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How to Improve Inflation Forecasting in Canada

by Troy Matheson

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How to Improve Inflation Forecasting in Canada

Prepared by Troy Matheson

Authorized for distribution by Cheng Hoon Lim

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Abstract

Against the backdrop of an ongoing review of the inflation-targeting framework, this paper examines the real-time inflation forecasts of the Bank of Canada with the aim of identifying potential areas for improvement. Not surprisingly, the results show that errors in forecasting non-core inflation (commodity prices etc.) are found to be the largest contributors to overall inflation forecast errors. Perhaps more importantly, relatively small core inflation forecast errors appear to mask large and offsetting errors related to the output gap and the policy interest rate, partly reflecting a tendency to overestimate the neutral nominal policy rate in real time. Faced with these uncertainties, the Governing Council's gradual approach to changing its policy settings appears to have served it well.

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Author's E-Mail Address: TMatheson@imf.org

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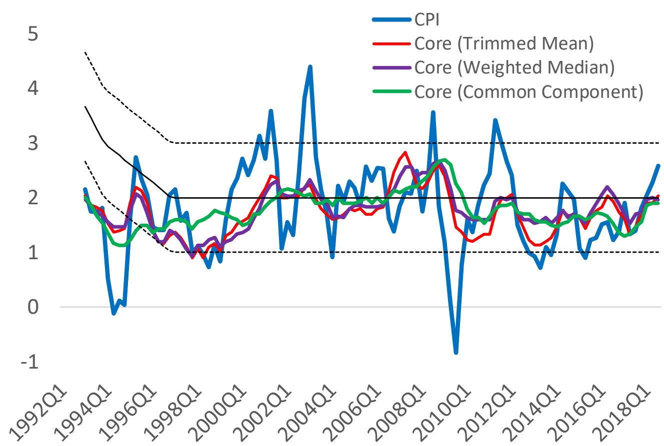
I. Introduction

The Bank of Canada has an outstanding record in achieving its inflation objectives. Since it began targeting inflation in 1992, the Bank of Canada has achieved great success in stabilizing inflation. Headline inflation has averaged close to the target of 2 percent, and inflation expectations have been firmly anchored through the ups and downs of the business cycle and bouts of external price shocks.

Figure 1. Canada: Inflation

(percent, year-over year)



Source: Statistics Canada and Bank of Canada

The Bank of Canada also has a strong track record at forecasting inflation. Quarterly economic projections made by Bank of Canada staff over a period spanning from 1982 to 2013 have recently been made publicly available, allowing researchers to assess the forecast accuracy of Bank of Canada staff in real time.[1] Champagne and others (2018a) found that staff's short-term forecasts for CPI inflation are significantly more accurate than forecasts produced by several commonly-used econometric models. At longer horizons, staff forecasts were found to compare favorably to forecasts made by Consensus Economics and have similar accuracy to the Governing Council's forecasts published in Monetary Policy Reports.[2]

How can inflation forecasts be improved? Given the importance of inflation forecasts in formulating monetary policy decisions in real time, the Bank of Canada is undoubtedly always looking for ways to improve its forecast accuracy. This paper assesses the time-series properties of inflation in Canada against other advanced economies. It then evaluates Bank of Canada staff's inflation forecast errors, with the view to highlight potential areas in which accuracy could be improved going forward.

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[1] See https://www.bankofcanada.ca/rates/staff-economic-projections/.

[2] Staff forecasts are a very important part of the analysis presented to the Governing Council every quarter in the weeks leading up to the publication of each Monetary Policy Report.

The paper proceeds as follows. Section B outlines the data used in the analyses. Section C compares the time series properties of inflation in Canada against other OECD countries, and assesses the stability of inflation expectations in Canada. Section D analyzes the forecasting performance of Bank of Canada staff over the inflation targeting period (1992-2013) and section E uses historical decompositions to identify the proximate sources of forecast error experienced over the sample. Section F highlights the importance of estimates of the output gap and the neutral nominal policy rate when forecasting inflation. Section G concludes with a summary of the key findings and policy conclusions.

