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Can exchange rate pass-through explain the price puzzle?

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Highlights

The price puzzle is examined using a macro model with expectations formed rationally.

We show that presence of a cost channel is necessary for the price puzzle to occur.

The price puzzle occurs in a closed economy even if the cost channel is not strong.

Our model shows that exchange rate pass-through can resolve the price puzzle.

Can exchange rate pass-through explain the price puzzle?

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Abstract

The anomalous behavior of inflation in response to contractionary monetary policy is known as the price puzzle. Using a simple open-economy macroeconomic model, with expectations formed rationally, we show that exchange rate pass-through can help in resolving the price puzzle.

JEL Classification: E31, E32, E52

Keywords: Price puzzle; cost channel; exchange rate pass-through; rational expectations

1. Introduction

Since the work of Sims (1992), a number of studies have attempted to explain why the price puzzle occurs. It is generally believed that the price puzzle (which refers to an increase in the inflation rate when the interest rate increases) occurs when there is a cost channel in the monetary policy transmission mechanism, or when the model is misspecified and/or incorrectly estimated (for a discussion, see Castelnuovo, 2012). Castelnuovo and Surico (2010) found evidence of the price puzzle in US data from 1966-1979 but not from 1979-2002. They argue that, until 1979, US monetary policy was not tight enough to control inflation. Kapinos (2011) showed that ignoring the effect of anticipated shocks to inflation and the forward-looking behavior of the central bank, in a macroeconomic model, can give rise to the price puzzle. However, no previous study has considered the role of exchange rate pass-through. This paper contributes to the literature by showing that exchange rate pass-through can influence the sign of the response of inflation to a monetary policy shock.

2. The Model

In order to examine the role of exchange rate pass-through, we use a relatively simple model, in which there are two types of firms (domestic and foreign) and agents form expectations rationally. Since it is always costly for firms to change commodity prices, firms adjust prices only sluggishly over time. We also assume that domestic firms borrow money to finance expenses at the market rate of interest and foreign firms measure cost and revenue in units of foreign currency. These two assumptions give rise to both the cost channel of monetary policy as well as exchange rate pass-through. As the domestic currency depreciates, in order to remain competitive, foreign firms selling in the domestic market tend not to increase their prices. But, as the domestic currency appreciates, foreign firms are more likely to reduce their prices.

Our macroeconomic model consists of the following equations, where all variables (except for the interest rate) are expressed in natural logarithms.

$$\pi_t^h = \beta E_t \pi_{t+1}^h + \alpha_1 x_t + \alpha_2 s_t + \alpha_3 i_t + u_{1t} \tag{2.1}$$

$$x_t = E_t x_{t+1} - \left(\frac{1}{\sigma}\right)\left[i_t - E_t \pi_{t+1}^h - \rho_t\right] - \left(\frac{\varepsilon_B \Theta}{\sigma}\right)\left[E_t s_{t+1} - s_t\right] + u_{2t} \tag{2.2}$$

$$i_t = i^f + E_t s_{t+1} - s_t + E_t \pi_{t+1}^h + u_{3t} \tag{2.3}$$

$$\rho_t = s_t - u_{3t} \tag{2.4}$$

$$i_t = \phi^\pi \pi_t^h + \phi^x x_t + u_{4t} \tag{2.5}$$

where

$\alpha_1 = \Omega^{-1}\left[1 + \varepsilon(\nu - 1)\right]^{-1} \geq 0$

$\alpha_2 = \Omega^{-1}\mu\left[1 + \varepsilon(\nu - 1)\right]^{-1} \geq 0$

$\alpha_3 = \Omega^{-1}\theta\left[1 + \varepsilon(\nu - 1)\right]^{-1} \geq 0$

$\Theta = \sigma\varepsilon_F + (1 - \varepsilon_B)(\sigma\varepsilon_H - 1) - 1$

π_t^h = domestic inflation; x_t = real domestic output; s_t = real exchange rate;

i_t = short-term interest rate; i^f = foreign rate of interest;

σ = inverse of interest elasticity of demand for goods;

ε_B = degree of openness (closer is to 1 implies a more open economy);

ε_F = elasticity of substitution between importing countries;

ε_H = elasticity of substitution in consumption between the domestic and foreign goods;

Ω = cost of price adjustments;

$\nu > 1$ is the cost function parameter; $\varepsilon > 1$ is the price elasticity of demand;

$\theta \geq 0$ captures the strength of the monetary policy cost channel;

E_t = expectations operator conditional upon period t information.

