The Price Puzzle and the Cost Channel in Monthly and Quarterly Data

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Abstract

This paper addresses the so-called 'price puzzle'—a positive response of prices to a monetary contraction. Using both reduced-form and structural models, it demonstrates that measures of output gap can be used to estimate the New Keynesian Phillips curve (NKPC). Contrary to much of the recent literature on the subject, it finds that the backward-looking component in the NKPC is insignificant. It also examines whether the cost channel of transmission of monetary policy can account for the price puzzle, documents its significant presence in both monthly and quarterly models, and shows that the latter account for the empirical inflationary dynamics obtained with structural vector autoregression quite well.

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1 Introduction

Concern with a positive response of prices to a contractionary monetary shock can be traced several decades back. Widely cited in the empirical literature on this subject is the 1970s comment of Congressman Wright Pitman that fighting inflation with higher interest rates was akin to "throwing gasoline on fire." His simile had little impact on the conduct of monetary policy, however, as the standard Keynesian models confidently predicted that an increase in interest rates would reduce aggregate demand and hence the price level, without considering its possible effects on aggregate supply. Starting with the seminal paper by Sims (1992), academic interest in the 'price puzzle'—a positive response of prices to a contractionary monetary policy shock—was resurrected.

The price puzzle is typically addressed in two ways: finding model specifications that resolve it and imply that the puzzle doesn't exist or finding modeling devices that provide theoretical substantiation for the puzzle. One such device is the presence of the cost channel of transmission of monetary policy, whereby interest rates enter a representative firm's marginal cost function. In this setup, a contractionary monetary policy shock raises interest rates and hence the firm's marginal cost. In the very short term, this increase in cost translates into an increase in prices, which later decline due to the decrease in aggregate demand. Hence models that incorporate the cost channel may be able to explain the price puzzle. More specifically, the cost channel is modeled as the nominal interest rate term entering the New Keynesian Phillips curve. One purpose of this paper is to investigate the strength of this relationship in the monthly and quarterly U.S. data.

There is no consensus in the literature on whether prices exhibit a positive response to a contractionary monetary policy shock or whether the cost channel plays an important role in the business cycles. As the empirical literature review presented in Section 2 documents, different datasets and methodologies seem to point to different conclusions. In particular, it appears that results based on quarterly data tend to reject the price puzzle, whereas the ones that rely on monthly data generally support it. This paper investigates whether this effect can be attributed to the stronger presence of the cost channel in the monthly rather than quarterly data.

The rest of the paper is organized as follows. Section 2 surveys empirical literature that addresses the price puzzle. Section 3 uses the standard structural vector autoregressive (SVAR) evidence to document the existence of the price puzzle in the U.S. data. Section 4 presents empirical results that demonstrate when and if the cost channel of transmission of monetary policy may be a suitable explanation for the price puzzle. Lastly, Section 5 concludes.

2 Review of the Empirical Literature

Recent interest in the 'price puzzle' began with the Sims' (1992) finding that prices responded positively to an increase in interest rates in several industrialized countries. He also found that introducing an index of commodity prices into the empirical system helped reduce the extent of the price puzzle, which led him to the conjecture that central banks may use 'information variables' that indicate the advent of inflation and allow them to react preemptively. He then suggested that failure to include these variables into an empirical system results in a misspecified model; correcting this misspecification would then remove the 'price puzzle'. These findings produced considerable controversy, prompting researchers to look for explanations of this ostensible anomaly. The proposed solutions draw upon a wide array of methodologies and offer rather different answers. However, one distinction seems to be pervasive: Studies that use monthly datasets find it hard to solve the price puzzle, whereas the ones that use quarterly data frequently suggest that it may not be an issue altogether.

Bernanke and Mihov (1998) developed a general model of monetary policy that nests several alternative assumptions, such as the central bank's targeting the federal funds rate, or total reserves, or non-borrowed reserves. This setup is used as a part of a general model of an economy and describes the variables' responses to monetary policy innovations. They provided evidence that in the 1986-1996 period, the federal funds rate model provides the best description of the data, which is why the same model is employed in this paper.[1] Hanson (2004) employed the Bernanke and Mihov (1998) empirical model of monetary policy and surveyed a wide gamut of potential 'information variables' in the monthly US data. Although some of these variables help alleviate

[1]Bagliano and Favero (1998) re-examined and largely upheld these findings.

the extent of the price puzzle, especially in the more recent sample, several specifications indicate that it still may be a palpable issue. Results from the monthly data in this paper point to similar conclusions.

Micro-level studies also suggest that the price puzzle indeed exists and propose the cost channel of transmission of monetary policy as its solution. Gaiotti and Secchi (2006) find that it plays a significant role in the data from 2,000 Italian manufacturing firms and that the parameter describing the extent of the cost channel is large and significant. Working with the U.S. industry-level manufacturing data, Barth and Ramey (2000) find that a contractionary monetary policy shock produces lower output and higher price-wage ratios.[2] They also show that this effect is much stronger in the time period up to 1979.[3] Therefore, it appears that manufacturing firms indeed tend to respond to a contractionary shock by raising prices.