II. DATA

The data used come from several sources. The time-series properties of inflation are examined using quarterly OECD data ranging from 2000 to 2018. Core inflation, in this context, is headline CPI inflation excluding Food and Energy. For the Canada-specific analysis, multiple data sources are examined, including data from Statistics Canada, the Bank of Canada, and Consensus Economics. Here, the definition of core inflation is determined by data availability in the Bank of Canada's real time database. Specifically, core inflation is defined as the CPI excluding Food and Energy from 1980Q1 to 2001Q1, and as the CPI excluding the 8 most volatile components from 2001Q2 to 2013Q4.[3]

III. TIME SERIES PROPERTIES OF INFLATION

Since 2000, inflation in Canada has averaged close to the rates seen in other advanced economies, while Canadian inflation outcomes have tended to be less volatile. Table 1 displays means and standard deviation of headline CPI inflation, core inflation, and non-core inflation for Canada and similar statistics for other OECD countries. While there is clearly a diversity of outcomes across the OECD, the results generally show that:

- Canadian inflation (headline, core, and non-core) has averaged very close to the OECD median countries (around 2 percent).
- Headline and core inflation have been less volatile than the median OECD country, while non-core inflation has been slightly more volatile than the median OECD country. Lower volatility could reflect a few factors, including more stable inflation expectations and less inflation persistence and more stable inflation expectations in Canada

Table 1. Canada: Inflation Statistics since 2000
(percent, year-over year)

	Canada	OECD *(median)*	OECD *(range)*
CPI Inflation			
Mean	1.9	2.0	[0.1, 4.6]
Std. Dev	0.8	1.2	[0.7, 3.2]
Core Inflation			
Mean	1.7	1.7	[-0.2, 4.7]
Std. Dev	0.6	0.8	[0.3, 2.8]
Non-Core Inflation			
Mean	2.8	2.7	[0.7, 5.9]
Std. Dev	4.4	3.5	[2.1, 6.7]

Source: OECD and staff estimates

[3] Both measures exclude the effects of changes in indirect taxes.

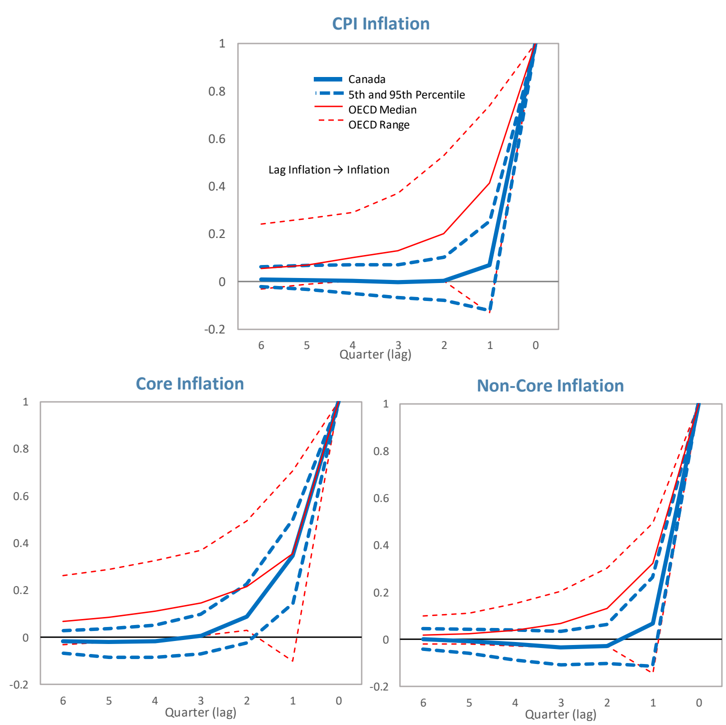
A. Inflation Persistence

Inflation in Canada has been far less persistent than inflation in other advanced economies. Figure 2 displays the persistence of quarterly inflation rates in Canada and other OECD countries, as measured by autocorrelation functions.[4] The results show that inflation is less persistent in Canada than in other countries. For headline inflation and non-core inflation, past inflation rates have no significant predictive power for inflation outcomes. There is slightly more persistence in Canada's core inflation, but it has also tended to be less persistent than core inflation in other countries. Over this sample, the evidence suggests that core inflation has statistically significant predictive power (albeit limited) for core inflation one quarter into the future and not beyond.