Equation (2.1) is the Phillips curve (see the Appendix for a detailed derivation). The rest of the model consists of typical demand side equations.[1] Equation (2.2) is the IS curve. Domestic demand is negatively related to the real rate of interest $\left(i_t - E_t\pi_t^h - \rho_t\right)$ and the depreciation rate of the domestic currency ($E_t s_{t+1} - s_t$). Equation (2.3) is the log-linear version of uncovered interest rate parity. Equation (2.4) determines the discount rate $\left(\rho_t\right)$ endogenously. Equation (2.5) is a standard Taylor rule; the central bank alters the short-term interest rate $\left(i_t\right)$ in response to domestic inflation and output. u_{1t} , u_{2t} , u_{3t}, and u_{4t} are the usual stochastic terms that capture random shocks to the economy. In order to derive clear analytic results, we do not consider factors such as habit persistence on the part of consumers.

The parameter $\alpha_3 = \theta\Omega^{-1}(1-\mu)\left[1+\varepsilon(\nu-1)\right]^{-1}$, which measures the strength of the cost channel, plays an important role in our model. If $\theta = 0$ then the interest rate has no bearing on inflation through the supply side. While examining the strength of the cost channel of monetary policy, Ravenna and Walsh (2006) estimated various values of θ, which were as low as 1.239 and as high as 11.831. The parameter $\alpha_2 = \mu\Omega^{-1}\left[1+\varepsilon(\nu-1)\right]^{-1}$, where $0 < \mu \le 1$, measures the impact of the exchange rate pass-through, which occurs due to the presence of foreign firms. If $\mu = 0$ then there is no exchange rate pass-through as all firms are domestic. Domestic firms do not adjust their prices in response to exchange rate fluctuations. From $\alpha_3 = \theta\Omega^{-1}(1-\mu)\left[1+\varepsilon(\nu-1)\right]^{-1}$, it is clear that the strength of the cost channel also depends on the degree of exchange rate pass-through. If all firms are foreign $\left(\text{i.e., } \mu = 1\right)$, the cost channel would be ineffective $\left(\text{i.e., } \alpha_3 = 0\right)$. Using panel data from 14 OECD countries over 1980:Q1-

[1] See Gali (2008, Chapter 7) for more details.

1998:Q4 and 1990:Q1-2007:Q2, Takhtamanova (2011) estimated the average value of α_2 as 0.92 and 0.19, respectively. She argued that the latter value was low because of low inflation during that period.

Our focus is on the response of inflation to monetary contraction; therefore, to simplify our calculations, we set all shocks equal to zero, except for u_{4t}. In order to solve the model analytically, we start with the following trial solution.

$$y_t = au_{4t},\ s_t = bu_{4t},\ \text{and}\ \pi_t^h = cu_{4t} \tag{2.6}$$

The final solution is derived by substituting the trial solution in equations (2.1) to (2.5) and using the method of undetermined coefficients. The following set of restrictions on parameters a, b, and c were derived.

$$\begin{aligned} \sigma a \ - \left(2+\varepsilon_B\Theta\right)b \quad &= 0 \\ \alpha_1 a + \left(\alpha_2-\alpha_3\right)b - c &= 0 \\ \phi^x a + b + \phi^\pi c \quad &= -1 \end{aligned} \tag{2.7}$$

The above system of equations yields the values of a, b, and c and, hence, the final solution. The solution for inflation is used to derive equation (2.8), which leads to four propositions.

$$\frac{\partial \pi_t^h}{\partial u_{4t}} = \frac{\sigma\left(1-\mu\right)\left[\theta-\mu\left(1-\mu\right)^{-1}-\sigma^{-1}\left(1-\mu\right)^{-1}\left(\nu-1\right)\left(2+\varepsilon_B\Theta\right)\right]}{\Omega\left[1+\varepsilon\left(\nu-1\right)\right]\left[\sigma+\phi^x\left(2+\varepsilon_B\Theta\right)\right]-\sigma\left(1-\mu\right)\phi^\pi\left[\theta-\mu\left(1-\mu\right)^{-1}-\sigma^{-1}\left(1-\mu\right)^{-1}\left(2+\varepsilon_B\Theta\right)\right]} \tag{2.8}$$