On the other hand, studies using quarterly data at the macro-level indicate that the price puzzle may not exist at all. Whereas including 'information variables' may be one way of addressing the potential misspecification problem that could produce the price puzzle, Giordani (2004) points to another potential source of misspecification and shows that the price puzzle disappears once a measure of output is replaced with a measure of the output gap, whose presence is motivated by theory. He rejects the necessity of 'information variables' and claims that they contribute to resolving the price puzzle, only because they are correlated with other targets of a central bank. In particular, he shows that once output is replaced by the output gap in a three-variable VAR (output gap, inflation, and the federal funds rate), the price puzzle disappears in the quarterly data. However, Giordani's (2004) brief inspection of the monthly data acknowledges that the price puzzle is harder to resolve at the monthly frequency. He attributes this effect to measurement errors in the monthly data.

Castelnuovo and Surico (2005) examine the VAR models of the price puzzle price at different time periods and show that, in the quarterly data, the price puzzle existed in the 1966-1979 sample

[2] They also provide evidence that this effect is primarily due to higher prices rather than lower wages.

[3] Hanson (2004) reaches a similar conclusion. Arguably, much of the puzzle in that dataset can be driven by the accommodating monetary policy the Fed was pursuing prior to the 1980s, which is documented by Clarida, Galí, and Gertler (1999).

but was absent in the 1979-2002 sample. Samples that span these two time periods are likely to produce some behavior consistent with the price puzzle. The authors explain the discrepancy in the results from these two subsamples by the difference in the conduct of monetary policy: Insufficiently tight monetary policy[4] may result in indeterminacy, which, as they demonstrate with the simulated data, produces the "price puzzle" impulse responses.

Small-scale structural explanations of the price puzzle frequently rely the cost channel of transmission of monetary policy whereby the nominal interest rate enters a representative firm's marginal cost function. Thus, a monetary contraction raises the firm's marginal cost and, if able to reset the price on its product in the Calvo (1983) pricing setup, the firm will raise it, which leads to behavior consistent with the cost channel. Ravenna and Walsh (2006) find that the cost channel has significant presence in the U.S. quarterly data and Chowdhury, Hoffman, and Schabert (2005) provide further support from the international quarterly data. Both of these studies employ the generalized method of moments to show this significance. Rabanal (2003) uses the Bayesian approach to Kalman-filter the data through a model with sticky prices and nominal wages and finds that the extent of the cost channel's presence is negligible. He advances the idea that the cost channel may be confused with countercyclical mark-up shocks. Barth and Ramey (2000), however, counter that argument by questioning the ad hoc nature of mark-up shocks and stressing that the cost channel produces behavior that is consistent with the theory of countercyclical mark-ups.

This paper will use structural vector autoregression to evaluate the presence of the price puzzle in the U.S. monthly and quarterly data along the lines of Hanson (2004) and Giordani (2004). Then it will show using the GMM methods employed in Ravenna and Walsh (2006) and Chowdhury, Hoffman, and Schabert (2005) to examine whether the estimates of the cost channel of transmission of monetary policy are consistent with the evidence on the price puzzle.

[4]Tightness of monetary policy is measured in the spirit of Clarida, Galí and Gertler (1999): To produce determinacy in the New Keynesian model, the coefficient on expected future inflation should be greater than 1 in the interest rate rule. Clarida, Galí, and Gertler (1999) also show that the this coefficient was less than 1 in the pre-1980 subsample, which is consistent with the results of Castelnuovo and Surico (2005).

3 Documenting the Price Puzzle

This section offers a brief documentation of the price puzzle typically found in the SVAR literature. The model takes the following form:

$$\mathbf{A_0 x_t} = \mathbf{A(L) x_{t-k}} + \epsilon_\mathbf{t}, \tag{1}$$

where $\mathbf{x_t}$ is the $n \times 1$ vector of variables, $\mathbf{A_0}$ is the matrix describing the contemporaneous relationship between the variables (with the lead diagonals of 1's) , L is the lag operator, and $\epsilon_\mathbf{t}$ is the vector of uncorrelated structural errors that are assumed to be white noise. In practice, it is convenient to estimate the reduced-form version of this model:

$$\mathbf{x_t} = \mathbf{A_0^{-1} A(L) x_{t-k}} + \mathbf{A_0^{-1}} \epsilon_\mathbf{t}, \tag{2}$$

and then impose necessary restrictions to recover the structural parameters. Errors from the reduced form model, $\mathbf{e_t}$, are related to the structural shocks by: $\mathbf{A_0 e_t} = \epsilon_\mathbf{t}$, or, defining $\mathbf{\Lambda} = \mathbf{A_0^{-1}}$:

$$\mathbf{e_t} = \mathbf{\Lambda} \epsilon_\mathbf{t}. \tag{3}$$

Imposing restrictions on $\mathbf{\Lambda}$ makes it possible to identify the SVAR system that consists of measures of output gap, inflation, and nominal interest rate.

