A parsimonious solution to the price puzzle

Arturo Estrella*

May 2006

JEL Codes: C32, E52

Keywords: vector autoregression; monetary policy lags

Abstract: In structural VARs, an unexpected monetary tightening often leads to a puzzling increase in inflation. This paper uses a standard stylized fact, the long lags of monetary policy, to simplify the VAR model and eliminate the price puzzle.

* Federal Reserve Bank of New York, 33 Liberty Street, New York, NY 10045. Tel. 1-212-720-5874. Fax 1-212-720-1582. E-mail: arturo.estrella@ny.frb.org.

1. Introduction

Twenty years after the identification of the price puzzle by Sims (1986), the current literature still contains many examples of papers that either acknowledge the existence of the puzzle or propose new solutions. The puzzle consists of the fact that in many structural VARs, an unexpected monetary tightening leads to an increase in inflation, not to a decline as intuition and theory would suggest.

Existing solutions to the puzzle normally introduce additional structure in the model to absorb at least some of the counterintuitive positive correlation between interest rates and inflation. In contrast, this paper uses a standard fact of monetary economics to solve the puzzle by simplifying the model. It is widely accepted that there exist long lags between changes in monetary policy and the consequent effects on inflation. When the structural VAR is adjusted to reflect this fact, the price puzzle disappears.

2. The price puzzle and earlier solutions

We begin with an illustrative simple structural VAR that exhibits the price puzzle. The VAR contains three variables: real GDP growth, CPI inflation, and the federal funds rate. The shock structure is identified by Choleski factorization with the above ordering. This order matches Sims (1986) and gives the funds rate equation the flavor of a Taylor rule. However, the precise order is inconsequential for our purposes. The model is estimated with quarterly U.S. data from 1955 to 2005, with CPI and the funds rate aggregated as quarterly averages of monthly figures. Growth rates are annualized quarterly log changes. We may write the three equations as

$$y_t = a_{10} + a_{11}(L)y_{t-1} + a_{12}(L)\pi_{t-1} + a_{13}(L)r_{t-1} + \varepsilon_{1t} \quad (1)$$

$$\pi_t = a_{20} + a_{21}(L)y_{t-1} + a_{22}(L)\pi_{t-1} + a_{23}(L)r_{t-1} + \varepsilon_{2t} \quad (2)$$

$$r_t = a_{30} + a_{31}(L)y_{t-1} + a_{32}(L)\pi_{t-1} + a_{33}(L)r_{t-1} + \varepsilon_{3t}\,. \tag{3}$$

In the standard formulation, all the $a_{ij}(L)$ are lag polynomials containing all powers from 0 to $n-1$.

Figure 1 presents impulse responses over 20 quarters for the model with $n = 3$, with error bands derived by Monte Carlo methods as suggested by Sims and Zha (1999). The solid line is the median of the simulated distribution and the dashed lines give a 95% confidence interval. With one exception, the results seem reasonable. For instance, we see across the diagonal that inflation and funds rate shocks are very persistent, but that output shocks are much less so. The response of inflation to output is positive, as in a Phillips curve, and the response of output to the funds rate is negative, as in an IS curve. The interest rate responses to both output and inflation are positive. The only exceptional case is the positive response of inflation to the funds rate, namely the price puzzle.

Various types of solutions to the puzzle have been put forth over the years. Sims (1992) conjectures that central banks have internal information about inflation expectations, which is not captured in the simple VAR structure. If the central bank reacts to an expected rise in inflation by raising the interest rate, but does not eliminate the risk entirely, the price puzzle may arise. Sims proposes including a measure of commodity price increases in the VAR as a proxy for unobserved inflation expectations. Other researchers have followed this lead and include various measures of commodity prices in structural VARs, for instance Kim (1999), Kim and Roubini (2000) and Barth and Ramey (2001), though the latter differ with Sims (1992) as to the interpretation of the role of this variable, as does Hanson (2004).

