Forward-looking Monetary Policy and Anticipated Shocks to Inflation

Pavel Kapinos†

Carleton College

Current version: August 25, 2010
First version: November 1, 2009

Abstract

This paper extends a standard New Keynesian model to describe the effects of anticipated shocks to inflation and forward-looking monetary policy. Using the data generated from this modified model confirms the conjecture of Sims (1992) that overlooking these two factors in the standard Cholesky structural vector autoregressive identification scheme will generate a price puzzle. Furthermore, this paper demonstrates that significant estimates of the cost channel of transmission of monetary policy—a popular explanation of the price puzzle—may result from failing to account for these two factors in estimation.

JEL Categories: E31; E32; E52.

Keywords: New Keynesian model; Price puzzle; Cost channel; Monetary policy; Anticipated shocks; Forecast-based rules.

†Department of Economics, Willis Hall 320, Northfield, MN 55057. Phone: (507) 222-7676. FAX: (507) 222-4044. E-mail: pkapinos@carleton.edu
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 appeared to be highly counterintuitive, as the standard models predicted that an increase in interest rates would reduce aggregate demand and hence the price level. Academic interest in the effect of shocks to the interest rate on the price level became prominent starting with the seminal paper by Sims (1992). In a comment on that work, Eichenbaum (1992) termed a positive response of prices to a contractionary monetary policy shock the ‘price puzzle’, a phenomenon that has been widely studied in the literature since.

The price puzzle is typically addressed in two ways: Finding empirical model specifications that resolve it and imply that the puzzle doesn’t exist, or finding theoretical modeling devices that provide substantiation for the puzzle. On the former front, much of the literature has evolved from Sims’ (1992) pioneering work, which found that introducing an index of commodity prices into the empirical system helped reduce the extent of the price puzzle, leading 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.

On the second front, several theoretical devices have been studied that give rise to the price puzzle. Ravenna and Walsh (2006), among others, investigate the role of the cost channel of transmission of monetary policy, whereby interest rates enter a representative firm’s marginal cost function and therefore become a part of the forcing process for inflationary dynamics. In this setup, a contractionary monetary policy shock raises interest rates and hence the firm’s marginal cost. In the short term, this increase in cost translates into an increase in prices, which later decline due to the decrease in aggregate demand that results from higher interest rates. Hence models that incorporate the cost channel may be able to explain the price puzzle. In a related paper, Berkelmans (2008) develops a model with imperfect information that generates the price puzzle because the agents cannot immediately distinguish between supply and monetary shocks.
Introducing indeterminacy into the model economy is another way of generating the price puzzle. Castelnuovo and Surico (2009) examine the SVAR (structural vector autoregressive) 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 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 may result in indeterminacy, which, as they demonstrate with simulated data, produces impulse responses consistent with the price puzzle.¹ Auray and Feve (2008) show that the price puzzle can arise due to indeterminacy in a model without sticky prices where the conduct of monetary policy is given by a money supply rule.

The present paper contributes to this strand of the literature by considering a data generating process (DGP) that has the following properties: (a) It generates a ‘price puzzle’ in a simple SVAR framework, even though it is not a feature of the theoretical DGP; (b) this process features a forward-looking monetary policy rules and anticipated shocks to inflation thus placing the Sims’ (1992) hypothesis into the dynamic stochastic general equilibrium (DSGE) context; (c) it shows that under some conditions where the ‘price puzzle’ appears in the SVAR framework, the estimates of the monetary policy-maker’s aggressiveness towards inflation will be much lower than in the true DGP, potentially leading to indeterminacy; and (d) it demonstrates that even though the DGP does not feature the cost channel of transmission of monetary policy, positive estimates of its extent can be obtained in a model that ignores the forward-looking aspect of monetary policy and anticipated shocks to inflation.

More specifically, this paper relies on two modeling devices whose role has not been formally studied in the DSGE explanations of the price puzzle. First, it assumes that the cost-push shock can be split into two components: anticipated and unanticipated. Wohltmann and Winkler (2009a, 2009b) study the impact of anticipated cost-push shocks on the conduct of optimal monetary policy and show that, in a model with sufficiently sticky prices, they generate larger social welfare losses than unanticipated shocks of the same size. More broadly, the idea that an exogenous shock may

¹Tightness 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 this coefficient was less than 1 in the pre-1980 subsample, which is consistent with the results of Castelnuovo and Surico (2009).
have anticipated and unanticipated components derives from the large recent literature on the so-called technological news shocks. See Beaudry and Portier (2006), Jaimovich and Rebelo (2006), Francis, Owayang, and Roush (2007), and Barksy and Sims (2009) for a discussion of alternative approaches to model and identify technological news shocks in the data. Fujiwara, Hirose, and Shintani (2008) and Schmitt-Grohe and Uribe (2008) provide empirical estimates of the importance of technological news shocks in a New Keynesian model and of several anticipated shocks in a real business cycle model, respectively.