The variables in the model have the standard lower-triangular ordering, with a measure of the output gap first and the nominal interest rate last. This specification assumes that the nominal interest rate is the most endogenous variable that can contemporaneously respond to output gap and inflation, inflation can contemporaneously respond only to the output gap, and the latter responds to both other variables with a lag. An alternative identification scheme, used by Bernanke and Mihov (1998) and Bagliano and Favero (1998) among others, models the monetary shocks more explicitly but yields very similar quantitative and qualitative results.[5] Two measures of output gap

[5] In their setup, variables are subdivided into two blocks. First, non-policy variables, $\mathbf{Y_t}$, include a measure of

available at the monthly frequency are used: linearly detrended within the subsample log index of industrial production (IP) and the percentage deviation of capacity utilization (CU) from its mean.[6] This comparison is interesting because Giordani (2004) claims that the latter is a better proxy of the output gap and using it instead of the IP resolves the price puzzle. Results presented below contest this claim. Inflation is measure as the annualized difference in log CPI. Finally, the Federal Funds rate is the measure of nominal interest rates. Estimation with the industrial production index is for the 1959:1—2005:5 time period, whereas the capacity utilization data is available only for the 1972:1—2005:5 time period. To make results comparable to Giordani (2004), models with monthly data are estimated with 6 lags, whereas quarterly models are estimated with 2 lags.

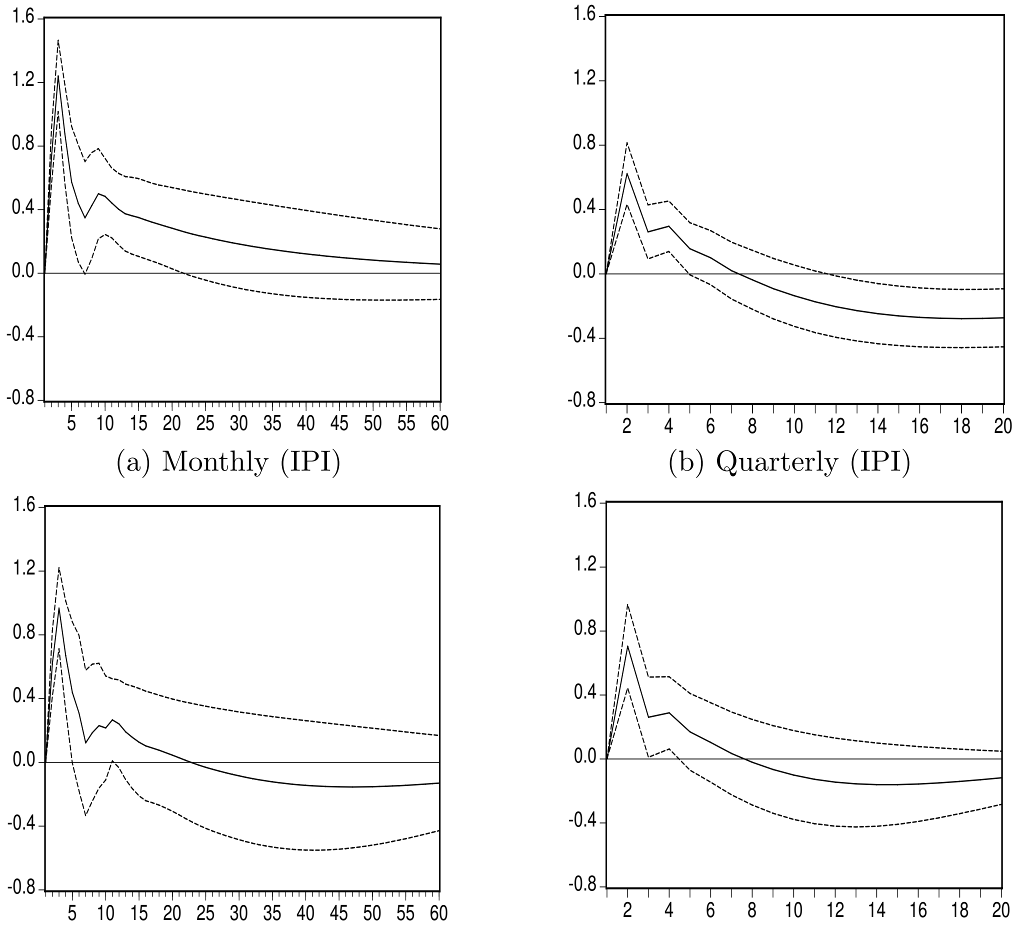
Figure 1 describes the difference in how the price puzzle appears in the monthly and quarterly data. Both measures of the output gap deliver similar predictions about the initial effect of a monetary contraction in the quarterly data: Inflation initially increases by about 0.7% and its impulse response stays positive and significant for about 4-5 quarters. Monthly results indicate a discrepancy between the two models: With detrended industrial production index as the output gap, inflation responds stronger (1.2% vs. 0.9%) and stays significantly positive longer (20 months vs. 6 months) than in the capacity utilization model. Both of these models, however, unequivocally point that the price puzzle exists in the full samples. The question that the next section attempts to answer is whether empirical estimates of the cost channel's presence using a specification of the

output gap and inflation. The second block consists of policy variables, $\mathbf{P_t}$: federal funds rate, total reserves, and non-borrowed reserves. As was mentioned in Section 2, they argue that this setup produces a monetary policy shock that originates in the reserves market rather than as the portion of nominal interest unexplained by macroeconomic variables as in Sims (1992) or Giordani (2004). Recursive structure of the policy block detailed below is consistent with a FFR-targeting regime. Matrix $\mathbf{\Lambda}$ is partitioned with its segments representing the relationships between different blocks of variables:

$$\mathbf{\Lambda} = \begin{bmatrix} \mathbf{\Lambda_{YY}} & \mathbf{\Lambda_{YP}} \\ \mathbf{\Lambda_{PY}} & \mathbf{\Lambda_{PP}} \end{bmatrix}. \quad (4)$$

