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Misspecification, Identification or Measurement? Another Look at the Price Puzzle*

by

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Abstract

This paper re-examines the VAR analysis of the price puzzle with regard to the issues of measurement, identification and misspecification. In an empirical analysis conducted for the US economy, we consider alternative measures of economic activity and inflation, alternative assumptions to identify the monetary policy shock and various VAR specifications making use of contemporaneous and forward looking variables. All three issues are found to be important for the resolution of the price puzzle and a robust preferred specification is proposed.

Keywords: Price puzzle, Monetary policy, Output gap, Expectations.
JEL Classification: E52, E31, C32.

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1 Introduction

The anomalous response of a rise in prices following a contractionary monetary policy shock, referred to as the 'price puzzle', has been documented in a large number of empirical studies conducted using the Vector Autoregressive (VAR) modelling framework (Sims, 1992 and Eichenbaum, 1992). 'Solutions' proposed within this framework to resolve the price puzzle emphasize the issue of misspecified VAR models and their ability to 'correctly' identify a monetary policy innovation (e.g., see Sims, 1992 and Giordani, 2004). However, such ability also hinges on the identification scheme adopted to identify the monetary policy shock and the measurement of variables included in the VAR, as suggested by the vast VAR literature on monetary policy. The identification issue concerns the *plausible definition* of the monetary policy innovation whilst the issues of measurement and misspecification concern the *accuracy* of the estimated monetary policy shock. These three categories, therefore, provide a useful framework to discuss the empirical consistency of various solutions to the price puzzle.

The *measurement* issue concerns the statistical measures of variables used in the estimation of the respective VAR. Although not formally discussed in the prize puzzle literature, this is a common concern in macroeconomic modelling or for forecasting purposes where variant measures of variables, say, output gap and inflation, can have markedly differing implications. For instance, Orphanides and van Norden (2002), Watson (2007) and Garratt *et al* (2008) highlight the uncertainties and sensitivities in a forecasting context surrounding various popular output gap measures. Orphanides (2001) demonstrates that the performance of the Taylor rule in capturing interest rate movements is considerably reduced when the real-time measures of output gap are used. Likewise, measurement issues surround the appropriate measure of inflation; even once-preferred measures of inflation by monetary authorities may change over time (Orphanides and Wieland, 2008).

The *identification issue* concerns the definition of the monetary shock in the VAR. Whilst there is little consensus, typically a recursive ordering identification scheme is assumed on a VAR consisting of a measure of economic activity, inflation and the interest rate as the minimal information set (Sims, 1980). Although consistent with a standard

Taylor rule (Christiano *et al.* 1999), the scheme is inconsistent with the New Keynesian class of theoretical models (Carlstrom et al, 2009). Various non-recursive identification schemes have been adopted in the price puzzle literature, ranging from assuming a general form indicated by theory (Sims and Zha, 2006, Kim, 1999) to the imposition of long-run restrictions (Clarida and Gali, 1994) and the inclusion of additional short-run restrictions (Bjornland and Leitemo, 2009). Further alternative 'operational' schemes pay attention to the timing of actual information flows in the economy (Orphanides, 2001 and Garratt et al, 2006).

The *misspecification issue* relates to the inclusion of all the variables in the information set of the monetary authority. Popular 'omitted variables' in the literature include commodity prices (Sims, 1992 and Christiano et al, 1996) and principal components extracted from relevant macroeconomic series (Bernanke et al, 2005). Survey measures of expected output and inflation are also thought to be important forward looking variables that should be considered (Castelnouvo and Surico, 2010). Misspecification also concerns the use of appropriate variables; Giordani (2004) and Hanson (2004) propose the use of the output gap instead of output to resolve the price puzzle, for instance.

Consideration of all possible combinations reflecting the three issues is clearly an exhaustive task. This paper therefore selects meaningful combinations of variables, identification schemes and measures of variables to provide insights into the contribution of relevant variables and the economically meaningful structures in resolving the price puzzle. In particular, the robustness of the 'output gap solution' proposed in Giordani (2004) to alternative measures of variables and identification schemes is examined and a robust preferred VAR specification is proposed.