The second modeling device investigated in this paper comes from the literature on the inflation-forecast-based monetary policy rules. Levine et al (2007) propose a class of inflation-forecast-based rules with desirable stabilizing properties and call them the Calvo-type interest rate rules. They also show that these rules have superior stabilizing properties over earlier forecast-based rules, where the central bank responds to expected inflation at a given forecast horizon.\(^2\) Gabriel et al (2009) demonstrate that such a rule describes the behavior of the US Federal Reserve quite well.

The rest of the paper is organized as follows. Section 2 makes two amendments to the standard New Keynesian model used as the workhorse for the analysis of monetary policy conduct. First, the standard Taylor rule is replaced with its forward-looking version that nests the former as a special case. The second modification allows a fraction of inflationary shocks to be anticipated. Section 3 uses the data generated by the modified model to obtain two results. It first presents estimates of the standard SVAR model of a measure of real activity, inflation, and interest rate using the Cholesky identification scheme. The price puzzle emerges when the central bank is sufficiently forward-looking and a large fraction of cost-push shocks can be anticipated, a result that echoes the Sims (1992) conjecture. Section 4 uses the same simulated data to estimate the standard model that assumes no forward-looking behavior on the part of the central bank and that none of the cost-push shocks are anticipated; however, it does allow for the cost channel to be present. The results suggest that as the degree of forward-looking behavior and the share of anticipated inflationary shocks increase in the true data generating process, so will the estimates of the extent of the cost channel of transmission of monetary policy. Finally, Section 5 concludes.

2 A Model of the Data Generating Process

Harking back to the conjecture of Sims (1992), this section develops a data generating process in the context of a standard dynamic stochastic general equilibrium (DSGE) model featuring an exogenously evolving process that carries information about future inflationary disturbances and a forward-looking rule for monetary policy conduct. The price puzzle is shown to arise when a forward-looking central bank's anticipation of impending inflationary pressure and its response to it are left out of the empirical framework. This paper demonstrates that, as the anticipated share of cost-push shocks and the extent of the central bank's forward-looking behavior increase, the comovement between the nominal interest rate and inflation increases as well. If a model that ignores these two factors is estimated, as is typically done in existing literature, this comovement will be picked up by positive estimates of the cost channel. This paper, therefore, provides an explicit potential source of the misspecification that generates the price puzzle in the SVAR literature and significant estimates of cost channel’s extent in structural estimation.

This section presents a version of the standard New Keynesian model with three sectors. First, households derive utility from individual consumption relative to last period’s aggregate level and disutility from labor supply. Second, firms produce intermediate goods in a monopolistically competitive product market that is then aggregated into the final consumption good using the Dixit-Stiglitz specification. Finally, the central bank sets the nominal interest rate in response to inflation and a measure of real activity.

Household behavior gives rise to the aggregate demand relation that describes the evolution of a measure of real activity:

\[(1 + h)x_t = hx_{t-1} + E_t x_{t+1} - \frac{1-h}{\sigma}(i_t - E_t \pi_{t+1}) + \varepsilon_t^x, \tag{1}\]

where \(h\) is the degree of habit persistence that characterizes households’ utility function with respect to consumption, \(\sigma\)—the coefficient of relative risk aversion, \(x_t\)—a measure of output gap, \(i_t\)—nominal interest rate, and \(\pi_t\)—inflation.

Firms use are assumed to use the simple constant-returns-to-labor production function and set

---

3 This so-called 'external habit formation' mechanism is necessary to match the persistence in output gap observed in the data. See Dennis (2009) for the alternative ways of modeling habit formation and estimates of structural parameters characterizing these different approaches.
the optimal price for their output gives rise to the Phillips curve that accounts for the evolution of inflation:
\[(1 + \beta \omega)\pi_t = \omega \pi_{t-1} + \beta E_t \pi_{t+1} + \kappa mc_t^j + \varepsilon_t^\pi,\]