Traditionally, $\mathbf{\Lambda_{YY}}$ has lower triangular ordering (see Bagliano and Favero (1998)). Hanson (2004) also imposes lower-triangular structure on $\mathbf{\Lambda_{PP}}$, with the federal funds rate placed first. FFR targeting implies that the federal funds rate is placed first, whereas the ordering of the two measures of reserves is unimportant. Policy is assumed to respond to current macroeconomic conditions, hence parameters in $\mathbf{\Lambda_{PY}}$ need to be estimated freely. Conversely, macroeconomic variables are assumed to respond to policy innovations with a lag; therefore $\mathbf{\Lambda_{YP}}$ is constrained to zero. For simplicity and without significant change to results, however, only the results from the three-variable SVAR are considered here.

[6] All data are from the Saint Louis Fed FRED II database (http://research.stlouisfed.org/fred2/).



(a) Monthly (IPI)

(b) Quarterly (IPI)

(c) Monthly (CU)

(d) Quarterly (CU)

Figure 1: Impulse responses of inflation to a 1% FFR shock; Full Sample

New Keynesian Phillips curve can account for these results.

4 Estimates of the Cost Channel's Extent

As was detailed in Section 2, the cost channel of transmission of monetary policy is a theoretical mechanism that gives rise to the price puzzle. If firms need to finance their labor expenditures with credit, the nominal interest rate will enter the marginal cost function, giving rise to an additional term in the New Keynesian Phillips curve. It becomes possible then for a positive response of inflation to a contractionary monetary policy shock. In particular, as in Ravenna and Walsh (2006), given the standard production function:

$$Y_t = Z_t N_T^{\nu}, \tag{5}$$

where Y_t is output, Z_t is the technological factor, N_t is the labor input, and ν is labor's share of output, the firm's marginal cost function becomes:

$$MC_t = \frac{I_t^{\chi} W_t^r}{MPN_t}, \tag{6}$$

where I_t is the gross interest rate paid to secure credit for financing expenses, W_t^r is the real wage rate paid to the labor input, and MPN_t is the marginal product of labor. The parameter $\chi \geq 0$ measures the extent of cost channel's presence and can be interpreted as a combination of the share of firms that are exposed to it and the premium over the federal funds rate they need to pay to obtain credit.

The general form of the Phillips curve that allows for both forward- and backward-looking dynamics can be posited as:

$$\pi_t = \frac{\beta}{1+\beta\gamma} E_t \pi_{t+1} + \frac{\gamma}{1+\beta\gamma} \pi_{t-1} + \frac{\kappa}{1+\gamma\beta} mc_t, \tag{7}$$

where mc_t is the log-deviation of the firm's real marginal cost from their deterministic steady state value. This specification can be formally derived by assuming the standard Calvo pricing mechanism where a share of firms θ cannot reset prices in a given time period. Endogenous persistence in inflation is introduced as in, for instance, Giannoni and Woodford (2003) and Rabanal and Rubio-Ramírez (2005) using the indexation mechanism, so that a fraction γ of firms that are not able to reset their prices, index them using last period's inflation. Sbordone (2002) has shown that the slope of the Phillips Curve is $\kappa = \frac{(1-\theta\beta)(1-\theta)}{\theta}\frac{\nu}{1+(1-\nu)\epsilon}$, where ϵ is the elasticity of substitution between differentiated goods that make up the composite consumption product.

Galí and Gertler (1999), Galí et al (2001, 2005) discuss estimates of this specification of the Phillips curve and find that the forward-looking component is quantitatively more important than the backward-looking one, although the latter typically is statistically significant. Their estimates of θ vary depending on the specification and typically fall within the 0.5-0.85 range. They emphasize that reliable estimates that fit the standard theory can be obtained with a measure of marginal (unit labor) costs but not with a measure of the output, which is what theoretical models routinely use. The coefficient on the output gap term they report is negative, which contradicts the standard theory. One contribution that the present paper makes is producing estimates of the Phillips curve that rely on measures of the output gap with stickiness parameter estimates that can fit the standard theory.

4.1 A Reduced-form Model

Persistence in output is a well-documented empirical phenomenon that has several theoretical explanations, some of which will be discussed below. Introducing this form of a real rigidity implies that the firm's marginal cost function relates not only to a concurrent measure of the output gap but also to its lag and, possibly, current expectation of its future value. Therefore, as a starting point, I estimate the reduced-form version of the Phillips curve as:

$$\pi_t = \hat{a}E_t\pi_{t+s} + \hat{b}\pi_{t-s} + \hat{c}x_t + \hat{d}x_{t-s} + \hat{e}E_t x_{t+s} + \hat{f}i_t. \quad (8)$$

In the quarterly case, s is set equal to 1 and to 3 in the monthly case to make the parameter estimates comparable to the quarterly ones.[7] Following Chowdhury, Hoffman, and Schabert (2005), equation

[7] Quantitatively and qualitatively comparable results can be obtained using $s = 1$ and $s = 2$.