2 An Empirical Analysis of the Price Puzzle for the US

The empirical analysis estimates alternative VAR models that consider various measures of variables, identification schemes and specifications to examine whether or not a price puzzle is present under various model specifications. The empirical analysis is conducted using quarterly data for the US over the sample period 1967q1 to 2010q2. A description of the data series is given in the Data Appendix.

2.1 Measurement

We first investigate the robustness of the output gap solution proposed in Giordani (2004) to alternative measures of output gap and inflation. We consider a simple VAR model consisting of output gap, inflation and interest rate $X_t = [y^g_{t,}\pi_t, r_t]$. The VAR model is estimated using two alternative measures of the output gap: the Congressional Budget Office measure ($y_t^{g\text{-}CBO}$) and the Greenbook real time measure ($y_t^{g\text{-}GB}$), two popular measures of inflation: the rate of change in the CPI (π_t^{CPI}) and the rate of change in the GDP deflator (π_t^{GDP}), and the monetary policy shock is identified using a typical recursive ordering.

Figure 1 displays the impulse response functions of inflation to a one standard deviation interest rate innovation from the estimated VAR model over four combinations of the respective measures (the dashed lines represent $+/-$ two standard error bands). Table 1 summarizes the results with regard to whether or not a price puzzle is observed. Figure 1 shows that the two measures of the output gap do not produce a significant difference in the dynamic response of inflation to the interest rate innovation, whilst a significant difference is observed for the two measures of inflation. With the π_t^{CPI} measure and either measure of the output gap, the impulse responses of inflation suggest a price puzzle which is close to being statistically significant when $y_t^{g\text{-}GB}$ is used. In contrast, with π_t^{GDP}, a price puzzle is not produced, although there is a prolonged response of inflation to the interest rate innovation.

These results suggest that the GDP deflator measure of inflation enables a more accurate estimate of the monetary policy shock.

Insert Fig 1 and Table 1 here

2.2 Identification

We then investigate the sensitivity of the output gap solution to an alternative identification scheme. The recursive ordering scheme used above assumes that the monetary authority has contemporaneous information about output and inflation when setting the policy instrument. This scheme has been criticized for being inconsistent with the ac-

tual timing of information flows (McCallum, 1999 and Orphanides, 2001). An alternative scheme that is also widely adopted (Leeper et al, 1996, Sims and Zha, 2006 and Garret et al, 2006) is to assume that the interest rate is set based on information on output and inflation from the previous period. This identification scheme is relatively more general in that it assumes that the monetary policy instrument is not contemporaneously affected by movements in output and prices. This structure is reflected in the VAR model $X_t = [r_t, y_t^g, \pi_t]$ with zero restrictions imposed only on the first row of the contemporaneous matrix (i.e., the first row reads as [1 0 0]).

Figure 2 plots the impulse responses of inflation to an interest rate innovation from the estimated VAR model over the four combinations of the alternative measures of the output gap and inflation and Table 2 summarizes the results. A striking finding is that the change in the identification scheme leads to significant differences in the dynamic response of inflation to the interest rate innovation, at least over the short horizon. A price puzzle is now observed in all cases. In particular, the price puzzle is large and significant when the π_t^{CPI} measure of inflation is used. When the π_t^{GDP} measure of inflation is used, the dynamic responses of inflation exhibit a smaller price puzzle which is also marginally significant. Further, in contrast to Figure 1, the impulse responses seem to be more plausible given the shorter duration associated with the dissipation of the interest rate innovation.

These results imply that the ability of the output gap to resolve the price puzzle crucially depends on the assumptions used to identify the monetary policy shock.

Insert Fig 2 and Table 2 here

2.3 Misspecification

Finally, we examine the misspecification issue by comparing impulse responses of inflation to an interest rate innovation generated from several specifications. The first comparison concerns the choice of whether to include output growth or the output gap in the VAR model, which is motivated by the finding in Giordani (2004) in that it is the use of output instead of output gap that generates a price puzzle. Another comparison concerns the

importance of augmenting the VAR with timely forward-looking information available to decision-makers, such as direct measures of expected future inflation and output growth.

