis. Some claimed that the Phillips curve had vanished. Because of the unobservable nature of the natural rates, estimation of the output and unemployment gaps might not offer precise outcomes. The inflation model permits a fraction of firms that use a backwards-looking rule to set prices, as Gali and Gertler (2000) did. The essential contrast between their paper and mine is that they utilized marginal cost estimates as the applicable determinant of inflation, and I utilized the estimated output gap. Gali and Gertler supposed real marginal costs are a significant determinant of inflation. They also believed the output gap was negative and inconsequential. I have indicated that a precise output gap estimate is significant and positive. CBO output gap is also used to inspect for robustness. However, it was also insignificant, as the literature suggests. Therefore, the model used the estimated output gap instead of marginal cost. I calculated the output gap with a new methodology and could replicate their results with the new measure. I extended their study to 2019Q4; It is showed that their measure for inflation slack which was marginal cost becomes insignificant; however, my measure of the output gap is still significant. Therefore, it was inferred that the New Keynesian Phillips curve reasonably still explains inflation dynamics. I also concluded that the hybrid new Keynesian Phillips curve might explain the inflation dynamics.

Keywords: Natural Rates, New Keynesian Hybrid Phillips Curve, GMM, Instrumental Variables

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Öz

Literatür işsizlik, üretim, işgücü payı ve enflasyon gibi gevşeklik ölçütlerinin son yıllarda, özellikle küresel krizden sonra ayrıldığını öne sürmektedir. Bazıları Phillips eğrisinin kaybolduğunu iddia etmiştir. Doğal oranların gözlemlenemeyen doğası nedeniyle, çıktı ve işsizlik slacklarının tahmini kesin sonuçlar vermeyebilir. Kullanılan enflasyon modeli, Gali ve Gertler (2000)'in yaptığı gibi fiyatları belirlemek için geriye dönük bir kural kullanan firmaların bir kısmına izin vermektedir. Makaleleriyle bu makale arasındaki en önemli fark, enflasyonun ilgili belirleyicisi olarak marjinal maliyet ölçüsünü kullanmaları, bu çalışmada ise çıktı farkının kullanılmasıdır. Gali ve Gertler reel marjinal maliyetleri enflasyonun önemli ve niceliksel olarak önemli bir belirleyicisi olarak görürken, çıktı farkını negatif ve önemsiz olarak değerlendirdiler. Bu çalışma, doğru bir çıktı farkı ölçüsünün önemli ve pozitif olduğu gösterilmiştir. Sağlamlığı kontrol etmek için CBO çıktı farkı da kullanılmıştır, ancak literatür bu katsayının negatif ve önemsiz olduğunu göstermektedir. Bu çalışmanın modeli marjinal maliyet yerine yazarın hesapladığı çıktı açığı kullanılmıştır ve çıktı açığı yeni bir metodoloji ile hesaplanmıştır. Bu metodolojiyle hesaplanmış çıktı açığıyla Gali ve Gertler'in 1999'a kadar olan sonuçları tekrarlanmıştır ve çalışma ayrıca 2019Q4'e kadar genişletilmiştir, marjinal maliyetin önemsiz hale geldiği enflasyon slackları için ölçümler gösterilmiştir. Bununla birlikte, hesaplanan çıktı açığı ölçüsü hala önemli çıkmıştır. Sonuç olarak, Yeni Keynesyen Phillips eğrisinin enflasyon dinamiklerinin iyi bir ilk yaklaşımını sağladığı sonucuna varılmıştır. Sonuçlar, hibrit yeni Keynesyen Phillips eğrisinin enflasyon dinamiklerini açıklayabileceğini de ayrıca göstermektedir.

Anahtar Kelimeler: Doğal Oranlar, Yeni Keynesyen Hibrid Phillips Eğrisi, GMM, Araç Değişkenler

JEL Kodları: E12, E31

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Introduction

Inflation was so low after the great recession and stayed low until 2020. Inflations slacks such as the output gap and marginal costs could not explain the behaviour of inflation. There is a debate about the disconnection between inflation slacks and inflation. In this regard, I attempt to answer an essential question of whether the Phillips Curve has vanished or not. One of the significant concerns in estimating the Phillips Curve is using the output gap. Because the output gap is unobservable, I might not estimate its coefficient accurately, so it might be considered insignificant in the literature.

Gali and Gertler (2000) developed a structural inflation model based on the Calvo (1983) model of sticky prices. As they pointed out, using the detrended output gap might be ridden, giving inaccurate results because natural rates are not estimated. So they used a particular aggregate marginal-cost measure (labour share) instead of the detrended output gap. They showed that labour share was an economically and statistically significant determinant of the inflation rate. In recent years, estimates of slack such as unemployment, output, and labour share detached from inflation, particularly after the global crisis. According to Coibion & Gorodnichenko (2015) and Bobeica, Jaroci´nski, European, & Bank (2019), inflation remained below its historical average after the great recession, disconnected from inflation slacks, and literature indicated that the Phillips curve had vanished.

McLeay and Tenreyro (2020) argued that the Phillips curve always held. They claimed that it seemed to disappear because of the actions of central banks. Central banks minimized welfare losses by increasing inflation when unemployment was higher than its natural level or decreasing inflation when unemployment was lower than its potential. This targeting rule obscures the identification of a negative Phillips curve.