Core inflation has limited predictive power to forecast headline inflation in Canada. Figure 3 displays cross-correlations between the different inflation rates. Unlike in other OECD countries, past core inflation rates in Canada have no statistical power in predicting headline inflation at any horizon. Indeed, the results suggest that headline inflation is a better predictor of core inflation than the other way around, albeit with less predictive power than seen in the typical OECD country.

Figure 2. Canada: Inflation Persistence

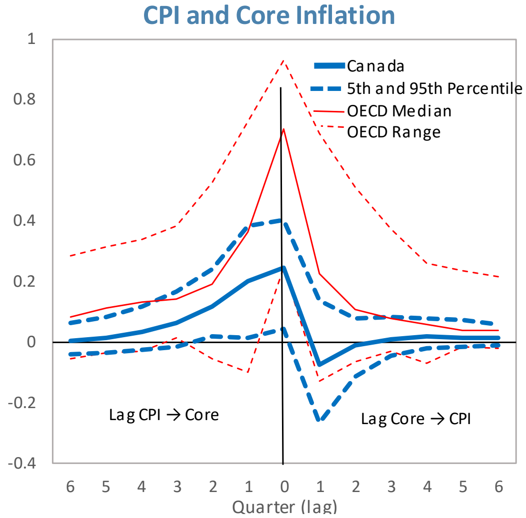
(autocorrelations, quarter-on-quarter)



Source: Staff estimates

[4] The statistics are derived from a vector-autoregressive model (VAR) containing quarterly inflation rates for headline CPI, core CPI, non-core CPI, the output gap (HP-filtered), and the short-term policy rate. The VAR includes 2 lags and is simulated 1000 times using bootstrapping methods.

Figure 3. Canada: Inflation Cross-Correlations
(cross correlations, quarter-on-quarter)