Others have added different types of variables to the VAR in search for the missing link that would absorb the unintuitive correlations. Bernanke et al. (2005) and Lagana and Mountford

(2005) include a few factors extracted from a large number of other variables; Giordani (2004) adds an output gap; Kozicki and Tinsley (2005) introduce an unobservable time-varying inflation target; and Francis and Owyang (2005) allow for Markov switching. Bierens (2000) extracts common nonlinear trends, and Scholl and Uhlig (2005) try the brute force approach of constraining the questionable impulse responses to be negative.

Most of these methods have had some measure of success in reversing the puzzle, albeit at the cost of additional – possibly substantial – complexity. The unique feature of the solution proposed below is that it makes the model somewhat simpler, not more complex.

3. The long lags of monetary policy

We look for guidance to the literature on monetary policy lags. This literature relies heavily on descriptive statistical analysis of dynamic economic relationships over the business cycle and at longer frequencies. Early on, Friedman (1958, 1960, 1961) concluded that the lag between monetary policy actions and their influence on prices and economic activity is “long and variable.” For instance, at various times, the lag between policy and inflation is seen to be anywhere from a few quarters to several years. Friedman (1958, p. 249) explains the “variable” part as a consequence of the endogeneity of the series in question and of the multiplicity of underlying shocks, features which are consistent with a structural VAR approach.

Friedman (1972) concludes that he might have, if anything, underestimated the length of the lags in his earlier work, and that the lag for inflation is longer than the lag for real activity. These results have been confirmed by Bernanke and Gertler (1995) and Batini and Nelson (2001) using more recent data and other methodologies.

A somewhat different but parallel perspective is provided by work on the ability of the term structure of interest rates to predict inflation and real activity. For instance, Estrella and Mishkin (1997) find that the term spread at a given time forecasts real activity about one year ahead, but forecasts inflation two or more years ahead. These findings are also consistent with the lag structure in theoretical models such as Svensson (1997) and in analogous empirical models such as Rudebusch and Svensson (1999).

4. Implications for solving the price puzzle

The long lag between monetary policy and inflation calls into question the appearance of short lags – low powers of L – in the polynomial $a_{23}(L)$ in equation (2). These lags are not problematic if the VAR is interpreted simply as a reduced-form predictive model, but the direct short-run effects are clearly inconsistent with the evidence of the previous section if the model is to be viewed as structural. The solution is simple and parsimonious: impose zero restrictions on low powers of L in $a_{23}(L)$, which results in a longer policy lag for inflation than for output, as the evidence suggests.

In fact, there is no need to go very far. Figure 2 presents impulse responses for the model with $n = 3$, as before, but with the first term of $a_{23}(L)$ excluded. The only panel that changes appreciably is the response of inflation to the funds rate, which becomes negative and significant at the 95% level over some horizons. The price puzzle is gone. Setting further terms in $a_{23}(L)$ to zero produces similar results, as seen in Figure 3. Note that setting $a_{23}(L) = 0$, that is, excluding interest rate lags altogether from the inflation equation, is consistent with the Svensson (1997) and Rudebusch-Svensson (1999) models.

The key to this solution of the puzzle is that the first lag of the funds rate in the inflation equation captures a strong empirical correlation that is inherent in the data, but inconsistent with a structural interpretation of the equation. This conclusion does not contradict Sims (1992) or most of the other solutions to the puzzle, but it provides a simpler means of arriving at an interpretable set of impulse responses.

References

Barth, M.J. III and V.A. Ramey, 2001, The cost channel of monetary transmission, NBER Macroeconomics Annual 16, 199-240.

Batini, N. and E. Nelson, 2001, The lag from monetary policy actions to inflation: Friedman revisited, International Finance 4, 381-400.

Bernanke, B.S., J. Boivin, and P. Eliasz, 2005, Measuring the effects of monetary policy: A factor-augmented vector autoregressive (FAVAR) approach, Quarterly Journal of Economics 120, 387-422.

Bernanke, B.S. and M. Gertler, 1995, Inside the black box: The credit channel of monetary policy transmission, Journal of Economic Perspectives 9, 27-48.

Bierens, H.J., 2000, Nonparametric nonlinear cotrending analysis, with an application to interest and inflation in the United States, Journal of Business and Economic Statistics 18, 323-337.