The new output gap measures estimate Gali and Gertler's (2000) hybrid new Keynesian Phillips curve. I replicated their results using their marginal cost proxy, labour share, my estimation of the output gap, and CBO's estimation for the same period they analyzed. The results were almost identical to those of Gali and Gertler (2000). However, when I extended the period to 2019Q4, labour share, their proxy for marginal cost and CBO's estimation of the output gap became insignificant, as the literature has suggested. It showed a disconnect between inflation and slack. However, when the calculated estimation of the output gap was used, it still was significant and positive, and the output gap was still an important determinant of inflation.

New Keynesian Phillips Curve and Hybrid Phillips Curve

Gali and Gertler (2000) developed a hybrid variant of the New Keynesian Phillips curve (NKPC). They tried to explain inflation with expected future inflation, lagged inflation, and actual marginal cost in a hybrid New Keynesian Phillips curve. Their generalized method of moments (GMM) estimates suggested that forward-looking behaviour was dominant and that the expected future inflation coefficient substantially exceeded the lagged inflation coefficient.

New Keynesian Phillips Curve

$$\pi_t = \beta \pi_{t+1}^e + \lambda mc_t + \epsilon_t \quad (1)$$

where π is the inflation rate, mc is marginal cost, π_{t+1}^e is expected future inflation rate, coefficient β is the subjective discount factor, $\lambda = (1-\theta)(1-\beta\theta)/\theta$, and θ is the frequency of price adjustment. In equation 1, current inflation can be explained by expected inflation and marginal cost, which can be approximated by the output gap, labour share, or unemployment gap. In this equation, a significant determinant of inflation was expected future inflation, but I cannot test lagged inflation as a significant determinant.

As with the traditional Phillips curve, inflation depends positively on the output gap, and it also depends on lagged inflation (π_{t-1}). However, in the new Keynesian Phillips curve, it depends on expected inflation (π_{t+1}^e), so I can say that inflation depends on the discounted sequence of future output gaps. Iterating equation 1 forward yields:

$$\pi_t = \lambda \sum_{k=0}^{\infty} \beta^k mc_{t+k}^e \quad (2)$$

Hybrid New Keynesian Phillips Curve

In the traditional form, I have only lagged inflation. To test current inflation dynamics, Gali and Gertler (2000) discussed a hybrid version that combined the new Keynesian Phillips Curve with the traditional one. The hybrid new Keynesian Phillips Curve is given in equation 3.

$$\pi_t = \phi\pi_{t-1} + (1-\phi)\pi_{t+1}^e + \delta x_t \quad (3)$$

With $0 < \phi < 1$, the hybrid new Keynesian Phillips curve is just a convex combination of lagged and expected future inflation and the output gap x_t.

According to Gali and Gertler (2000), is approach had some problems. They noted that conventional output gap measures were likely to be ridden with error. The main reason for that is the unobservability of the natural output rate. They also observed that the Congressional Budget Office (CBO) estimates and uses a deterministic trend to measure the natural output rate, which involves considerable measurement error.

Gali and Gertler's Hybrid Phillips Curve[1]

Gali and Gertler (2000) said there were two types of firms. $1-\omega$ of the firms behave like the firms in Calvo's model. They called them "forward-looking." ω of the firms, which they referred to as "backwards-looking," use the recent history of aggregate price behaviour.

$$p_t = \theta p_{t-1} + (1-\theta)\bar{p}_t^* \quad (4)$$

where $1-\theta$ is the probability that each firm would adjust its price in any given period and $\bar{p}_t^*$ is an index for the prices newly set in period t. The equation can also be shown as:

$$\bar{p}_t^* = (1-\omega)p_t^f + \omega p_t^b \quad (5)$$

where p_t^f is the price set by a forward-looking firm at t, and p_t^b does a backwards-looking firm set the price? They claimed that by using Calvo's model as a baseline, p_t^f can be shown as:

$$p_t^f = (1-\theta\beta)\sum_{k=0}^{\infty}(\theta\beta)^k mc_{t+k}^n \quad (6)$$

p_t^b can be shown as:

$$p_t^b = p_{t-1}^* + \pi_{t-1} \qquad (7)$$

A backwards-looking firm sets its price equal to the average price in the most recent round plus inflation.

Gali and Gertler obtained their hybrid Phillips curve by combining equations 4, 5, 6, and 7:

$$\pi_t = \gamma_b\pi_{t-1} + \gamma_f\pi_{t+1}^e + \lambda mc_t \qquad (8)$$

Where

λ= (1-ω)(1-θ)(1- $\beta\theta$)/θ + ω(1-θ(1-))

γ_f = $\beta\theta$ / θ + ω(1-θ(1- β))

γ_b = ω / θ + ω(1-θ(1- β))

[1] Derivation can be found in the appendix

θ is the degree of price stickiness, ω is the degree of "backwardness" in price setting, and β is the discount factor. When $\omega = 0$, all firms are forward-looking, and the model becomes the new Keynesian Phillips curve, and when $\beta = 1$, then $\gamma_b + \gamma_f = 1$. This implies that the model forms the hybrid equation discussed earlier.