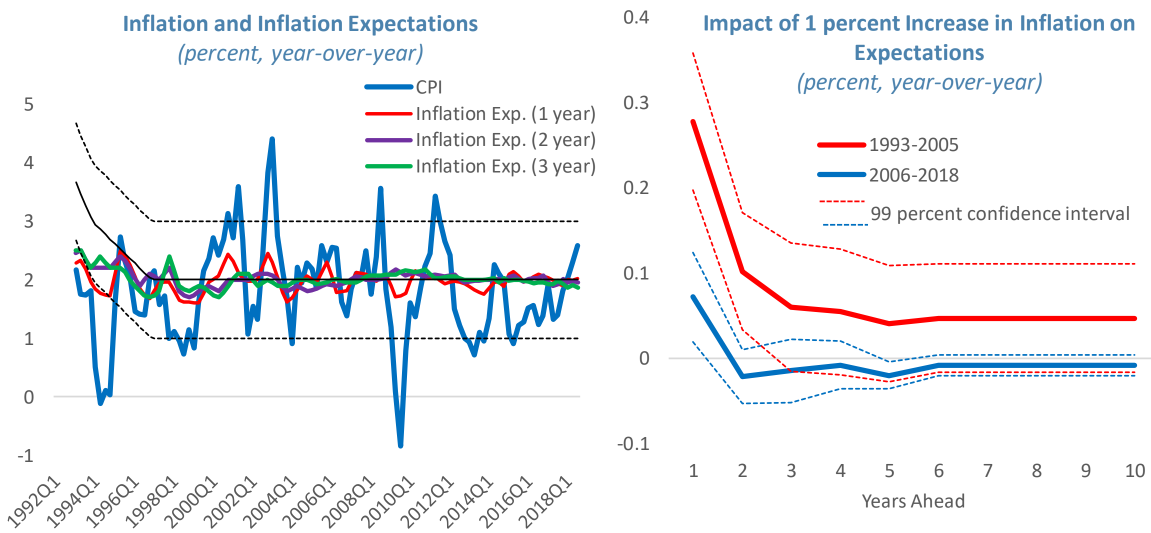


Source: Staff estimates

B. Inflation Expectations

Inflation expectations are remarkably stable, and they have become more anchored over time. The Bank of Canada's proven track record in keeping inflation close to target over time has made monetary policy highly credible. Private sector forecasters generally expect inflation to converge rapidly to the inflation target (figure 4, left-hand side). The credibility of the Bank of Canada in achieving its inflation objective has also improved since the early days of inflation targeting. Figure 4 (right-hand side) shows that the current level of inflation has a very limited impact on the way forecasters see inflation evolving in the future, and that this impact has declined over time. Essentially, because the Bank of Canada is viewed as highly credible in returning inflation back to target, forecasters effectively disregard the current level of inflation when forming their views about future inflation.

Figure 4. Canada: Inflation and Expectations [1/]



[1/]The chart on the right displays the estimated coefficients from regressions of annual inflation expectations from Consensus Economics on current levels of annual inflation. Both variables are expressed as deviations from the inflation target.

Source: Consensus Economics, Bank of Canada Staff estimates

IV. Bank of Canada Staff's Inflation Forecast Errors

A. Inflation Forecast Errors

Inflation forecast errors are errors made when predicting annual inflation at various horizons. The annual inflation forecast error at horizon h is defined to be the difference between observed annual inflation in period $t+h$ and the inflation forecast for period $t+h$ made in period t. Specifically, the inflation forecast error is:

$$e_{t+h} = \pi^4_{t+h} - E_t\pi^4_{t+h} \quad (1)$$

where e_{t+h} is the inflation forecast error, for year-over year inflation, π^4_{t+h}, based on the expectation (forecast) of inflation (year-over year) formed in period t, $E_t\pi^4_{t+h}$. The inflation forecast errors described below related to a sample period beginning in 1992Q1 and ending in 2013Q4. The mean forecast error (or 'bias') and mean-squared forecast error (MSE) are then, respectively: E_te_{t+h}, and $E_te^2_{t+h}$.[5]

Three different models are used to examine the forecasting performance of Bank of Canada staff for both headline and core inflation. All forecasts are produced using the same data that were available to the Bank of Canada in real time. The models are:

[5] In the terminology of Champagne and others (2018a), all forecasts have the same 'jump-off' point, period t.

- *Simple Model:* This is a very simple model of Canadian economy that includes a Phillips curve, an IS curve, and a Taylor-type policy rule. The model also allows for the endogenous estimation of the key trends in the economy; potential output, the trend real interest rate, and the neutral nominal policy rate. The model is estimated using Bayesian methods over a sample ranging from 1992 to 2018.[6]

- *Consensus Economics:* This model simply takes the average forecast from Consensus Economics for horizon h as the forecast for annual headline inflation and core inflation.

- *Inflation Target.* This model simply takes the inflation target as the forecast for both annual headline inflation and core inflation at all horizons.

The overall accuracy of staff forecasts is good compared to the other forecasting methods examined, although there appears to be some room for improvement along several dimensions. Forecast error statistics are displayed in table 2. Overall, the forecast comparisons show:

- *Bias.* Staff forecasts are less biased than forecasts from the other models, both for headline inflation and core inflation. All other models tend to over predict inflation, particularly for core inflation.

- *MSE.* For headline inflation, staff forecasts tend to be more accurate than the other methods up to two years ahead. However, at a horizon of three years, the simple model and the inflation target produce more accurate results. For core inflation, the results are less positive. While the improvements tend not to be statistically significant, the simple model and the inflation target yield more accurate forecasts than Bank of Canada staff at most horizons.

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[6] See the appendix for more details on the model and An and Schofheide (2007) for more details on Bayesian estimation.