Estrella, A. and F.S. Mishkin, 1997, The predictive power of the term structure of interest rates in Europe and the United States: Implications for the European Central Bank, European Economic Review 41, 1375-1401.

Francis, N. and M.T. Owyang, 2005, Monetary policy in a Markov-switching vector error-correction model: Implications for the cost of disinflation and the price puzzle, Journal of Business and Economic Statistics 23, 305-313.

Friedman, M., 1958, The supply of money and changes in prices and output, in: U.S. Congress, Joint Economic Committee, The relationship of prices to economic stability and growth: Compendium, (Government Printing Office, Washington, D.C.), 241-256.

Friedman, M., 1960, A program for monetary stability (Fordham University Press, New York)

Friedman, M., 1961, The lag in effect of monetary policy, Journal of Political Economy 69, 447-466.

Friedman, M., 1972, Have monetary policies failed?, American Economic Review 62, 11-18.

Giordani P., 2004, An alternative explanation of the price puzzle, Journal of Monetary Economics 51, 1271-1296.

Hanson, M.S., 2004, The “price puzzle” reconsidered, Journal of Monetary Economics 51, 1385-1413.

Kim, S., 1999, Do monetary policy shocks matter in the G-7 countries? Using common identifying assumptions about monetary policy across countries, Journal of International Economics 48, 387-412.

Kim, S. and N. Roubini, 2000, Exchange rate anomalies in the industrial countries: A solution with a structural VAR approach, Journal of Monetary Economics 45, 561-586.

Kozicki, S. and P.A. Tinsley, 2005, Permanent and transitory policy shocks in an empirical model with asymmetric information, Journal of Economic Dynamics and Control 29, 1985-2015.

Lagana, G. and A. Mountford, 2005, Measuring monetary policy in the UK: A factor-augmented vector autoregression model approach, The Manchester School, Supplement 73, 77-98.

Rudebusch, G.D. and L.E.O. Svensson, 1999, Policy rules for inflation targeting, in: Taylor, J., Monetary policy rules (U. of Chicago Press, Chicago), 203-246.

Scholl, A. and H. Uhlig, 2005, New evidence on the puzzles: Results from agnostic identification on monetary policy and exchange rates, SFB Discussion Paper 2005-037.

Sims, C.A., 1986, Are forecasting models usable for policy analysis?, Federal Reserve Bank of Minneapolis Quarterly Review 10, 2-16.

Sims, C.A., 1992, Interpreting the macroeconomic time series facts: The effects of monetary policy, European Economic Review 36, 975-1000.

Sims, C.A. and T. Zha, 1999, Error bands for impulse responses, Econometrica 67, 1113-1155.

Svensson, L.E.O., 1997, Inflation forecast targeting: Implementing and monitoring inflation targets, European Economic Review 41, 1111-1146.