where \(\beta\) is the discount factor, \(\omega\) is the degree of price indexation to last period’s inflation adopted by firms that cannot reset their price optimally, \(\kappa = \frac{(1-\alpha\beta)(1-\alpha)}{\alpha}\) is the slope of the Phillips curve, \(\alpha\) is the Calvo probability that a given firm may not be able to reset its price optimally within the given time period, and \(j = \{0, \chi\}\) designates whether the cost channel is present \((j = \chi > 0)\) or not \((j = 0)\). Using the production function and the firms’ and households’ first-order conditions, one can show that, in the absence of the cost channel, marginal costs can be related to output gap by:
\[mc_t^0 = \eta x_t + \frac{\sigma}{1-h}(x_t - hx_{t-1}),\]
where \(\eta\) is the elasticity of labor supply. Unlike the standard definition of an unexpected exogenous cost-push shock, however, this paper assumes that it follow a process given by:
\[\varepsilon_t^\pi = \delta u_{t-\tau}^n + (1-\delta)u_t,\]
where both the concurrent inflationary shock, \(u_t\), and inflationary ‘news’ shock, \(u_t^n\), follow white noise processes and \(\tau\) is the number of periods ahead that the information about the future shock is revealed. This framework does not take a stance on which variables carry informational content regarding sources of impending inflationary pressure and simply models them as an exogenous process.

Following the work of Clarida et al. (1999, 2000), the central bank sets the nominal interest rate as a weighted average of the target nominal interest rate and a lagged interest rate term that accounts for the observed persistence in interest rates:
\[i_t = (1-\rho)i_t^* + \rho i_{t-1} + \epsilon_t^i.\]
Ordinarily, the nominal interest rate target, \(i_t^*\), is set in response to the current inflation and output gap. This is at odds with the central banks’ claim and theoretical desirability for using
forward-looking and preemptive monetary policy action. Levine et al (2007) propose a class of inflation-forecast-based rules that reduces the indeterminacy resulting from earlier forecast-based rules in New Keynesian models and call them 'the Calvo-type interest rate rules'. The mechanism for the rule is similar to the one used to derive the Phillips curve (2). The central bank sets the target interest rate according to:

\[ i_t^* = \gamma_\pi \Theta_t + \gamma_x x_t, \tag{6} \]

where

\[ \Theta_t = (1 - \phi)E_t \sum_{i=0}^{\infty} (\phi^i \pi_{t+i}) \tag{7} \]

is the discounted sum of future expected inflation rates. This specification implies that the mean forecast horizon for inflation is \( \frac{1}{1-\phi} \) periods.\(^4\) Gabriel et al (2009) find that, for instance, the Federal Reserve sets the nominal interest rate in a forward-looking fashion and show that combining (6) with (5) yields the following expression for the actual nominal interest rate:

\[ i_t = \frac{\rho}{1 + \rho \phi} i_{t-1} + \frac{\phi}{1 + \rho \phi} E_t i_{t+1} + \frac{\gamma_\pi (1 - \phi)}{1 + \rho \phi} \pi_t + \frac{\gamma_x}{1 + \rho \phi} (x_t - \phi E_t x_{t+1}) + \epsilon_t. \tag{8} \]

The model presented here nests a version of the standard New Keynesian model that has been thoroughly examined in the literature. For \( \phi = 0 \), the central bank does not respond to inflation forecasts and sets the target nominal interest rate in response to current inflation and output gap. For \( \delta = 0 \), the cost-push shock does not have an anticipated component. Relaxing these restrictions has profound implications for the dynamics of the model’s endogenous variables and their role in the price puzzle and the cost channel of transmission of monetary policy.

### 2.1 Model Parameterization

The model’s parameter values are fairly standard; Table 1 summarizes their values obtained from empirical studies of the US data at the quarterly frequency. The degree of habit persistence, \( h \), is set to equal 0.85. Fuhrer (2000) obtains estimates between 0.8 and 0.9, whereas Bouakez et al (2005) estimate it at 0.98. Dennis (2009) surveys the literature on this parameter’s estimates.

\(^4\) As Gabriel et al (2009) demonstrate, a similar modification can be performed to include a forecast-based output gap target. Since this paper focuses on inflationary dynamics, the central bank is assumed to respond only to the forecasts of future inflation.
and provides robustness checks for alternative forms of habit formation, with the lowest estimate at about 0.7; 0.85, therefore, in the middle of the range of existing estimates. The value of the coefficient of relative risk aversion, $\sigma$, is set to to 1.1 following Amato and Laubach (2004), which implies nearly logarithmic preferences with respect to quasi-growth in consumption. The Frisch elasticity of labor supply, $\eta$, is set to 0.8 following Dennis (2005). The discount factor $\beta$ equals 0.99 to reflect the long-run real interest rate of about 4% per annum. The Calvo probability that a firm will keep its output price unchanged in a given time period, $\alpha$, is set to the standard 0.75, implying that prices reset, on average, every four quarters. Dennis (2007) provides a comprehensive survey of estimated values of this parameter, placing the present choice well within the range of available estimates. The price indexation parameter $\omega$ is set to 0.7 to obtain a slightly larger weight on the expected future inflation rather than lagged inflation term in the Phillips curve; Cho and Moreno (2006) provide FIML estimates that demonstrate the robustness of this result in the US data. The variances of supply and demand shocks, $\sigma^x$ and $\sigma^x$, are also close to the ones obtained by Cho and Moreno (2006). The supply shock can have anticipated and unanticipated components, with $\delta$ being the share of the former. The value of this parameter is imposed across different simulations.