Proposition 1: *The Price puzzle occurs only when the cost channel of monetary policy is present.*

Proposition 1 is derived by substituting $\Theta = \sigma\varepsilon_F + \left(1-\varepsilon_B\right)\left(\sigma\varepsilon_H - 1\right) - 1$ in equation (2.8). It can be confirmed that a necessary condition for the price puzzle to occur is the presence of a cost channel $\left(\text{i.e., } \theta > 0\right)$ and the effect of the cost channel must be sufficiently strong, which implies that the following conditions must hold.

$$\theta > \frac{\mu}{1-\mu} + \left[\frac{\nu-1}{\sigma(1-\mu)}\right]\left[2-\varepsilon_B+\varepsilon_B\sigma\varepsilon_F+\varepsilon_B\left(1-\varepsilon_B\right)\left(\sigma\varepsilon_H-1\right)\right]$$

and $\theta \in \left[0,\bar{\theta}\right]$

$$\bar{\theta} \equiv \left[\frac{\mu}{1-\mu} + \frac{(\nu-1)(2+\varepsilon_B\Theta)}{\sigma(1-\mu)} + \frac{\sigma\left[1+\varepsilon(\nu-1)\right]+\phi^x(2+\varepsilon_B\Theta)}{\phi^\pi\sigma(1-\mu)}\right] \tag{2.9}$$

Proposition 2: *In a closed economy, the price puzzle occurs even if the cost channel is not strong.*

Proposition 2 can be confirmed by setting $\mu = \varepsilon_B = \varepsilon_H = \varepsilon_F = 0$ in equation (2.9). The price puzzle occurs when $\theta > 2(\nu-1)\sigma^{-1}$. It is interesting to note that when $\nu = 1.5$ and $\sigma = 1$, $\theta > 1$ is a sufficient condition for prize puzzle to occur. In contrast, the empirical work of Rabanal (2007), which is based on a medium-scale DSGE model, suggests that the puzzle occurs only if the effect of an increase in the interest rate on marginal cost is not offset by the decline in real wage and the rental rate of capital.[2]

Proposition 3: *In an open economy, with no exchange rate pass-through ($\mu = 0$), the price puzzle occurs only if the cost channel is sufficiently strong.*

$$\textit{i.e., } \theta > \left[\frac{\nu-1}{\sigma}\right]\left[1+\varepsilon_B\sigma\varepsilon_F+\varepsilon_B\left(1-\varepsilon_B\right)\left(\sigma\varepsilon_H-1\right)\right] \tag{2.10}$$

[2] It is worth mentioning that our paper utilizes a small-scale model that does not explicitly capture the effect of factors such as the real wage and rental rate of capital. Moreover, in a large-scale model, the response of inflation to a monetary innovation will also be affected by the nature of wage contracts and variability in capital utilization.

From equation (2.10), it is clear that in an open economy, even when exchange rate pass-through is absent, the condition for the price puzzle to occur is much harder to satisfy. The intuition behind this result is quite straightforward. A contractionary monetary shock that increases the interest rate also results in appreciation of the real exchange rate, which depresses the demand for domestic goods, thereby exerting downward pressure on prices. Unlike the case of a closed economy, in order to offset the combined effect of the interest rate and exchange rate, only a very strong cost channel can generate the price puzzle.

Proposition 4: *The likelihood of a price puzzle varies inversely with the strength of exchange rate pass-through.*

In condition (2.9), parameters ε_B, σ, ε_F, and ε_H, capture the contractionary demand side effects of a real exchange rate appreciation, whereas $\mu(1-\mu)^{-1}$ captures the degree of exchange rate pass-through. A contractionary monetary shock leads to higher interest rates and currency appreciation, which causes a significant decrease in aggregate demand for domestic goods for higher values of $\sigma, \varepsilon_B, \varepsilon_F$, and ε_H. This situation tends to offset the impact of the cost channel. Furthermore, in the presence of foreign firms, real exchange rate appreciation puts negative pressure on domestic inflation as foreign firms tend to reduce their prices in response to exchange rate appreciation and hence a higher value of μ lowers the likelihood of a price puzzle.