The use of expected inflation and output growth instead of other indicator variables that may contain information on future inflation and output can be justified on several grounds. First, whilst the inclusion of the typical indicator variables, such as commodity prices, have weak theoretical basis, the addition of direct measures of expectations is very much in keeping with standard New Keynesian models and have strong theoretical foundations in the analysis of monetary policy (Lubik and Schorfheide, 2004, Gali and Gertler, 2007). Second, the direct measures of expectations far outperform other forecasts of inflation (see Hanson, 2004 and Ang, Bekaert and Wei, 2007). Third, the inclusion of expectation variables provides a means to improve the measurement of the monetary policy shock in the presence of a change in monetary policy regime. Rather than conducting an analysis on sub-samples (see Castelnuovo and Surico, 2010) or working within a non-linear framework, inflation expectations can be used in the VAR to capture the additional information on future inflation that is not reflected in current inflation and thereby improve the specification of the VAR model. This is especially relevant for monetary policy regimes that are considered to be 'passive'.

In terms of the identification scheme we assume that contemporaneous values of macroeconomic variables are not available when forecasts are made, while the forecasts of inflation and output are available to policy-makers when interest rates are set. [1]

Figure 3 plots the impulse responses of inflation to an interest rate innovation from the following estimated VAR models: $\left(\widetilde{y}_t, \pi_t^{GDP}, r_t\right)$, $\left(r_t, \widetilde{y}_t, \pi_t^{GDP}\right)$, $\left(E_t\pi_{t+1}, E_t\Delta y_{t+1}, \widetilde{y}_t, \pi_t^{GDP}, r_t\right)$, $\left(E_t\pi_{t+1}, E_t\Delta y_{t+1}, r_t, \widetilde{y}_t, \pi_t^{GDP}\right)$, where $\widetilde{y}_t$ takes the form of either Δy_t or $y_t^{g\_CBO}$; Table 3 summarizes the results. Several clear findings emerge from these results. First, the addition of the expectation variables either eliminates or substantially mitigates the positive response of inflation to the interest rate innovation for both identification schemes. This highlights the importance of including direct measures of expectations in the VAR specification for a more accurate measure of the monetary policy shock. Second, including output gap instead of output growth yields a smaller positive response of inflation, although

[1] This is the assumption adopted in Leduc, Sill and Stark (2007) and Mehra and Herrington (2008).

the degree of uncertainty indicated by the confidence bands is of a similar magnitude. However, including output growth seems to produce more sensible dynamic responses of inflation to the interest rate innovation with a more reasonable rate of dissipation of the impact.

With regard to the misspecification issue, these results suggest that the preferred specification would be one that includes direct measures of expectations and with output growth as a measure for economic activity.

Insert Fig 3 and Table 3 here

3 Conclusion

With regard to the identification issue, the previously proposed 'output gap solution' was found to be markedly sensitive to a more general identification scheme. With regard to the accuracy of the estimated monetary policy shock, concerning both the measurement and misspecification issues, the paper found that the preferred VAR specification is one that includes direct measures of expectations, output growth as a measure of economic activity and the GDP deflator as a measure of inflation. Further, this specification was found to be robust to the two identification schemes considered.

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Data Appendix

Description of Data

Variable	Units	Period	Frequency
Real GDP (y_t)	bns of chained 2000 $	1967:1-2010:2	Quarterly
Consumer Price Index (π_t^{CPI})	Index 1982-84=100	1967:1-2010:2	3 mth average
Fed Funds Rate (r)	per cent	1967:1-2010:2	3 mth average
GDP deflator (π_t^{GDP})	Index 2000=100	1967:1-2010:2	Quarterly
CBO measure of potential GDP ($y_t^{g\text{-}CBO}$)	bns of chained 2000 $	1967:1-2010:2	Quarterly
Greenbook real time measure of output gap ($y_t^{g\text{-}GB}$)	per cent	1987:3-2004:4	Quarterly
Greenbook forecasts of inflation ($E_t\pi_{t+1}$)	annualised percentage points	1968:3-2004:4	Quarterly
Greenbook forecasts of output growth ($E_t\Delta y_{t+1}$)	annualised percentage points	1968:3-2004:4	Quarterly

Notes: The Greenbook projections of inflation and output growth are one quarter ahead forecasts of the quarter by quarter rates of change in the chain weighted GNP/GDP price index and real GNP/GDP, respectively. All the Greenbook projections are available from the Federal Reserve Bank of Philadelphia. The CBO measure of potential GDP is obtained from the Congressional Budget Office. All other data are from the Federal Reserve Bank of St. Louis Economic Database. The output growth rate, the federal funds rate, and both measures of inflation are generally treated as stationary series in the literature.[2] Standard tests for unit root suggest that both measures of the output gap considered are stationary. For all the VAR models estimated, the optimal lag length is chosen to be two lags by the Schwarz and Hannan-Quinn criteria.