Insert Table 1 about here

The remainder of the parameters characterizes the conduct of monetary policy. The central bank is assumed to comply with the Taylor principle; its response to inflationary target is set at $\gamma_\pi = 2 > 1$. The response to output gap is set at $\gamma_x = 1$ and the interest-smoothing parameter, $\rho$, to 0.75. These parameters are close to the ones obtained by Clarida et al (2000) for the Volcker-Greenspan era. Cho and Moreno (2006) and Rabanal and Rubio-Ramirez (2005) report similar estimates for $\rho$ and lower estimates for $\gamma_\pi$ and $\gamma_x$. The value of the former is particularly important because its low values may generate indeterminacy in the model, which, as Castelnuovo and Surico (2009) find, can lead to the appearance of a price puzzle in the SVAR context. This paper provides an alternative explanation: particularly low estimates of $\gamma_\pi$ may obtain if the true data generating process features forward-looking monetary policy and a large anticipated share of cost-push shocks, whereas the estimated models fails to capture them. The degree of forward-looking behavior, $\phi$, that is directly proportionate to the inflation-forecast horizon varies across simulations. Finally,

---

<sup>5</sup>Amato and Laubach (2004) use $\eta = 0.6$, whereas Christiano et al (2005) set $\eta = 1$.  

---
the standard deviation of the monetary shock, \( \sigma^i \), is set to 0.25 percent, which is slightly above the estimates of Rabanal and Rubio-Ramirez (2005) and well below the estimates of Cho and Moreno (2006). Simulation results presented below show that if a standard Taylor rule were estimated using the data generated by a model with an inflation-forecast-based rule, the obtained estimate of the standard deviation of the monetary shock would be considerably larger.

2.2 Effects of Anticipated Cost-push Shocks and Forward-looking Monetary Policy

Before proceeding with the investigation of what these two new elements imply for the price puzzle and the cost channel of transmission of monetary policy, it is useful to develop some intuition about the changes that they bring to the standard New Keynesian model. This subsection explores the responses of the key variables—inflation and nominal interest rate—to anticipated inflationary shocks under alternative assumptions about their share in the cost-push shock, the forward-looking extent of monetary policy, and the lag with which these shocks may hit the economy.

Insert Figure 1 about here

Figure 1 documents impulse responses of inflation and the nominal interest rate to an unanticipated cost-push shock of size \( \sigma^\pi \). Since the shock is unanticipated, impulse responses do not change much as the degree of central bank’s forward-looking behavior, \( \phi \), increases. Their magnitudes decline proportionately as the unanticipated share of the cost-push shock, \((1 - \delta)\), decreases, since that reduces the size of the shock’s impact on inflation. Importantly, the hump-shaped response of the nominal interest rate, motivated by the own lagged term in the monetary policy rule, suggests that the peak response of inflation to the cost-push shock occurs after its largest impact on inflation at \( t = 0 \).

Insert Figure 2 about here

This result is in contrast to the case when some of the cost-push shock can be anticipated \( \tau > 0 \) periods ahead. Figure 2 considers the case when the anticipated shock occurs three periods ahead, \( \tau = 3 \). The possibility of acting preemptively, through the use of an inflation-forecast-based rule, allows the Fed to start raising the nominal interest rate sooner, moving the peak of the nominal
interest rate response closer to the peak of inflationary response to the shock. This generates closer comovement between inflation and the interest rate. The farther in advance that the shock can be anticipated, the stronger is this effect, and the peak responses of inflation and the nominal interest rate coincide more closely. Therefore, insofar as a large fraction of the cost-push shock can be anticipated and the central bank takes action to respond to it preemptively, the correlation between inflation and the nominal interest rate will be stronger than what a model that does not consider these factors can capture. Section 4 argues that the cost channel of transmission of monetary policy—an element that is meant to address the larger comovement of inflation and nominal interest than can be generated in the standard New Keynesian DSGE model—may be a direct result of the failure to account for these two factors.