3. Model Calibration

In order to provide further insight into our theoretical results, we calibrated our model by using the following parameter values (selected from the existing literature).

$\Omega = 5,\ \beta = 0.75,\ \sigma = 1,\ \varepsilon_B = 0.25,\ \varepsilon_F = \varepsilon_H = 1.1,\ \theta = 1.25,\ v = \varepsilon = 1.05,\ \phi^{\pi} = 1.5,\ \phi^{x} = 0.5.$

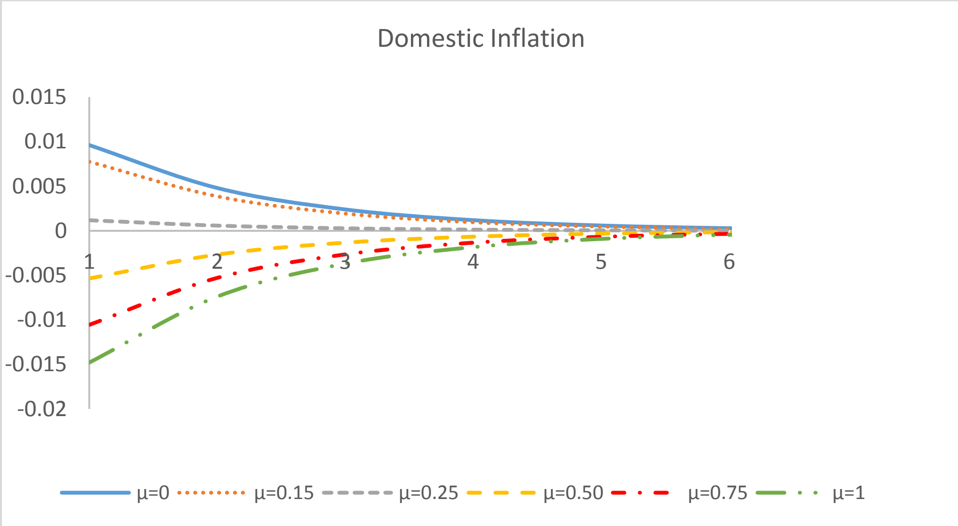

Figure 1: Impulse response functions (IRFs)

Note: μ, which varies between zero and 1, measures the degree of exchange rate pass-through.

The impulse response functions (IRFs) in Figure 1 are generated by giving a one standard deviation shock to the error term u_{4t}. We consider the case of a moderate cost channel of monetary policy $(\theta = 1.25)$. In Figure 1, the price puzzle is visible when exchange rate pass-through is not very strong. However, as the degree of exchange rate pass-through exceeds 0.25, the price puzzle starts disappearing.

4. Conclusion

This paper contributes to the literature on the price puzzle using a simple open economy macro model, with expectations formed rationally. When the monetary policy transmission mechanism includes a cost channel, we show that exchange rate pass-through, which has been ignored in the previous literature, can resolve the price puzzle. In the model, the exchange rate pass-through arises due to the presence of foreign firms.

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Appendix (Philips Curve Derivation)

Equation (2.1) is derived assuming that price adjustments are costly. Following Takhtamanova (2008), we assume that the representative domestic firm, *i*, chooses price p_t^D while the representative foreign firm, j, (operating domestically) chooses p_t^F so that the cost of being away from the optimal price is minimized. If the optimal price for the domestic firm is p^{*D} then the firm seeks to minimize the following cost function by choosing p_t^D.

$$\min Z_{it} = E\sum_{\tau=1}^{\infty}\beta^{\tau-1}\left[\left(p_{i\tau}^D - p_{i\tau}^{*D}\right)^2 + \Omega\left(p_{i\tau}^D - p_{i\tau-1}^D\right)^2\right] \tag{A1}$$

where

Z_{it} = total cost of firm *i* at time *t* and β = discount factor.