Literature

The literature has used many variables for the unobservable factors in the new Keynesian Phillips curve. As a result, inaccurate calculations of those factors heavily affect the results, and inflation slacks have become unrelated in recent years. According to the new Keynesian Phillips curve I showed in equation 8, current inflation depends on both lagged and future expected inflation and marginal cost. Estimating equation 8 yielded different results in the literature. Gali and Gertler (2000) found γ_f significantly higher than γ_b, so they expected future inflation to be a better determinant of current inflation. Gali and Gertler (2000) also observed that using the output gap for marginal cost is an ad hoc approach, which is why the output gap's coefficient was insignificant and incorrectly signed in the literature. So, Gali and Gertler (2000) used labour share instead of the output gap for marginal cost. Roberts (1995) found γ_f significantly less than γ_b. Fuhrer (1997) also supported the traditional Phillips Curve. Mehra (2004) stated that, with supply shock in the model, the estimated coefficient on lagged inflation is more significant than on future inflation, so expected future inflation is not a significant determinant.

One of the significant problems in estimating the equation is using the output gap. The output gap is not observable because of the natural output rate, so this might be a reason that the coefficient of the output gap was incorrectly signed and considered insignificant in the literature. Another problem is estimating future expected inflation, which also is not observable. Roberts (1995) used the output gap (the gap between actual and trend GNP), and for the expectation, the actual future value of inflation was used as a proxy. Fuhrer (1997) used the deviation of GDP from the segmented trend and the federal funds rate to provide reasonable predictions of the output gap. They also dropped the expectation operator for simplicity.

Gali and Gertler (2000) stated that marginal cost and output gap relation were proportionate in the sticky price framework when capital is not variable. The relationship is very close when capital is variable but might not be proportionate. So instead of using detrended log GDP, they used the per cent deviation in the labour share. When deterministically detrended output was used, the new-Keynesian Phillips curve could not explain the empirical behaviour of inflation. They also used instruments including four lags of inflation, labour income share, employment, the spread between long-term and short-term interest rates, wage inflation, and commodity price inflation to estimate the expected inflation. They used the GMM approach in their paper. There is a potential difficulty with that approach. The instrument set might have some variables which can cause inflation. Because they did not include those variables in their hybrid model, their estimation may be biased, and it could cause a significant expected future inflation. They claimed that allowing for additional lags of inflation on the right-hand side of their hybrid model did not affect current inflation and that those additional lags were not significant.

Mehra (2004) used a lagged output gap and the change in the output gap instead of using the current output gap, and he added a supply shock to the model. The supply shock variables were the dummy variable of President Nixon's price controls and the relative price of imports. Moreover, for expected inflation, he used instruments such as the federal funds rate, the change in nominal defence expenditures, four lagged inflation values, relative import prices, and the output gap.

According to Rudd and Whelan (2005), using labour share instead of the output gap as a proxy of marginal cost is a significant problem in Gali and Gertler (2000). In practice, labour share is low if the economy is expanding and high if the economy is in recession. So, labour share is a poor proxy for marginal cost. They concluded that labour income share is not a good measure of the output gap. Rudd and Whelan (2005) also claimed that a specification bias was associated with Gali and Gertler's GMM procedure. Gali, Gertler, & David (2005) stated that Rudd and Whelan's claim was incorrect and that Gali and Gertler (2000)'s results were robust for various estimation procedures.

Estimation and results

This article provides new evidence for explaining inflation by a calculated output gap and the natural unemployment gap. In previous studies, the coefficient of the output gap was considered insignificant, and it was wrongly signed (negative) because most researchers used the detrended output gap and CBO's estimate of the natural output rate instead of the natural output rate. Therefore, Demir's (2020) estimations of natural rates were used in this work.

Output gap based on Non-accelerating Inflation Rate of Output (NAIR Output-Gap)

I estimated the non-accelerating inflation rate (the natural output rate). From the definition of the rate of unemployment:

$E = L(1 - u)$ (9)

where u is the unemployment rate, E is employment, and L is the labour force. The production function can be written as:

$Y = [L(1 - u)]^{\gamma} * K^{1-\gamma}$ (10)

If I assume that L and K are constant over time. Using log-linearization, I can rewrite equation 10:

$y = \gamma * l + (1 - \gamma) * k + -\gamma u$ (11)

where y is the log of real gross domestic product (real GDP), l is the log of the labour force, and k is the log of capital. Grouping the constant terms, I obtain:

$y = \psi - \gamma u$ (12)

where $\psi = \gamma * l + (1 - \gamma) * k$

Relation 12 is known as Okun's Law. Using Okun's Law, the natural rate of output can be written as a function of the natural rate of unemployment:

$y^n = \psi - \gamma u^n$ (13)

Subtracting 13 from 12, I obtained the output gap:

$OutputGap = -\gamma * (u - u^n)$ (14)

I obtained the following equation shown in regression form:

$\pi - \pi^e = -\beta * (u - u^n) + \epsilon = \beta/\gamma(y - y^n) + \xi$ (15)