[2]Unit root tests on the stationarity of the two measures of inflation for the sample period 1967q1 – 2010q2 produce mixed results, however, see Henry and Shields (2004) for a detailed examination on this issue.

Tables and Figures

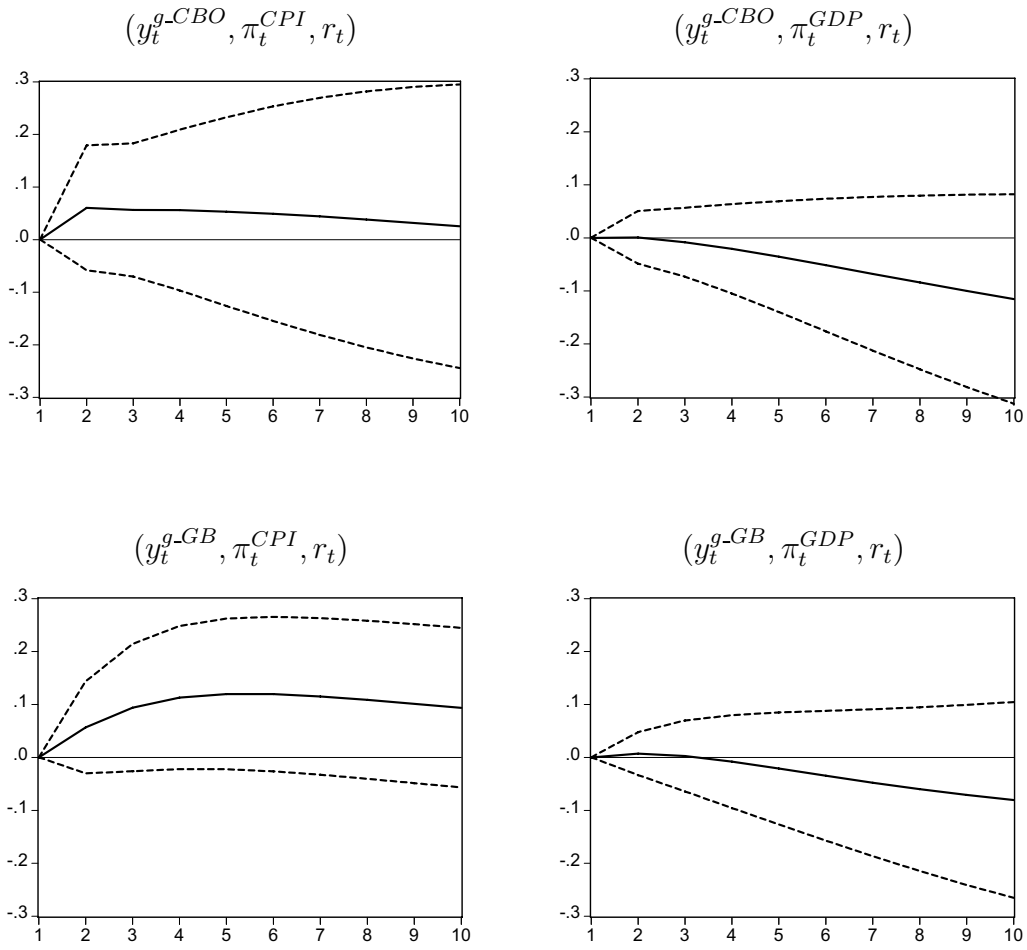

Figure 1: Impulse response functions of inflation to an interest rate innovation for the VAR model: (y_t^g, π_t, r_t)

Table 1
Response of inflation to an interest rate innovation
for the VAR model: (y_t^g, π_t, r_t)

Measure of Output gap	Measure of Inflation	Price Puzzle
CBO	CPI	Yes (not significant)
CBO	GDP	No (not significant)
GB	CPI	Yes (not significant)
GB	GDP	No (not significant)