(8) is estimated together with an interest-rate monetary policy rule to control for the interplay between the Phillips curve and the monetary policy rule. I choose the standard specification from Clarida, Galí, and Gertler (1999), viz.:[8]

$$i_t = (1-\rho)(\gamma_\pi E_t \pi_{t+s} + \gamma_x x_t) + \rho i_{t-s}, \tag{9}$$

where the lagged interest rate term adjusts for the observed persistence in the nominal interest rate targeted by the Federal Reserve and, again, $s = 1$ in the quarterly case and $s = 3$ in the monthly case. The system of equations (8) and (9) is estimated using the generalized method of moments with a set of instruments that is standard in the literature: lags of the Federal Funds rate, measure of the output gap, inflation, and the spread between interest rates on long- and short-term Treasury bonds. Four lags are used in quarterly estimation and twelve lags are used in monthly estimation.

There are several differences in the specification of the estimated system between Chowdhury, Hoffman, and Schabert (2005) and this paper. In their specification, these authors follow Clarida, Galí, and Gertler (1999) and use a measure of the unit labor cost instead of the output gap term used here. Additionally, this specification allows for persistence in output gap—and finds it significant—whereas theirs does not and, contrary to their results, the backward-looking inflationary term is found to be insignificant.

Table 1 presents the reduced-form results. The striking outcome of the models that allow for the backward-looking inflation term is that it is insignificant in three cases out of four and appears to be quantitatively unimportant in the one case where it is statistically significant. The coefficients on all three output gap terms are significant at the 1% level in all models, except the coefficient on the lagged output gap term in the monthly IP model, which is significant at the 5% level. The estimates of the "cost channel" coefficient are significant at the 1% level but quantitatively small. Note, however, that $\hat{f}$ captures the interaction between χ and κ, hence when κ is small, χ can be large. Finally, the coefficients in the monetary policy rules indicate that both ρ and γ_π are

[8] In this equation, the following restrictions are motivated by theory (and common sense): $0 < \rho < 1$, γ_π, $\gamma_x > 0$. To produce stability in a system of equations with (**??**), (9), and an aggregate demand equation, γ_π should be greater than 1. See Clarida, Galí and Gertler (1999) for a discussion and estimates of this parameter for the U.S. data.

Table 1: Reduced-form Parameter Estimates (standard errors in parentheses)

	IP Model				CU Model			
	Monthly		Quarterly		Monthly		Quarterly	
Phillips Curve	$\gamma > 0$	$\gamma = 0$	$\gamma > 0$	$\gamma = 0$	$\gamma > 0$	$\gamma = 0$	$\gamma > 0$	$\gamma = 0$
$\hat{a}$	0.7176‡	0.7176‡	0.9216‡	0.8668‡	0.6285‡	0.7044‡	0.7767‡	0.8613‡
	(0.0481)	(0.0400)	(0.0975)	(0.0472)	(0.0376)	(0.0337)	(0.0553)	(0.0364)
$\hat{b}$	0.0007	——	-0.0597	——	0.1002‡	——	0.0929	——
	(0.0308)	——	(0.0953)	——	(0.0247)	——	(0.0632)	——
$\hat{c}$	0.7723‡	0.7668‡	1.4853‡	1.4217‡	0.8663‡	0.8828‡	1.1487‡	1.4334‡
	(0.1657)	(0.1626)	(0.4585)	(0.4366)	(0.1137)	(0.1184)	(0.2390)	(0.2544)
$\hat{d}$	-0.1611†	-0.1554†	-0.5754‡	-0.5663‡	-0.2733‡	-0.2365‡	-0.6304‡	-0.6058‡
	(0.0677)	(0.0652)	(0.1975)	(0.1932)	(0.0535)	(0.0525)	(0.1116)	(0.1127)
$\hat{e}$	-0.6080‡	-0.6084‡	-0.9327‡	-0.8748‡	-0.6043‡	-0.6620‡	-0.8461‡	-0.8823‡
	(0.0647)	(0.1150)	(0.2864)	(0.2638)	(0.0871)	(0.0901)	(0.1472)	(0.1625)
$\hat{f}$	0.1758‡	0.1765‡	0.0914‡	0.0878‡	0.1760‡	0.1901‡	0.0894‡	0.0955‡
	(0.0277)	(0.0272)	(0.0345)	(0.0328)	(0.0236)	(0.0248)	(0.0291)	(0.0280)
Interest Rate Rule								
γ_π	1.4416‡	1.4416‡	1.5125‡	1.5092‡	1.3965‡	1.3872‡	1.3943‡	1.3987‡
	(0.0562)	(0.0564)	(0.1216)	(0.1187)	(0.0535)	(0.0524)	(0.1018)	(0.1008)
γ_x	0.0345	0.0345	0.1367*	0.1312	0.4967‡	0.4944‡	0.5287‡	0.5248‡
	(0.0332)	(0.0333)	(0.0825)	(0.0798)	(0.0704)	(0.0702)	(0.1259)	(0.1239)
ρ	0.8452‡	0.8458‡	0.9081‡	0.9065‡	0.8758‡	0.8751‡	0.9041‡	0.9040‡
	(0.0118)	(0.0117)	(0.0148)	(0.0143)	(0.0083)	(0.0082)	(0.0118)	(0.0118)

‡—significant at the 1% level
†—significant at the 5% level
*—significant at the 10% level

significant at the 1% level and the former is significantly different from 1. An interesting result that emerges from Table 1 is that IP models indicate that the Fed does not respond to the output gap in significant fashion, whereas the CU models suggest that it does, raising the nominal interest rate by about 0.5% in response to a percentage increase in output gap.