I can again think that supply shock ξ can capture short-run fluctuation, and y^n captures the long-term relationship between output and inflation change. I estimated y^n by positing that it follows a stochastic process (such as a random walk) and that ξ also follows a stochastic process (such as white noise). Then, I used a statistical procedure that separated shifts of the Phillips curve into these two kinds of shocks. Rearranging the terms in 15, I obtained:

$y^n + \frac{\gamma}{\beta}\xi = y + \frac{\gamma}{\beta}\Delta\pi$ (16)

All terms on the left-hand side of the equation are unobservable, but everything on the right-hand side is observable. I can use the HP filter and a constant coefficient of y to decompose smooth shift y^n and high-frequency shift $\frac{\gamma}{\beta}\xi$. From the right-hand side of the equation $(y + \frac{\gamma}{\beta}\Delta\pi)$, I can reach the unobservable left-hand side $(y^n + \frac{\gamma}{\beta}\xi)$ and by using the HP filter, I can show trend component y^n and cyclical component $\frac{\gamma}{\beta}\xi$.

Using constant coefficients for γ and β to find y^n can be misleading because of the effect of permanent changes in the output structure. So instead, I used changing coefficients to estimate the right-hand side of equation 17 by using a structural break test and divided the data into subsamples.

$y^n + \frac{\gamma_i}{\beta_i}\xi = y + \frac{\gamma_i}{\beta_i}\Delta\pi$ (17)

Where $\frac{\gamma_i}{\beta_i}$ is different values of $\frac{\gamma}{\beta}$, for regimes i=0,...,m; one for each subsample. The start and end dates of each subsample, i.e., the multiple unknown breakpoints, were found using the Bai-Perron tests of 1 to M globally determined breaks method introduced in a series of three papers: (Bai, 1997), (Bai & Perron, 1998), and (Bai & Perron, 2003).

Using those regime changes and different coefficients, I estimated the output gap using the HP filter. I calculated the observable right-hand side of equation 17 $(y + \frac{\gamma_i}{\beta_i}\Delta\pi)$, I reached the unobservable left-hand side $(y^n + \frac{\gamma_i}{\beta_i}\xi)$ and by using the HP filter, I showed trend component y^n and cyclical component $\frac{\gamma_i}{\beta_i}\xi$. I also used Ball and Mankiw's (2002) method to calculate the output gap using constant coefficients. I calculated the observable right-hand side of equation 16 $(y + \frac{\gamma}{\beta}\Delta\pi)$, I reached the unobservable left-hand side ($y^n + \frac{\gamma}{\beta}\xi$) and by using the HP filter, I showed trend component y^n and cyclical component $\frac{\gamma}{\beta}\xi$.

Application of the method to real data

The hybrid New Keynesian Phillips Curve (NKPC) has been estimated for the U.S. The data for the estimation of the hybrid NKPC were obtained from the U.S. Bureau of Labor Statistics. Again, instrumental variables have been used to estimate future expected inflation. The instrument set included four-legged price inflation, the unemployment gap, the output gap, wage inflation, oil price inflation, and the treasury spread (10-year constant maturity minus 3-month market rate)-the same instruments Gali and Gertler (2000) used.

The estimates reported below are based on quarterly postwar U.S. data over two sample periods. The first period was 1960Q1–2000Q4. It was chosen to replicate Gali and Gertler's (2000) estimation and show the difference between my estimation and theirs. The second period was 1960Q1–2019Q4, which I analyzed for recent developments. I reported results for GDP deflator inflation, which is the logarithmic difference in GDP, an implicit price deflator. I used real GDP per person for output. The population-level monthly series came from the "Current Population Survey (Household Survey)" from the Census Bureau. I used quarterly averages to calculate real GDP per person. I used two series for the output gap and the unemployment gap.

The first series, Real Potential Gross Domestic Product and Natural Rate of Unemployment (Long Term), was taken from the U.S. Congressional Budget Office (CBO). The second series used measures of the estimated output gap and the estimated unemployment gap. Two Treasury spreads were calculated. The 5-Year Treasury Constant Maturity Rate, 10-Year Treasury Constant Maturity Rate, and 3-Month Treasury Bill: Secondary Market Rate were taken from the Board of Governors of the Federal Reserve System. Those three series are monthly series converted to quarterly series by taking simple averages. The Spot Crude Oil Price: West Texas Intermediate (WTI) was used for oil price inflation. That series was created by the Federal Reserve Bank of St. Louis to expand the history of the monthly West Texas Intermediate oil price series in FRED. Finally, I combined the Federal Reserve Economic Database series and converted them into quarterly series.

Empirical specification

I follow Gali and Gertler (2000). My first goal in this paper is to replicate their results with their methodology. I also extended the period to 2019Q4 to show my estimation of the output gap is significant and that inflation slacks are still relevant. They used the GMM approach in their paper. I replicated their results with the same slack measure and instruments, and I also showed that my results and their results were the same for the same period. However, there is a potential difficulty with that approach. The instrument set might have some variables which can cause inflation. Because they did not include those variables in their hybrid model, their estimation may be biased, and it could cause a significant expected future inflation. They claimed that allowing for additional lags of inflation on the right-hand side of their hybrid model did not affect current inflation and that those additional lags were not significant. Nonlinear estimation using GMM is susceptible to how the orthogonality conditions are normalized in small samples. Because of this, they and I use two alternative specifications of the orthogonality requirements as the base for the GMM analysis.