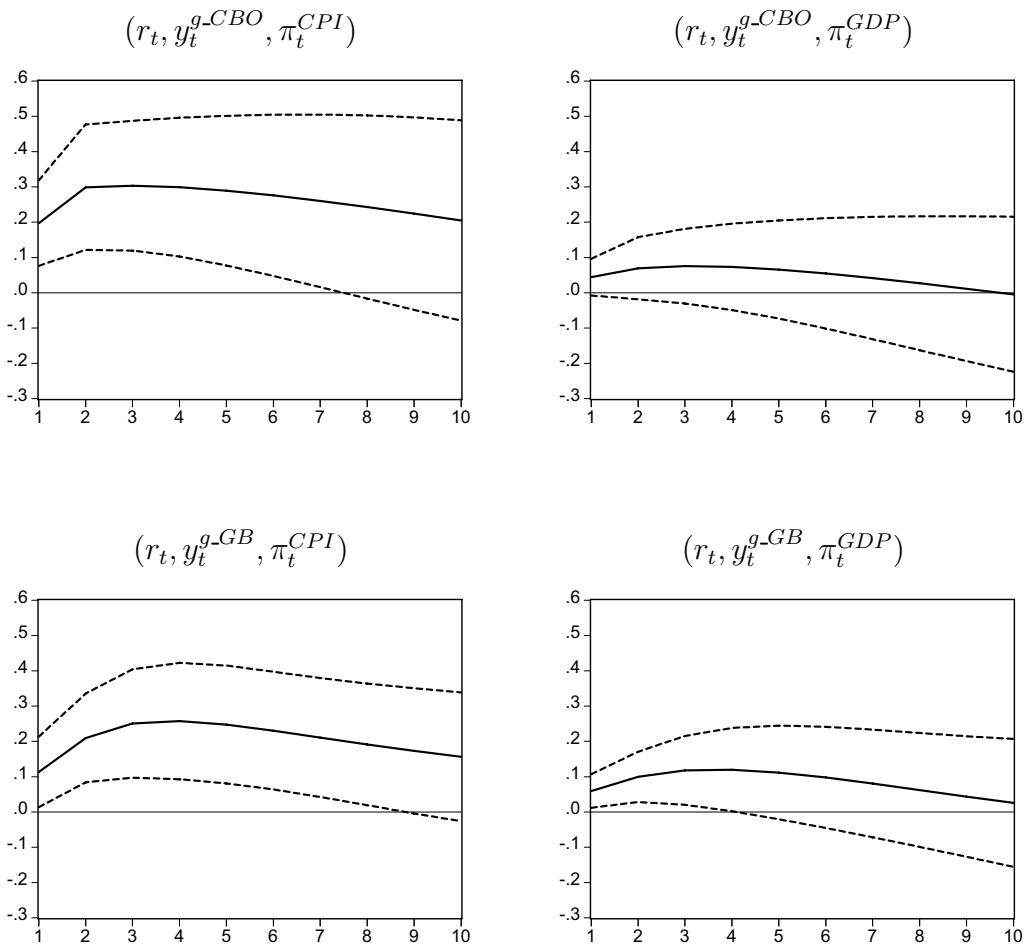

Figure 2: Impulse response functions of inflation to an interest rate innovation for the VAR model: (r_t, y_t^g, π_t)

Table 2
Response of inflation to an interest rate innovation
for the VAR model: (r_t, y_t^g, π_t)

Measure of Output gap	Measure of Inflation	Price Puzzle
CBO	CPI	Yes (significant)
CBO	GDP	Yes (not significant)
GB	CPI	Yes (significant)
GB	GDP	Yes (significant)