Table 2. Canada: Inflation Forecast Errors

	Bias			MSE		
h (quarters ahead)	4	8	12	4	8	12
Headline Inflation						
BoC Staff	0.04	0.02	0.00	0.78	0.82	0.83
	[0.38]	[0.39]	[0.40]			
Simple Model	-0.39	-0.33	-0.18	0.99	0.97	0.69
	[0.01]	[0.06]	[0.16]	[0.17]	[0.33]	[0.09]
Consensus Economics	-0.31	-0.35	-0.29	1.08	1.20	0.86
	[0.08]	[0.09]	[0.11]	[0.13]	[0.26]	[0.39]
Inflation Target	-0.19	-0.28	-0.22	0.93	1.04	0.81
	[0.19]	[0.13]	[0.17]	[0.14]	[0.28]	[0.38]
Core Inflation						
BoC Staff	0.08	0.11	0.05	0.33	0.51	0.33
	[0.29]	[0.31]	[0.37]			
Simple Model	-0.44	-0.35	-0.25	0.40	0.29	0.22
	[0.00]	[0.00]	[0.00]	[0.32]	[0.28]	[0.25]
Consensus Economics	-0.36	-0.36	-0.36	0.34	0.36	0.35
	[0.00]	[0.00]	[0.00]	[0.39]	[0.27]	[0.38]
Inflation Target	-0.24	-0.29	-0.28	0.23	0.28	0.29
	[0.00]	[0.00]	[0.00]	[0.18]	[0.25]	[0.36]

[ ] HAC-adjusted p-value (Newey-West lag length is *h* - 1). P-values relate to the significance of the constant in Diebold and Mariano (1995) regressions. For MSEs, the test is in relation to the BoC Staff forecast.

Source: Bank of Canada and staff estimates

V. What Went Wrong?

Not surprisingly, unforeseen shocks to non-core inflation are by far the largest contributors to Bank of Canada staff's overall inflation forecast errors.[7] Figure 5 displays contributions to staff's headline inflation errors from errors in predicting core and non-core inflation. Non-core inflation forecast errors account for by far the largest share of staff's inflation forecast errors. The largest forecast errors occurred during episodes with particularly large fluctuations (non-core) in commodity and oil prices, particularly around the global downturn in the early 2000s, and around the global financial crisis and the early part of the recovery (2008-2011). While smaller in magnitude, core inflation forecast errors tended to have a negative impact on forecast accuracy in the latter part of the sample (2011 to 2015), reflecting a tendency of staff to overpredict core inflation.

Shock decompositions can provide more information on the key contributors to forecast errors. A historical shock decomposition of inflation can be made at any point in time. These

[7] This analysis uses $e_{t+h}=\alpha e^{c}_{t+h} + (1-\alpha)e^{x}_{t+h}$ (see equation 1 and the appendix).

decompositions essentially decompose the level of inflation into contributions from idiosyncratic shocks that have hit the economy up to that point, where the idiosyncratic shocks are determined by the structure and dynamics underpinning the model being used to compute the decomposition. A historical shock decomposition for headline inflation in quarter *t* is:

$$\pi_t^4 - \pi_t^* = \sum_{i=1}^{N} H_t^i \tag{2}$$

where H_t^i is the shock contribution to the deviation of annual headline inflation from the inflation target π_t^* from the *i*th shock, where *N* is the number of shocks contained in the structural model. Using the simple model described in section D, the shock depositions (H_t^i) of inflation from 1992 to 2018 are displayed in figure 6 (top left panel). Since the global financial crisis, this decomposition shows that:

- Negative demand shocks (the output gap) have been a significant drag on inflation and these shocks have been broadly offset by accommodative monetary policy settings (policy rate shocks).

- Non-core inflation is a significant contributor to the volatility of headline inflation. More recently, idiosyncratic shocks to core inflation have also acted to reduce overall inflation.