I estimated the model's structural parameters outlined in the previous section by employing a single equation approach. Equation 8 is estimated with the generalized method of moments (GMM) estimator proposed by Hansen (1982). This estimator has been widely used in solving the orthogonality conditions implied by forward-looking rational expectation models. Gali et al. (2005) stated that the GMM estimates from the hybrid NKPC obtained in Gali and Gertler (2000) were robust for different estimation procedures. Thus, I believe the GMM estimator with an appropriately chosen instrument set might not create a finite sample bias. I also believe I can reach reliable parameter estimates of the NKPC.

Results

In this section, I present estimates of the structural model equation 8. I used two different periods. First, I estimated the period between 1960Q1 and 1997Q4 to compare my results with those from Gali and Gertler (2000). Second; I used labour share, my output gap estimation, and CBO's output gap to measure real marginal cost. Results from my estimation and Gali and Gertler's (2000) original results are in table 1.

Table 1: GMM Estimates, Sample period: 1960:1–1997:4

	Unrestricted		**GMM**		**Restricted**		**γf + γb = 1**	
	GGL	**Labor Share**	**Ygap-CBO**	**Ygap-cal**	**GGL**	**Labor Share**	**Ygap-CBO**	**Ygap-cal**
γf	0.618***	0.619***	0.727***	0.602***	0.627***	0.643***	0.723***	0.625***
	(0.033)	(0.060)	(0.041)	(0.068)	(0.022)	(0.042)	(0.075)	(0.032)
γb	0.374***	0.361***	0.281***	0.381***				
	(0.028)	(0.043)	(0.080)	(0.033)				
λ	0.013**	0.008	-0.015	0.003*	0.010***	0.006	-0.016	0.004**
	(0.004)	(0.012)	(0.019)	(0.001)	(0.001)	(0.011)	(0.016)	(0.002)
ω	0.489	0.483	0.379	0.55	0.498	0.485	1.02	0.536
θ	0.828	0.880	0.965	0.92	0.837	0.874	2.66	0.892
β	0.975	0.941	1.02	0.94	1	1	1	1
J	19.419		12.866	15.749	21.200		13.344	16.918
J df	13.000		13.000	13.000	14.000		14.000	14.000
J p	0.11		0.46	0.26	0.10		0.50	0.26

Source: Produced by authors

Note: t statistics in parentheses, the dependent variable is quarterly inflation measured using the GDP deflator. The instrument set includes two lags of the output gap, labour share and wage inflation. GGL column shows Gali, Gertler, and Lopez-Salido's (2005) results. J: Hansen J χ2 statistic. Jdf: J statistic degrees of freedom. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The first and fifth columns in table 1 are from Gali et al. (2005). I used labour share to measure real marginal cost in the second and sixth columns. CBO's output gap was used in the third and seventh columns. The estimated output gap measure was used in the fourth and eighth columns. In all cases, the dependent variable was quarterly inflation measured using a GDP deflator. I estimated the structural parameters $\gamma_f, \gamma_b, \lambda, \omega, \theta$, and β using the GMM estimator. The instrument set was the same as those of Gali and Gertler (2000) and Gali et al. (2005). It included two lags in the output gap (labour share and wage inflation) and four lags in price inflation.

I considered two cases: the baseline model and the model restricted to unity. The first four columns present the results from the baseline model. The following four columns give the results from the model restricted to unity. The first three rows give the estimated structural parameters. The next three give the implied values of the reduced form coefficients in equation 8.

Our labour share estimates were consistent with those of Gali and Gertler (2000) and Gali et al. (2005). The estimates on expected future inflation were 0.62 for γ_f in my estimation and that of Gali et al. (2005). The coefficient of lagged inflation (γ_b) was 0.37 in Gali et al. (2005) and 0.36 in my estimation. The slope coefficients on the labour share (λ), and other implied coefficients β, ω, θ are 0.01 and 0.008; 0.97 and 0.94; 0.48 and 0.48; and 0.83 and 0.88 respectively. As shown in Table 1, my labour share estimation and their estimation results were quite similar between 1960:Q1 and 1997:Q4.

The parameter θ was 0.83 in their estimation. That implied that prices were fixed for almost six quarters on average [2]. Using my labour share estimation, I calculated the period that prices were fixed as 8. It was 12 when I used my output gap estimation. When I used CBO's output gap, the estimation was 28 quarters which seemed somewhat long.

The estimate of the fraction of backwards-looking price-setters ω was 0.48 in Gali et al. (2005) and my labour share estimation. This implied that roughly half of the price-setters were backwards-looking. However, they claimed that forward-looking behaviour remained predominant because γ_f was almost two times bigger than γ_b in all cases. When I used my output gap estimation instead of labour share, even though the fraction of backwards-looking price-setters ω was more than half, I observed dominant forward-looking behaviour. γ_f was 0.60 and γ_b was 0.38, which was very similar to the labour share estimations of Gali et al. (2005) and my own. Forward-looking behaviour was more critical than backwards-looking behaviour in all cases.