2.3 Generating Simulated Data

The model of the data generating process is described by (1), (2), (3), (4), and (8). Since the main focus of the present exercise is to determine the impact of forward-looking central bank behavior in response to anticipated cost-push shocks, alternative values of $\phi$ and $\delta$ in the range between 0 and 0.75 are employed. The case where $\phi = \delta = 0$ results in the standard case of the non-forward-looking Taylor rule and entirely unanticipated cost-push shocks. For each combination of $\delta$ and $\phi$, the same 10,000 realizations of the stochastic shocks were used to construct the simulated series of output gap, inflation, and nominal interest rate of length 200, after dropping the initial 100 observations.\footnote{All simulation and estimation procedures were performed using Dynare 4 (http://www.dynare.org/); see Juillard (1996).} Hence all differences in the evolution of the time series can be attributed to the differences in the values of $\phi$ and $\delta$, as opposed to the stochastic shock realizations. As described below, these simulated data are then used to study the emergence of the price puzzle in the SVAR context and the possibility of the cost channel capturing the comovement of nominal interest rate and inflation in addition to what the standard Taylor rule estimates may reflect.

3 The Price Puzzle in a Cholesky SVAR

The emergence of the price puzzle and ways of modifying the empirical model to generate impulse responses consistent with the standard theory have been extensively documented in the literature.
Employing the Bernanke and Mihov (1998) empirical model of monetary policy, Hanson (2004) surveyed a wide gamut of potential ‘information variables’ in the monthly US data. Although some of these variables help alleviate the extent of the price puzzle, especially in the more recent sample, most specifications suggest that the ‘price puzzle’ remains a tangible empirical phenomenon. Importantly, Hanson (2004) found no link between the inflation-forecasting effectiveness of an ‘information variable’ and its ability to reduce 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 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 output gap, which he proxies with the capacity utilization rate, in a three-variable VAR (output gap, inflation, and the federal funds rate), the price puzzle disappears in the quarterly data.\(^7\) However, Giordani’s (2004) brief inspection of the monthly data acknowledges that the ‘price puzzle’ is harder to resolve at the monthly frequency and attributes this effect to measurement errors in that data.

This section investigates whether the data generated in the model with anticipated cost-push shocks and forward-looking monetary policy can generate the price puzzle in the standard structural vector autoregressive setting. The empirical model takes the following form:

\[
A_0 y_t = A(L)y_{t-1} + \epsilon_t, \quad (9)
\]

where \(y_t = [x_t, \pi_t, i_t]^{\prime}\) is the \(3 \times 1\) vector of variables, \(A_0\) is the matrix describing the contemporaneous relationship between the variables (with the lead diagonals of 1’s), \(L\) is the lag operator, and \(\epsilon_t\) 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:

\[
y_t = A_0^{-1} A(L)y_{t-1} + A_0^{-1}\epsilon_t. \quad (10)
\]

\(^7\)Unlike the standard theoretical models, Giordani (2004) uses a year-over-year, and not period-by-period measure of inflation, hence his results may not immediately comparable to much of the rest of the literature. In fact, using the period-by-period measure inflation in the Cholesky SVAR still generates the price puzzle, even if capacity utilization is used for the measure of real activity.
Errors from the reduced form model, \( e_t \), are related to the structural shocks by: 
\[
A_0 e_t = \epsilon_t, \quad \text{or,}
\]
defining \( \Lambda = A_0^{-1} \):
\[
e_t = \Lambda \epsilon_t. \quad (11)
\]

Imposing restrictions on \( \Lambda \) makes it possible to identify the structural shocks to output gap, inflation, and the nominal interest rate. The latter becomes a proxy for the structural monetary shock, \( \epsilon_i^t \), in (8).

These three variables in the SVAR 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. Clearly, this identification scheme is not a perfect match with the data generating model where all exogenous shocks have an instant impact on all endogenous variables. The purpose of this exercise is merely to ascertain how far the estimated impulse responses may depart from the true theoretical ones.

**Insert Figure 3 about here**

Figure 3 considers the theoretical and estimated impulse responses of inflation to a positive (contractionary) monetary shock for the DGP with \( \tau = 2 \). Estimated responses are obtained by estimating the above SVAR model with lag order set to 4 using the simulated time series of endogenous variables. The figure shows that, for low values of \( \phi \) and \( \delta \) the SVAR model does a reasonable job of capturing the theoretical impulse responses, aside from the zero restriction on the response at the zero horizon. However, as both the degree of central bank’s behavior and the anticipated share in the cost-push shock increase, the price puzzle begins to emerge. As Figure 4 highlights, the results are even more striking when the cost-push shocks can be anticipated farther ahead (\( \tau = 3 \)). The magnitudes of obtained positive impulse responses of inflation to the contractionary monetary shock are comparable to those found in the empirical literature. Similar dynamics can be observed for other values of \( \tau \): For \( \tau = 1 \), the positive impulse responses are more muted than for \( \tau = 2 \), and for \( \tau = 4 \), these responses are even stronger than for \( \tau = 3 \).