4.2 Structural Explanation of the Reduced-form Estimates

The reduced-form estimates of (8) suggest that a structural model that would explain inflationary dynamics would need to incorporate forward- and backward-looking persistence in output gap but only forward- and not backward-looking persistence in inflation. This eliminates the motivation for the popular indexation-to-past-inflation device and also questions the applicability of some mechanisms that imply backward persistence in output gap but also in inflation, such as the real wage rigidity due to Blanchard and Galí (2005).

A popular explanation for the relationship between a firm's marginal cost and the backward- and forward-looking persistence in output is the assumption of internal habit formation in either consumption or labor supply. For instance, Amato and Laubach (2004) show that internal habit formation allows to relate marginal cost to output gap through the definition of the real wage that emerges from the household's first order condition with respect to labor supply in the following fashion:

$$mc_t = \left(\frac{\eta_2}{1-\beta h} + \phi\right) x_t + \frac{\eta_1}{1-\beta h}\left(x_{t-s} + \beta E_t x_{t+s}\right) + \chi i_t, \tag{10}$$

where $\eta_1 = h(1-\sigma)$ and $\eta_2 = \sigma - \beta h(1+h(1-\sigma))$ are parameters that describe the contributions of backward- and forward-looking persistence in output gap relative to its current measure.[9] Regardless of whether internal habit formation is introduced in consumption or labor supply, it predicts that, in terms of the reduced-form estimates of (8), $\hat{e} = \beta\hat{d}$, which, since $0 < \beta < 1$, implies that $|\hat{e}| < |\hat{d}|$. But the estimates in Table 1 suggest that this is not the case in either of the models. Hence the standard model of internal habit formation needs to be adjusted for this difference.

Assuming that the backward- and forward-looking persistence in output gap comes from the relationship between the real wage and the consumption-leisure tradeoff, preferences for a household i can be modified in the following way:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{1}{1-\sigma}\left(\frac{C_t^i}{(C_{t-1}^i)^{h_c}}\right)^{1-\sigma} - \frac{1}{1+\phi}\left(\frac{N_t^i}{S_t^i}\right)^{1+\phi}\right], \tag{11}$$

where $S_t^i = (N_t/N_{t-1}^{h_n})^{\delta}$ is a negative externality proportional to the quasi-growth in aggregate labor supply.[10] $-1 \leq h_c \leq 1$ is the parameter that measures the extent of internal habit formation

[9]Households maximize the following utility function:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{1}{1-\sigma}\left(\frac{C_t}{C_{t-1}^h}\right)^{1-\sigma} - \frac{1}{1+\phi} N_t^{1+\phi}\right],$$

where h is the parameter that governs the extent of habit formation. For $h = 0$, therefore, there is no habit formation and the lead and lagged output gap terms disappear from the Phillips curve.

[10]This externality can be viewed as the skills that the household accumulates while learning-by-doing from quasi-growth in aggregate labor supply. In this case, the household can be viewed as optimizing over the disutility from

in consumption. Positive values of this parameter suggest that the household experiences utility from quasi-growth in consumption; negative that consumption is a durable good and that some of the utility from consumption is carried over into the next period. $\delta \geq 0$ describes the extent of the quasi-growth in aggregate labor supply on the individual decision to supply labor; $0 \leq h_n \leq 1$ characterizes this quasi-growth. Note that for households to experience disutility from labor supply in the steady state, it must be the case that

$$\delta(1 - h_n) < 1; \tag{12}$$

hence these parameters are set in such a way that this inequality holds.

Only two parameters need to be calibrated for the estimation of the Phillips curve: ϕ, the inverse elasticity of labor supply, is set to 1; ν, labor's share of output, is set to 0.7. To obtain θ, ϵ, the elasticity of substitution between different goods that are aggregated into the consumption index, is set to 11, which implies a 10% steady-state markup. A full derivation of the model will be available in the Appendix.