[2] $\frac{1}{1-\theta} = 5.81$

The slope coefficients on the CBO output gap estimation (λ) were negative and insignificant, as expected. However, my output gap estimation (λ) was positive and significant, as was the labour share estimation of Gali et al. (2005). I also tested the implications of restricting equal to unity, which I explained in Section 3.2 about the hybrid new Keynesian Phillips curve. Gali et al. (2005) found almost no impact on estimates. The estimation showed similar results. Thus, restricting β did not affect the results.

I also estimated equation 8 for a more extended period to make inferences for today. The period was from 1960Q1 to 2019Q4. As shown in Table 2, their coefficient of labour share as a proxy of the marginal cost was no longer joyous and significant. The slope coefficients for the CBO output gap estimation (λ) also were not different from zero. Therefore, I could not see a significant impact of marginal costs on inflation if I used just labour share and CBO's output gap estimation. The estimation of the output gap was still positive and significant.

Table 2: GMM Estimates, Sample period: 1960:1–2019:4.

	Unrestricted GMM			**Restricted $\gamma_f + \gamma_b = 1$**		
	Labor Share	**Ygap-CBO**	**Ygap-cal**	**Labor Share**	**Ygap-CBO**	**Ygap-cal**
γ_f	0.687***	0.670***	0.678***	0.673***	0.676***	0.681***
	(11.23)	(10.62)	(11.62)	(16.50)	(16.06)	(16.19)
γ_b	0.328***	0.322***	0.322***			
	(7.58)	(6.91)	(7.26)			
λ	-0.002	-0.000	0.004**	-0.001	-0.000	0.004**
	(-0.67)	(-0.02)	(2.18)	(-0.47)	(-0.06)	(2.44)
ω	0.484	0.474	0.430	0.484	0.478	0.423
θ	0.973	1.01	0.906	0.99	0.99	0.904
β	1.04	0.977	0.99	1	1	1
J	15.002	14.809	15.628	15.923	16.489	16.942
J df	25.000	25.000	25.000	26.000	26.000	26.000
J p	0.94	0.95	0.93	0.94	0.92	0.91

Source: produced by authors.

Note: t statistics in parentheses, the dependent variable is quarterly inflation measured using the GDP deflator. The instrument set includes four lags output gap, labour share and wage inflation, price inflation, and exchange rate growth. J: Hansen J $\chi 2$ statistic. Jdf: J statistic degrees of freedom. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

In Table 2, labour share, their proxy for marginal cost, and CBO's estimation of the output gap became insignificant, as the literature has suggested. When I used my estimation of the output gap, it still was significant and positive, and the output gap was still an important determinant of inflation. The weight of future inflation γ_f was estimated to be two times the weight of lagged inflation γ_b. Future expected inflation was still a more important determinant of current inflation than lagged inflation. γ_f increased from 0.60 to 0.68, and γ_b decreased from 0.38 to 0.32 in all cases. The parameter theta was 0.90. The average time prices in the U.S. decreased to 10 quarters from 12.

Conclusion

Unemployment, output, labour share (and other measures of slack), and inflation have been separated in current years, mainly after the global crisis. According to Coibion & Gorodnichenko (2015) and Bobeica et al. (2019), inflation remained below its historical average after the great recession, disconnected from inflation slacks. Some asserted that the Phillips curve had evaporated. McLeay & Tenreyro (2020) argued that the Phillips curve always held. They claimed that it seemed to disappear because of the actions of central banks. Central banks minimized welfare losses by increasing inflation when unemployment was higher than its natural level or decreasing inflation when unemployment was lower than its potential. This targeting rule obscures the identification of a negative Phillips curve.

Estimating the domestic product and unemployment gaps might not offer precise results because natural rates are unobservable. Gali and Gertler (2000) stated that using the detrended output gap or CBO's output gap measure might be ridden. It gave inaccurate results in the literature because natural rates are not estimated. They thought that the "measured output gap is well above trend, but inflation is well below trend, so mismeasurement of the true output gap is confounding the ability of the traditional Phillips curve to explain the data."

I used a new measure of the output gap to estimate Gali and Gertler's (2000) hybrid new Keynesian Phillips curve. I replicated their results using their marginal cost proxy, labour share, my estimation of the output gap, and CBO's estimated output gap for the same period they analyzed. The results were almost identical to those of Gali and Gertler (2000). However, when I extended the period to 2019Q4, labour share, their proxy for marginal cost and CBO's estimation of the output gap became insignificant, as the literature has suggested. It showed a disconnect between inflation and slack. When I used my estimation of the output gap, it still was significant and positive, and the output gap was still an important determinant of inflation.

Our outcomes indicate that the hybrid new Keynesian Phillips curve may clarify inflation dynamics. The fraction of backwards-looking price setters, ω, declined from 0.55 to 0.43. However, forward-looking behaviour remained dominant. γ_f increased from 0.60 to 0.68.

Estimating unobserved factors implies a negative connection between inflation and the output gap that confuses the identification of the Phillips curve. The paper clarifies the identification problem. I clear empirical literature findings and discuss a practical solution to the identification problem. For this reason, adjusting current theories to estimate marginal costs and output gap delivers a crucial understanding of inflation dynamics.