Shock decompositions suggest errors in predicting non-core inflation, the output gap, and the policy rate are key sources of forecast errors. Figure 6 displays historical shock decompositions of staff's inflation forecast errors. Here, the decompositions are the difference in shock contributions to headline inflation from the simple model described above (figure 6, top left panel) and decompositions computed using staff's real-time forecasts.[8] Specifically, forecast errors are decomposed using:

$$e_{t+h} = \sum_{i=1}^{N} (H_{t+h}^i - E_t H_{t+h}^i) \tag{3}$$

where $E_t H_{t+h}^i$ is the expected contribution to headline inflation (deviation from target) from shock *i* at horizon *h* formed in period *t*, and $H_{t+h}^i - E_t H_{t+h}^i$ is the contribution to the overall forecast error from the *i*th shock at horizon *h*. The results from the historical shock decompositions of staff's forecast errors over the last 15 years of the sample show that:

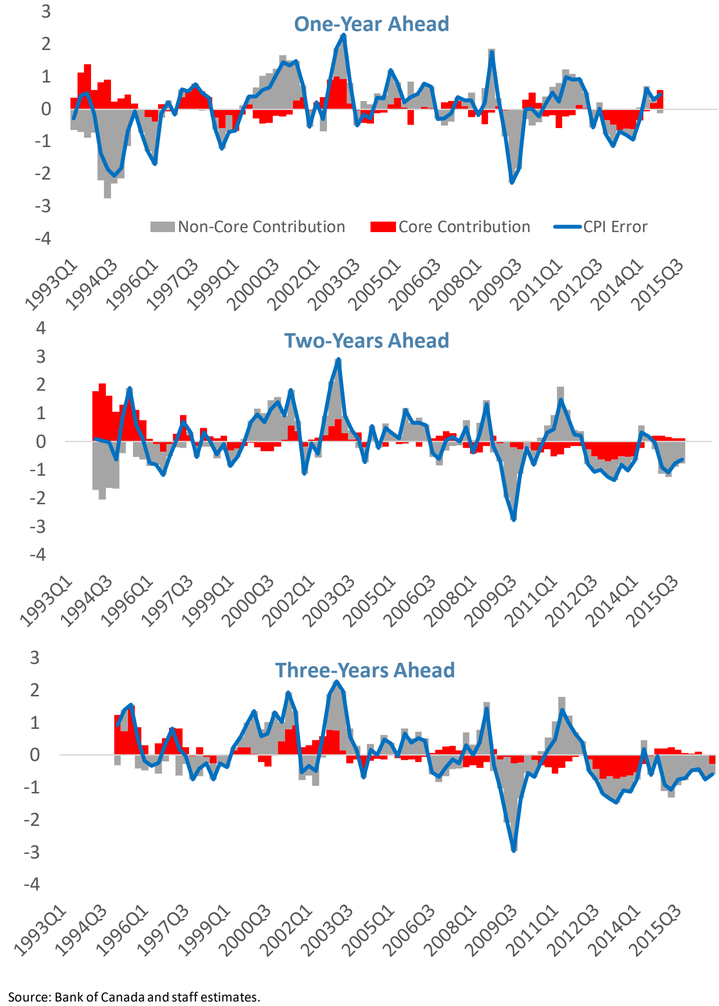
- Consistent with the previous results, idiosyncratic shocks to non-core inflation are key contributors to the largest inflation forecast errors.

- At longer forecasting horizons, errors in predicting the output gap and the policy rate play an increasingly important role. In real time, the simple model suggests that staff generally expected the output gap to be stronger and the policy interest rate more contractionary than observed ex-post.

[8] The real-time historical shock decompositions of staff forecasts are computed by running a Kalman filter over the observable data contained in the Bank of Canada's real-time database in each quarter, including the projection period.