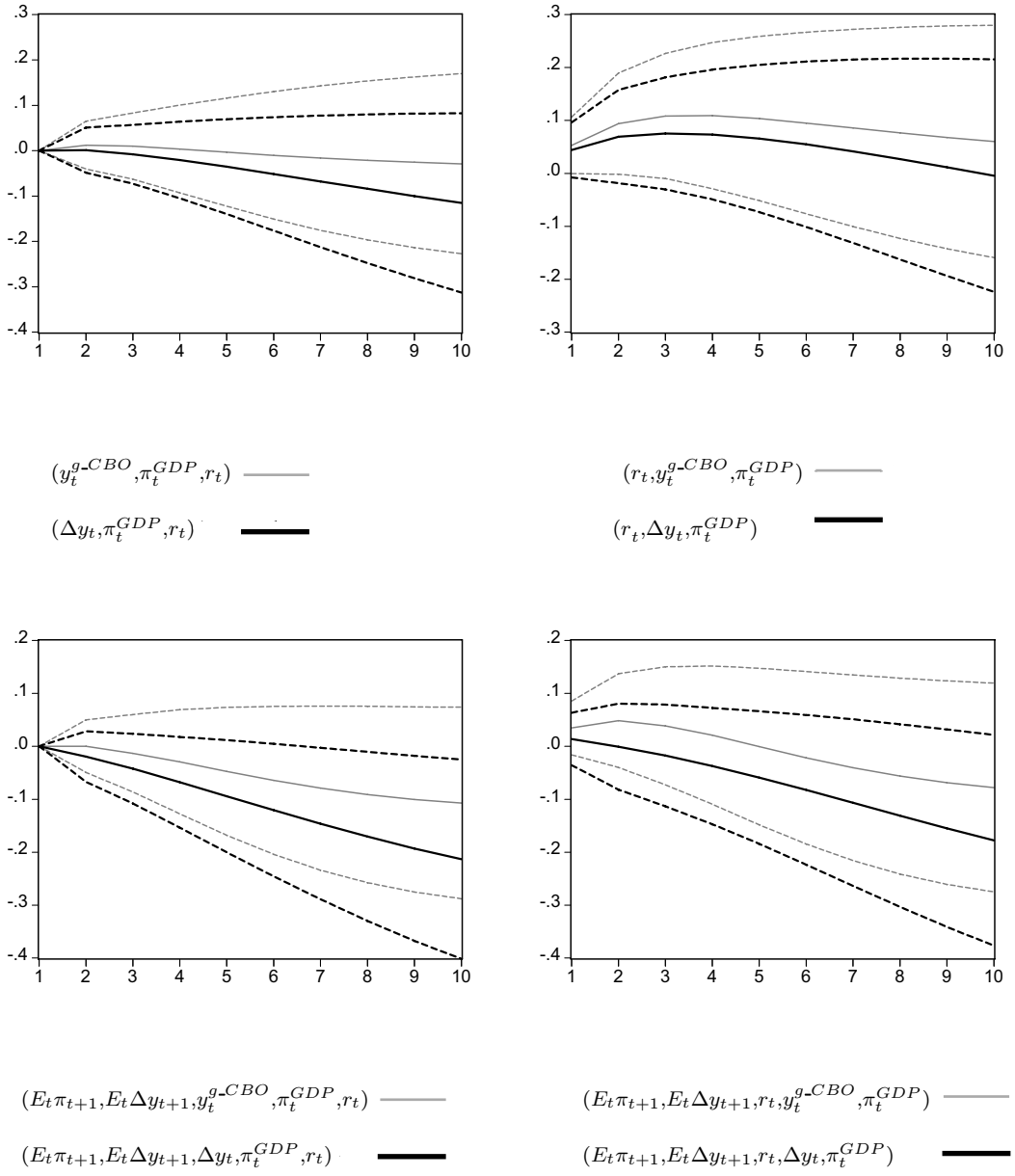

Figure 3: Impulse response functions of inflation to an interest rate innovation for alternative specifications of VAR models

Table 3
Response of inflation to an interest rate innovation
for alternative VAR specifications

VAR	Price Puzzle
$\Delta y_t, \pi_t^{GDP}, r_t$	Yes (not significant)
$y_t^{g\_CBO}, \pi_t^{GDP}, r_t$	No
$r_t, \Delta y_t, \pi_t^{GDP}$	Yes (not significant)
$r_t, y_t^{g\_CBO}, \pi_t^{GDP}$	Yes (not significant)
$E_t\pi_{t+1}, E_t\Delta y_{t+1}, \Delta y_t, \pi_t^{GDP}, r_t$	No
$E_t\pi_{t+1}, E_t\Delta y_{t+1}, y_t^{g\_CBO}, \pi_t^{GDP}, r_t$	No
$E_t\pi_{t+1}, E_t\Delta y_{t+1}, r_t, \Delta y_t, \pi_t^{GDP}$	Yes (not significant)
$E_t\pi_{t+1}, E_t\Delta y_{t+1}, r_t, y_t^{g\_CBO}, \pi_t^{GDP}$	No