Differentiating (A1) with respect to p_{it}^D yields

$$\beta\Omega E_t\pi_{it+1}^D = p_{it}^D - p_{it}^{*D} + \Omega\pi_{it}^D \tag{A2}$$

Similarly, we can derive an equation for the foreign firm:

$$\beta\Omega E_t\,\pi_{it+1}^F = p_{it}^F - p_{it}^{*F} + \Omega\pi_{it}^F \tag{A3}$$

The desirable price for the domestic firm is obtained by solving the following profit maximization problem:

$$\Pi_{it} = P_{it}^D X_{it} - C_{it} \tag{A4}$$

Firm profit is defined as:

$$\frac{\Pi_{it}}{P_t} = \frac{P_{it}^D X_{it}}{P_t} - \frac{C_{it}}{P_t} \tag{A5}$$

$$P_t^h = \mu P_t^D + \left(1-\mu\right)P_t^F \tag{A6}$$

To proceed further, we assume the following demand and cost functions:

$$X_{it} = X_t \left(\frac{P_{it}^D}{P_t^h} \right)^{-\varepsilon} \quad \text{(A7)}$$

$$C_{it} = \left[\frac{\varepsilon - 1}{\nu\varepsilon} \right] X_{it}^{\nu} \left(1 + i_t\right)^{\theta} \quad \text{(A8)}$$

Substituting equations (A7) and (A8) into (A5), we get

$$\frac{\Pi_{it}}{P_t^h} = \pi_{it} = X_t \left(\frac{P_{it}^D}{P_t^h} \right)^{1-\varepsilon} - \left(\frac{\varepsilon - 1}{\nu\varepsilon} \right) \left(\frac{P_{it}^D}{P_t^h} \right)^{-\nu\varepsilon} \left(1 + i\right)^{\theta} X_t^{\nu} \quad \text{(A9)}$$

Differentiating (A9) with respect to P_{it}^D and setting the result equal to zero yields the ideal price for the domestic firm as follows:

$$p_{it}^{*D} = p_t^h + k_1 x_t + k_2 i_t \quad \text{(A10)}$$

where $k_1 = \dfrac{\nu - 1}{1 + \varepsilon\left(\nu - 1\right)}$ and $k_2 = \dfrac{\theta}{1 + \varepsilon\left(\nu - 1\right)}$

The cost function for the foreign firm is:

$$C_{it}^F = \left(\frac{\varepsilon - 1}{\nu\varepsilon} \right) \left(1 + r^f\right)^{\theta} X_{it}^{\nu} S_t \quad \text{(A11)}$$

where $S_t = \dfrac{E_t P^f}{P_t^h}$ is the real exchange rate, which is used to measure the cost of production of the foreign firm in local currency units.

Using the demand function for goods produced by foreign firms, $X_{it} = X_t \left(\dfrac{P_{it}^F}{P_t^h} \right)^{-\varepsilon}$, the ideal price charged by the representative foreign firm can be derived as follows:

$$p_{it}^{*F} = p_t^h + k_1 x_t + k_3 s_t + k_4 i_t^f \quad \text{(A12)}$$

where $k_1 = \dfrac{\nu - 1}{1 + \varepsilon\left(\nu - 1\right)}, k_3 = \dfrac{1}{1 + \varepsilon\left(\nu - 1\right)}, k_4 = \dfrac{\theta}{1 + \varepsilon\left(\nu - 1\right)}$, and $\ln S_t = s_t = p^f + e_t - p_t^h$

In a symmetric equilibrium, all foreign firms set $p_{it}^F = p_t^F$ and all domestic firms set $p_{it}^D = p_t^D$. Multiplying equation (A2) by $(1 - \mu)$ and (A3) by μ, using (A6), (A10) and (A11) and assuming $i_t^f = 0$, after some manipulation, gives equation (2.1).

$$\pi_t^h = \beta E_t \pi_{t+1}^h + \alpha_1 x_t + \alpha_2 s_t + \alpha_3 i_t + u_{1t} \quad \text{(A13)}$$

where $\alpha_1 = \Omega^{-1}(\nu - 1)\left[1 + \varepsilon(\nu - 1)\right]^{-1}$

$\alpha_2 = \dfrac{\mu}{\Omega\left[1 + \varepsilon(\nu - 1)\right]}$, and

$\alpha_3 = \dfrac{\theta(1-\mu)}{\Omega\left[1 + \varepsilon(\nu - 1)\right]}$

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