The log-deviation of the firm's marginal cost can be expressed in terms of the output gap and the nominal interest rate, which leads to the following specification of the Phillips curve:

$$\pi_t = \beta E_t \pi_{t+1} + \kappa \left\{ \left[\frac{(1+\phi)(1-\delta)}{\nu} + \frac{\xi(1+\beta h_c^2)}{h_c} \right] x_t - \left[\xi - \frac{\delta h_n (1+\phi)}{\nu} \right] x_{t-1} - \beta \xi E_t x_{t+1} + \chi i_t \right\}, \tag{13}$$

where $\xi = \frac{h_c(\sigma-1)}{1-\beta h_c}$. The presence of preference parameters in the Phillips curve motivates adding an expression for the aggregate demand, which in the model takes the form:

$$\left[1 - \xi^{-1} + \frac{1+\beta h_c^2}{h_c} \right] x_t = x_{t-1} - \beta x_{t+2} + \left[\beta + \frac{1+\beta h_c^2}{h_c} - \xi^{-1} \right] E_t x_{t+1} - \xi^{-1}(i_t - E_t \pi_{t+1}). \tag{14}$$

Several empirical issues arise in joint estimation of versions of (13), (14), and (9). First, $|\frac{1+\beta h_c^2}{h_c}|$ should be greater than or equal to $1+\beta$ but estimating this parameter separately produces estimates

hours supplied to the labor market: $H_t^i = N_t^i / S_t^i$, where N_t^i is effective labor and S_t^i is the stock of skills that the household possesses.

that are below this value. Hence h_c is set to 1, which is the value used by Giannoni and Woodford (2003) and is close to the estimates of Dennis (2005) that lie in the 0.85-0.90 range. Second, absolute values of unconstrained estimates of δ and h_n are large, violating condition (12), but the likelihood function with respect to them seems to have a flat slope. Hence their values are imposed to ensure that the remaining parameter values have plausible estimates; δ is set to 2.9 and h_n is set to 0.7.

The following system is estimated jointly using the GMM with the same instruments as in the previous subsection:

$$0 = \left[\widehat{\xi^{-1}} - 2 - \widehat{\beta}\right] x_t + x_{t-s} - \widehat{\beta} x_{t+2s} + \left[1 + 2\widehat{\beta} - \widehat{\xi^{-1}}\right] E_t x_{t+s} - \widehat{\xi^{-1}}(i_t - E_t \pi_{t+s}) \tag{15}$$

$$\pi_t = E_t \pi_{t+s} + \widehat{\kappa\xi} \left\{ \left[\frac{1+\phi}{\nu}(1-\delta)\widehat{\xi_{-1}} + 1 + \widehat{\beta}\right] x_t - \left[1 - \delta h_n \frac{1+\phi}{\nu}\widehat{\xi^{-1}}\right] x_{t-s} - \beta E_t x_{t+s} + \widehat{\chi\xi^{-1}} i_t \right\} \tag{16}$$

$$i_t = (1-\widehat{\rho})(\widehat{\gamma_\pi} E_t \pi_{t+s} + \widehat{\gamma_x} x_t) + \widehat{\rho} i_{t-s}. \tag{17}$$

'Hats' are placed over parameters to be estimated; 'unhatted' parameters are imposed. Products of parameters with 'widehats' over them are estimated as one coefficient and then disentangled given other estimates.

Table 2 reports the results of baseline estimation. Although the reduced-form coefficient on the nominal interest rate ($\hat{f}$ in Table 1) appears larger in the monthly models, the value of χ that gauges the extent of the cost channel is higher in the quarterly data. This happens because the sensitivity of demand to the real interest rate ξ^{-1} is much higher in the monthly series than in the quarterly. This reinforces a puzzling result: In 3 out of 4 models in Table 1 $\hat{c}$ is lower in quarterly than in monthly models; similarly, $\kappa\xi$ in Table 2 is lower in all 4 quarterly models. This implies that *ceteris paribus* the estimates θ, the degree of price stickiness, are going to be lower in the monthly data than in the quarterly. Combined with a higher implied χ this implies that a monetary contraction will produce an larger positive response in inflation in the quarterly rather than monthly data.

Table 2: Structural Parameter Estimates (s.e.)