Figure 1. Impulse responses with full VAR lag structure

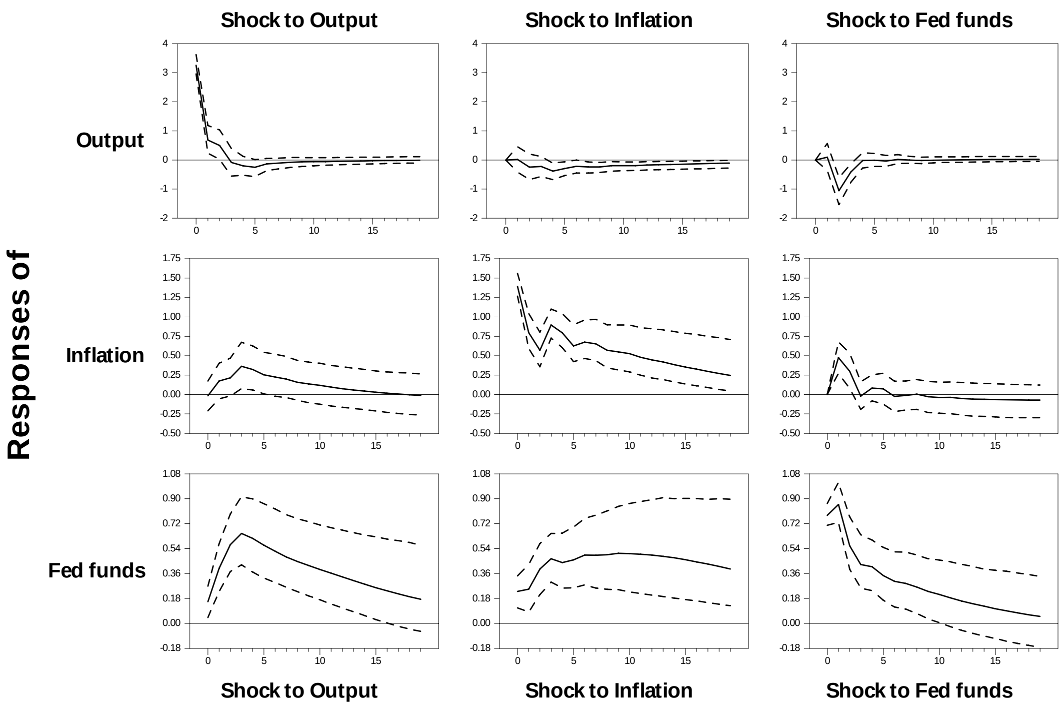

Figure 2. Impulse responses with near VAR lag structure:
Excludes first lag of the fed funds rate in inflation equation

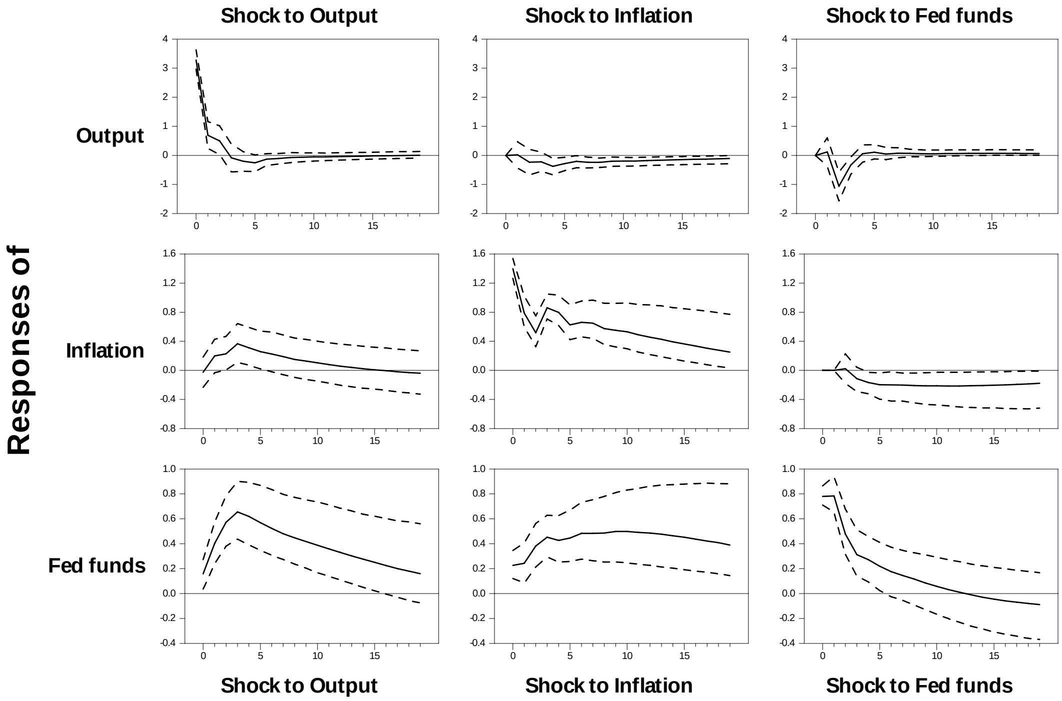

Figure 3. Response of inflation to unexpected monetary shock:
With zero restrictions on the first *k* lags of the fed funds rate in inflation equation (2)