**Insert Figure 4 about here**
The intuition for why the price puzzle arises in the SVAR estimation is fairly straightforward. The companion form of the data-generating model is given by:

\[ y_t = By_{t-1} + C\epsilon_t, \]  

where \( \epsilon_t = [\epsilon_t^x, u_t, n_t, \epsilon_t^i] \)' and \( n_t = [u_{t}^n, \ldots, u_{t-\tau}^n]' \) is a \((\tau + 1) \times 1\) vector of inflationary news shocks. The standard SVAR specification, therefore, cannot disentangle monetary shocks from anticipated inflationary shocks and, when the effect of the latter dominates, inflation begins to move in the same direction as the shock.

4 Estimates of the Cost Channel’s Extent: Setup, Results, and Implications

This paper also makes a contribution to the large literature on the cost channel of transmission of monetary policy. The phenomenon has been extensively studied in the empirical literature with aggregate macroeconomic data.\footnote{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 (2001) find that a contractionary monetary policy shock produces lower output and higher price-wage ratios and provide evidence that this effect is primarily due to higher prices rather than lower wages.} Using the generalized method of moments in the single-equation framework, Ravenna and Walsh (2006) find that the cost channel has significant presence in the U.S. at the quarterly frequency, while Chowdhury et al. (2006) provide further support from the international quarterly data. Christiano et al (2005) provide estimates of a DSGE model using US quarterly data and find that monetary policy has a supply-side effect on inflationary dynamics. Tillmann (2008) presents evidence that augmenting the Phillips curve to include the cost channel significantly reduces the difference between actual inflation and estimates of fundamental inflation in the U.S., U.K., and Euro area data.

However, there does not appear to be a consensus on the empirical relevance of the cost channel in aggregate data. Rabanal (2007) uses Bayesian methods to estimate a model with price and wage rigidities and finds that the extent of the cost channel’s presence, while statistically significant, is not large enough to generate the price puzzle. He then ascribes the puzzle in the SVAR context to a
misspecified empirical model; the present paper provides a potential source of this misspecification. Kaufmann and Scharler (2006) estimate a model that features incomplete pass-through of monetary shocks to producers and conclude that the extent of the cost channel is small in both European and U.S. data. In a related paper that also features a similar form of incomplete pass-through, Hülsowig et al. (2006) find evidence in favor of the cost channel’s presence that bears, however, quantitatively small impact. On the other hand, Castelnuovo (2009) uses a framework similar similar to that of Rabanal (2007) but allowing for a larger range values for the parameter that captures the extent of the cost channel; he finds that introducing this modification results in higher estimates of that parameter’s value.

Conclusions regarding cost channel’s ability to produce the price puzzle are also markedly different. At one end of the spectrum, Ravenna and Walsh (2006) and Chowdhury et al. (2006) produce estimates that support this possibility. Henzel et al (2009) apply a minimum-distance estimation approach to the European data and show that the cost channel may be able to generate a price puzzle under plausible parameterization that cannot be rejected by the data. On the other hand, the results of Rabanal (2007), largely corroborated by Castelnuovo (2009), strongly reject it. This paper shows that positive and significant estimates of the cost channel’s presence may arise in a framework that does account for the forward-looking nature of monetary policy-making and anticipated shocks to inflation.

As in Ravenna and Walsh (2006), the cost channel of transmission of monetary policy is introduced by assuming that firms have to borrow wage-related expenses at the nominal interest rate. If firms are subject to this requirement, then their marginal cost function has to be modified to

\[ mc_t^X = mc_t^0 + \chi i_t, \]  \hspace{1cm} (13)

where \( mc_t^0 \) is still given by (3) and \( \chi > 0 \) 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. This setup allows for increases in the nominal interest rate to generate an increase in inflation—the defining aspect of the price puzzle.

The rest of the model is the same as in Section 2 under the assumption that all of the cost-push shocks are unanticipated (\( \delta = 0 \)) and the monetary policy rule is not forward-looking (\( \phi = \)
0). The same simulated data described in Section 2.3 and used in Section 3 are employed for this exercise. Castelnuovo (2009) finds that the estimates of $\chi$ may be sensitive to changes in the parameter’s search region and, given his use of the Bayesian estimation framework, the prior imposed on the value of this parameter. This paper employs a maximum likelihood approach to estimating the parameters of the model given by (1), (2), (3), (13), and (8) under the assumption that $\phi = 0$. Ireland (2004) demonstrated how rational-expectations models can be represented in state-space form and their parameter estimates be obtained using maximum likelihood estimation. The companion form of the estimated model can be summarized by the following equations:

$$y_t = B(\theta)y_{t-1} + e_t,$$  \hspace{1cm} (14)

$$e_t = C(\theta)e_t,$$  \hspace{1cm} (15)

$$E(e_t e'_t) = C(\theta)E(e_t e'_t)C(\theta)' = \Omega(\theta),$$  \hspace{1cm} (16)