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References

Bai, J. (1997). Estimating Multiple Breaks One at a Time. *Econometric Theory*, *13*(3), 315–352. https://doi.org/10.1017/S0266466600005831

Bai, J., & Perron, P. (1998). Estimating and Testing Linear Models with Multiple Structural Changes. *Econometrica*, *66*(1), 47. https://doi.org/10.2307/2998540

Bai, J., & Perron, P. (2003). Computation and analysis of multiple structural change models. *Journal of Applied Econometrics*, *18*(1), 1–22. https://doi.org/10.1002/JAE.659

Ball, L., & Mankiw, N. G. (2002). The NAIRU in Theory and Practice. *Journal of Economic Perspectives*, *16*(4), 115–136. https://doi.org/10.1257/089533002320951000

Bobeica, E., Jaroci´nski, M., European, J., & Bank, C. (2019). *Missing Disinflation and Missing Inflation: A VAR Perspective **.

Calvo, G. A. (1983). Staggered prices in a utility-maximizing framework. *Journal of Monetary Economics*, *12*(3), 383–398. https://doi.org/10.1016/0304-3932(83)90060-0

Coibion, O., & Gorodnichenko, Y. (2015). Information Rigidity and the Expectations Formation Process: A Simple Framework and New Facts. *American Economic Review*, *105*(8), 2644–2678. https://doi.org/10.1257/AER.20110306

Demir, H. (2020). Three Essays on Natural Rates. *Dissertations, Theses, and Capstone Projects*. https://academicworks.cuny.edu/gc_etds/3937

Fuhrer, J. C. (1997). The (Un)Importance of Forward-Looking Behavior in Price Specifications. *Journal of Money, Credit and Banking*, *29*(3), 338. https://doi.org/10.2307/2953698

Gali, J., & Gertler, M. (2000). *Inflation Dynamics: A Structural Econometric Analysis*. https://doi.org/10.3386/W7551

Galıá, J., Gertler, M., & David Lo´pezlo´pez-Salido, J. (2005). Robustness of the estimates of the hybrid New Keynesian Phillips curve. *Journal of Monetary Economics*, *52*, 1107–1118. https://doi.org/10.1016/j.jmoneco.2005.08.005

Hansen, L. P. (1982). Large Sample Properties of Generalized Method of Moments Estimators. *Econometrica*, *50*(4), 1029. https://doi.org/10.2307/1912775

McLeay, M., & Tenreyro, S. (2020). Optimal Inflation and the Identification of the Phillips Curve. *Https://Doi.Org/10.1086/707181*, *34*(1), 4–255. https://doi.org/10.1086/707181

Mehra, Y. P. (2004). The Output Gap, Expected Future Inflation and Inflation Dynamics: Another Look. *SSRN Electronic Journal*. https://doi.org/10.2139/SSRN.2184948

Roberts, J. M. (1995). New Keynesian Economics and the Phillips Curve. *Journal of Money, Credit and Banking*, *27*(4), 975. https://doi.org/10.2307/2077783

Rudd, J. B., & Whelan, K. (2005). Does labor's share drive inflation? *Journal of Money, Credit and Banking : JMCB*, *37*(2).

Appendix

Appendix 1: Derivation of New Keynesian Phillips Curve

Gali and Gertler (2000) assume monopolistic competitive market and firms. θ is degree of price stickiness. 1-θ is a probability which a firm can adjust its price in any given period. So Gali and Gertler (2000) calculates average k period unchanged prices as

$(1-\theta)\sum_{k=0}^{\infty} k\theta^{k-1} = 1/1-\theta$

Price index P_t can be calculated by using constant elasticity of substitution.

P_t = $[\int_0^1 (P_t(z)_t)^{1-\epsilon} dz]^{1/1-\epsilon}$

I can rewrite the expression by using the fraction of the firms.

P_t = $[\theta(P_{t-1})^{1-\epsilon} + (1-\theta)(P_t^*)^{1-\epsilon}]^{1/1-\epsilon}$

P_t^* is set prices.

If I write a loss function for set prices,

L(p_t^*) =$\sum_{k=0}^{\infty} (\theta\beta)^k E_t(p_t^* - z_{t+k})^2$

z_t is is optimal price at time t.

dL/dp_t = 2$\sum_{k=0}^{\infty} (\theta\beta)^k E_t(p_t^* - z_{t+k})$ = 0

$\sum_{k=0}^{\infty} (\theta\beta)^k E_t(p_t^*)$ = $\sum_{k=0}^{\infty} (\theta\beta)^k z_{t+k}$

1/(1-$\theta\beta$)p^*= $\sum_{k=0}^{\infty} (\theta\beta)^k z_{t+k}$

p^*= (1-$\theta\beta$)$\sum_{k=0}^{\infty} (\theta\beta)^k z_{t+k}$

p_t^* =(1-$\theta\beta$)[$z_t + (\theta\beta)z_{t+1} + (\theta\beta)^2 z_{t+2}+\ldots$]