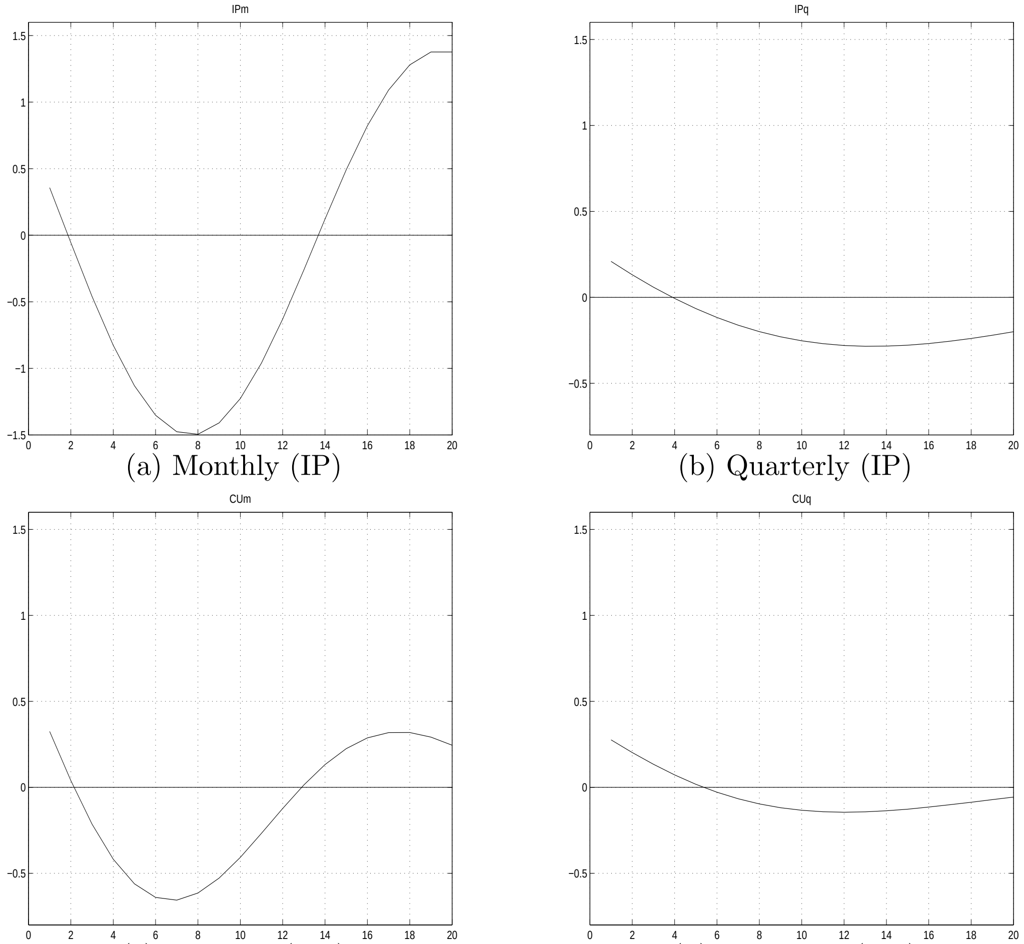
	IP Model		CU Model	
Estimated Parameters	Monthly	Quarterly	Monthly	Quarterly
ξ^{-1}	0.1141‡	0.0364†	0.1158‡	0.0399†
	(0.0071)	(0.0105)	(0.0056)	(0.0099)
β	0.6666‡	0.8022‡	0.6474‡	0.7763‡
	(0.0253)	(0.0292)	(0.0177)	(0.0234)
$\kappa\xi$	0.6039‡	0.5952‡	0.6709‡	0.6298‡
	(0.0820)	(0.1749)	(0.0671)	(0.1102)
$\chi\xi^{-1}$	0.3599‡	0.2290‡	0.3508‡	0.2503‡
	(0.0576)	(0.0962)	(0.0408)	(0.0623)
ρ	0.8457‡	0.9051‡	0.8747‡	0.9019‡
	(0.0079)	(0.0124)	(0.0056)	(0.0094)
γ_π	1.4166‡	1.3874‡	1.4091‡	1.4105‡
	(0.0432)	(0.0749)	(0.0349)	(0.0559)
γ_x	0.0481*	0.1411†	0.4686‡	0.4881‡
	(0.0245)	(0.0701)	(0.0461)	(0.0858)
Implied Parameters				
σ	3.9220	6.4341	4.0450	6.6065
κ	0.0689	0.0217	0.0777	0.0251
θ	0.5892	0.7497	0.5695	0.7354
χ	3.1542	6.2912	3.0294	6.2731

‡—significant at the 1% level
†—significant at the 5% level
*—significant at the 10% level

4.3 Can the Cost Channel Resolve the Price Puzzle?

Parameters described in Table 2 indicate that the cost channel does have a sizeable presence in the U.S. data. But is it enough to explain the price puzzle illustrated on Figure 1? Using the estimated parameters to construct a DSGE model allows to obtain theoretical impulse responses to a contractionary monetary policy shock, given the model's structural equation. Figure 2 presents these impulse responses obtained using an implementation of the Anderson and Moore (1985) AIM algorithm.

The monthly models (implemented at the quarterly frequency) do replicate the price puzzle in



(a) Monthly (IP) (b) Quarterly (IP)

(c) Monthly (CU) (d) Quarterly (CU)

Figure 2: Theoretical impulse responses of inflation to a 1% FFR shock

the sense that the initial impulse response to a contractionary monetary shock is positive but fail to generate a realistic evolution of the response thereafter, as the amplitude of oscillation increases for a considerable amount of time before it dies down.[11] The quarterly models, on the other hand, produce impulse responses that are remarkably similar to the empirical ones (see Figure 1) in shape, although the initial response is not as pronounced: Empirical responses rise to about 0.7%, whereas the theoretical ones only reach about 0.3%. The shape and duration of these responses, however,

[11]The IP monthly model presented here is the only one whose vertical axis needs to be adjusted relative to the SVAR response scale.

match their SVAR counterparts quite well.

5 Conclusion

This paper has reviewed evidence from the monthly and quarterly U.S. data on inflationary dynamics, the price puzzle and the cost channel of transmission of monetary policy. It has demonstrated that measures of output gap can be used to obtain reliable estimates of the New Keynesian Phillips curve using both quarterly and monthly data. Evidence that relies on two different measures of output gap points that the price puzzle exists in the U.S. data at both frequencies. A structural model developed here indicates that the presence of the cost channel is considerable at both monthly and quarterly frequencies, although it is only in the latter case that this model produces dynamics that are comparable to the empirical impulse responses.

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Appendix: Derivation of the Theoretical Model

This section will be available for the Workshop in Macroeconomic Research at Liberal Arts Colleges.