where $\theta = [\sigma, h, \kappa, \omega, \gamma_x, \gamma_x, \rho, \chi]$ and $B, C$ and $\Omega$ are matrices whose elements are non-linear functions of these structural parameters. This setups lends itself to evaluating the likelihood function by using the Kalman filter. In particular, the likelihood function is given by:

$$\mathcal{L}(y_t|\theta) = \prod_{t=1}^{T} \left\{ (2\pi)^{-\frac{3}{2}} |\Omega^{-1}(\theta)|^{\frac{1}{2}} \exp \left[ -\frac{1}{2} (y_t - B(\theta)y_{t-1})' \Omega^{-1}(\theta) (y_t - B(\theta)y_{t-1}) \right] \right\}$$

The second-order Taylor series approximation of the log transformation of the likelihood function around the vector of true parameter values $\bar{\theta}$ is given by

$$f(\theta) = f(\bar{\theta}) + (\theta - \bar{\theta})J(\theta) + \frac{1}{2} (\theta - \bar{\theta})'H(\theta)(\theta - \bar{\theta}),$$

where $J$ is the Jacobian vector of first derivatives and $H$ is the Hessian matrix of second derivatives evaluated at $\bar{\theta}$. Differentiating with respect to $\theta$ and rearranging the resulting first-order condition, we get the iterative scheme for the Newton method convergence algorithm:

$$\theta^{j+1} = \theta^j - H^{-1}(\theta)J(\theta).$$
The Hessian in this equation is updated using the Sims implementation of the Broyden-Fletcher-Goldfarb-Shanno method to avoid problems associated with discontinuities in the surface of the loglikelihood function.\(^9\)

Since the estimated model is misspecified by construction, the surface of the loglikelihood function may not be well-behaved with respect to the main parameter of interest. To ensure that the iterative search process reaches all regions of the loglikelihood function, I vary the initial guess of \(\chi\) over the \([0, 1.8]\) range in increments of 0.2.\(^{10}\) The following two subsections investigate the biases in four estimated parameters of interest; the remaining parameters do not show pronounced biases. To economize on space, the results are only presented for simulations where \(\delta = \phi\), because, as Figures 3 and 4 reveal, only relatively small changes occur due to a change in one of those parameters while keeping the other one constant.\(^{11}\)

4.1 Implications for inflationary dynamics: Are cost channel’s estimates a result of misspecification?

Insert Figure 5 about here

Figure 5 investigates the effect of changes in the values of \(\delta\) and \(\phi\) on the estimates of \(\chi\) (vertical axis), given different values for the initial guess of that parameter (horizontal axis). In the case where the values of the former two parameters are sufficiently close to zero, estimates of the cost channel are also close to their true value of zero. However, as \(\delta\) and \(\phi\) increase and the degree of model misspecification increases, estimates of \(\chi\) increase and eventually become heavily concentrated around the guess for the initial value of \(\chi\), suggesting that the surface of the loglikelihood function is flat with respect to this parameter. This may explain the differences in outcomes of Rabanal (2007) and Castelnuovo (2009): In otherwise similar setups, the latter obtains higher estimates of \(\chi\) by imposing a larger prior and lifting the upper boundary of the region of possible values.

---


\(^{10}\)Values of \(\chi > 1.8\) typically result in indeterminacy. 1000 replications are performed for each of the 10 possible values of the initial guess for \(\chi\), resulting in 10,000 simulations for each combination of \(\phi, \delta,\) and \(\tau\). The search boundaries for \(\sigma\) are restricted to \([0, 4]\), for \(\gamma_\pi\) to \([0, 3]\), for \(\gamma_x\) to \([0, 2]\), and for the rest of the estimated parameters to \([0, 1]\). Note that given the computational costs, it is not feasible to perform sensitivity analysis with respect to the initial values for all parameters or to carry out Bayesian estimation for a large number of replications.

\(^{11}\)Complete results are available upon request.
Figure 6 demonstrates that insofar as the model is misspecified, estimates of inflationary inertia are also going to be substantially biased upwards. This result is likely driven by the fact that as anticipated inflationary shocks gain relative weight in the composition of the cost-push shock, the forward-looking component of inflationary expectations will motivate firms to change inflation in the direction of the shock, which smoothes out the evolution of inflation and appears to render it more inertial than it is in reality.

4.2 Implications for the coefficients describing monetary policy conduct

Similarly, inability to account for anticipated inflationary shocks and forward-looking monetary policy has important implications for the estimates of parameters that characterize the standard Taylor rule. Figure 7 shows that estimates of $\gamma_\pi$ will be biased downward, with the bias being the most pronounced when the guess for the initial value of $\chi$ is close to zero and the value of $\phi$ is large. The intuition for the latter result is relatively straightforward: As the response to future inflation increases, the estimated response to current inflation will be lower. This relates to the results of Castelnuovo and Surico (2009) who find extremely low estimates of $\gamma_\pi$ that lead to indeterminacy. Therefore, making a judgment about the true aggressiveness of central bank towards inflation may critically dependent on its degree of forward-looking behavior and the extent of information that it has about future outcomes.