$E(p_{t+1}^*)$ =(1-$\theta\beta$)[$z_{t+1} + (\theta\beta)z_{t+2} + (\theta\beta)^2 z_{t+3}+\ldots$]

$\theta\beta E(p_{t+1}^*)$ =(1-$\theta\beta$)[($(\theta\beta)z_{t+1} + (\theta\beta)^2 z_{t+2} + (\theta\beta)^3 z_{t+3}+\ldots$]

p_t^* - $\theta\beta E(p_{t+1}^*)$ = (1-$\theta\beta$)z_t

I also know that

P_t = $[\theta(P_{t-1})^{1-\epsilon} + (1-\theta)(P_t^*)^{1-\epsilon}]^{1/1-\epsilon}$

I can log-linearize this equation as

p_t = $\theta(p_{t-1}) + (1-\theta)(p_t^*)$

p_t^* = $(p_t - \theta p_{t-1})/(1-\theta)$

$E(p_{t+1}^*)$ = $(E(p_{t+1}) - \theta p_t)/(1-\theta)$

then

$(p_t - \theta p_{t-1})/(1-\theta)$ - $\theta\beta$ $(E(p_{t+1}) - \theta p_t)/(1-\theta)$ = (1-$\theta\beta$)z_t

$(p_t - \theta p_{t-1}) - \theta\beta(E(p_{t+1}) - \theta p_t)$ = $(1-\theta)(1-\theta\beta)z_t$

$\theta\beta E(p_{t+1})$ = $(1-\theta^2\beta)p_t - \theta p_{t-1} - (1-\theta)(1-\theta\beta)z_t$

$\theta\beta E(p_{t+1}) - \theta\beta p_t$ = $(1-\theta\beta-\theta^2\beta)p_t - \theta p_{t-1} - (1-\theta)(1-\theta\beta)z_t$

$\theta\beta(E(p_{t+1}) - p_t)$ = $(1-\theta\beta-\theta^2\beta)p_t - \theta p_{t-1} - (1-\theta)(1-\theta\beta)z_t + \theta p_t - \theta p_t$

$\theta\beta(E(p_{t+1}) - p_t)$ = $(1-\theta-\theta\beta-\theta^2\beta)p_t - \theta(p_t - p_{t-1}) - (1-\theta)(1-\theta\beta)z_t$ (E(p_t+1) - p_t) =(1 -)(1-)p_t - (p_t - p_t-1) - (1-)(1-)z_t

$\theta\beta E(\pi_{t+1})$ = $\theta\pi_t - (1-\theta)(1-\theta\beta)(z_t - p_t)$

π_t = $\beta E(\pi_{t+1}) + (1-\theta)(1-\theta\beta)/\theta(z_t - p_t)$

Equation 1 shows $z_t - p_t$ as mc (real marginal cost)

Appendix 2: Derivation of Hybrid New Keynesian Phillips Curve

Gali and Gertler (2000) assumes two types of firms. $(1-\omega)$ of firms ("forward looking") behave like the firms in the Calvo model.

From previous section

$p_t = \theta(p_{t-1}) + (1-\theta)(p_t^*)$

than set price

$p_t^* = \omega(p_t^b) + (1-\omega)(p_t^f)$

$p_t^f = (p_t^* - \omega p_t^b)/(1-\omega)$

because the baseline is Calvo model I can also write p_t^f as

$p_t^f = (1-\theta\beta)\sum_{k=0}^{\infty}(\theta\beta)^k E_t z_{t+k}$

I can rewrite this equation

$p_t^f = \theta\beta E p_{t+1}^f + (1-\theta\beta)z_t$

$(p_t^* - \omega p_t^b)/(1-\omega) = \theta\beta E((p_{t+1}^* - \omega p_{t+1}^b)/(1-\omega)) + (1-\theta\beta)z_t$

Backward looking firms set

$p_t^b = p_{t-1}^* + \pi_{t-1}$

than

$(p_t^* - \omega(p_{t-1}^* + \pi_{t-1}))/(1-\omega) = \theta\beta E((p_{t+1}^* - \omega(p_t^* + \pi_t))/(1-\omega)) + (1-\theta\beta)z_t$

Again by using

$p_t = \theta(p_{t-1}) + (1-\theta)(p_t^*)$

$p_t^* = (p_t - \theta p_{t-1})/(1-\theta)$

I can rewrite the equation

$((p_t - \theta p_{t-1})/(1-\theta) - \omega((p_{t-1} - \theta p_{t-2})/(1-\theta) + \pi_{t-1}))/(1-\omega) = \theta\beta E(((p_{t+1} - \theta p_t)/(1-\theta) - \omega((p_t - \theta p_{t-1})/(1-\theta) + \pi_t))/(1-\omega)) + (1-\theta\beta)z_t$

by combining the equation I can reach

$\pi_t = \gamma^f E(\pi_{t+1}) + \gamma^b \pi_{t-1} + \lambda(z_t - p_t)$

$\lambda = (1-\omega)(1-\theta)(1-\beta\theta)/\theta + \omega(1-\theta(1-\beta))$

$\gamma^f = \beta\theta/\theta + \omega(1-\theta(1-\beta))$

$\gamma^b = \omega/\theta + \omega(1-\theta(1-\beta))$