Finally, Figure 8 demonstrates that the estimated size of the standard deviation of the monetary shock increases from the true value of 0.25 to about 0.4 as the values of $\phi$ and $\delta$ increase. Ignoring the forward-looking nature of monetary policy as it becomes more important together with a higher weight of anticipated inflationary shocks results in attributing a larger share of non-systematic monetary policy conduct.
5 Conclusion

This paper has investigated the role of anticipated shocks to inflation and the inflation-forecast-based monetary policy in the context of a standard New Keynesian DSGE model. Data generated from the models where the presence of these two additional factors is largest produce an important stylized fact captured by an empirical SVAR model: the positive response of inflation to a contractionary monetary policy shock. It is important to emphasize, however, that insofar as the underlying DSGE model is a reasonably correct representation of the actual macroeconomy, the SVAR model produces the price puzzle simply because it does not allow for the correct identification of the monetary policy shock. Although the model used in this paper is parameterized to match quarterly US data, the DGP’s mechanism may help explain why the price puzzle is easier to resolve at that rather than monthly frequency: Explicitly unmodeled inflationary pressure may be more apparent to the agents and the policy maker at shorter time intervals. Finally, the theoretical device frequently employed to explain the price puzzle, the cost channel of transmission of monetary policy, may find empirical justification simply because the estimated model ignores these two factors. This finding is consistent with the earlier literature that posited that the price puzzle is a result of model misspecification. The present paper builds on this literature by providing an explicit source of this misspecification.
References


<table>
<thead>
<tr>
<th>Parameters</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$h$</td>
<td>Degree of habit persistence</td>
<td>0.85</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>Coefficient of relative risk aversion</td>
<td>1.1</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Discount factor</td>
<td>0.99</td>
</tr>
<tr>
<td>$\omega$</td>
<td>Degree of price indexation</td>
<td>0.7</td>
</tr>
<tr>
<td>$\eta$</td>
<td>Frisch elasticity of labor supply</td>
<td>0.8</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Calvo probability</td>
<td>0.75</td>
</tr>
<tr>
<td>$\rho$</td>
<td>Interest-smoothing parameter</td>
<td>0.75</td>
</tr>
<tr>
<td>$\gamma_\pi$</td>
<td>Magnitude of response to inflation</td>
<td>2</td>
</tr>
<tr>
<td>$\gamma_y$</td>
<td>Magnitude of response to output gap target</td>
<td>1</td>
</tr>
<tr>
<td>$\phi$</td>
<td>Degree of CB forward-looking behavior</td>
<td>Free</td>
</tr>
<tr>
<td>$\delta$</td>
<td>Anticipated share of the cost-push shock</td>
<td>Free</td>
</tr>
<tr>
<td>$\sigma^x$</td>
<td>Standard deviation of demand shock</td>
<td>0.4</td>
</tr>
<tr>
<td>$\sigma^\pi$</td>
<td>Standard deviation of supply shock</td>
<td>0.5</td>
</tr>
<tr>
<td>$\sigma^t$</td>
<td>Standard deviation of demand shock</td>
<td>0.25</td>
</tr>
</tbody>
</table>
Figure 1: Impulse responses to an unanticipated cost-push shock (Blue solid line—inflation; red dotted line—interest rate)
Figure 2: Impulse responses to an anticipated cost-push shock, $\tau = 3$ (Blue solid line— inflation; red dotted line— interest rate)
Figure 3: Impulse responses to the monetary shock (Green solid line—theoretical; Black dashed line—estimated; red dotted lines—10th and 90th percentiles)
Figure 4: Impulse responses to the monetary shock (Green solid line—theoretical; Black dashed line—estimated; red dotted lines—10th and 90th percentiles)
Figure 5: Estimates of $\chi$ (Black dashed line—median estimate; red dotted lines—10th and 90th percentiles; green solid line—true value in the DGP)
Figure 6: Estimates of $\omega$ (Black dashed line—median estimate; red dotted lines—10th and 90th percentiles; green solid line—true value in the DGP
Figure 7: Estimates of $\gamma_s$ (Black dashed line—median estimate; red dotted lines—10th and 90th percentiles; green solid line—true value in the DGP)
Figure 8: Estimates of $\sigma^i$ (Black dashed line—median estimate; red dotted lines—10th and 90th percentiles; green solid line—true value in the DGP)