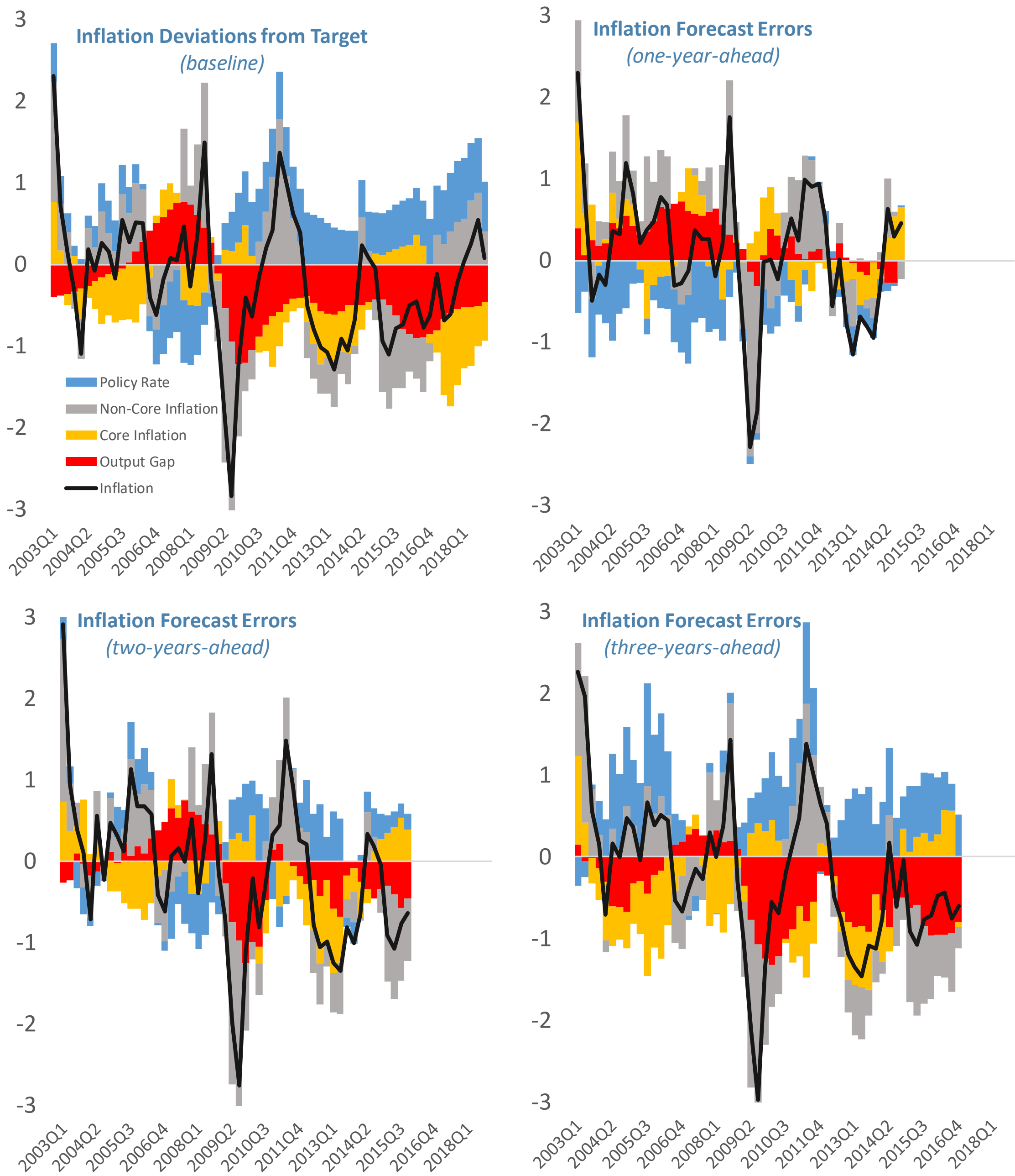
Figure 5. Canada: Inflation Forecast Errors and Contributions

(percent, year-over-year)



Source: Bank of Canada and staff estimates

Figure 6. Canada: Historical Shock Dompositions: Inflation and Forecast Errors
(percent, year-over-year; deviations from target; bars are contributions from shocks)



Source: Bank of Canada and staff estimates

VI. The Output Gap and the Neutral Nominal Policy Rate in Real Time

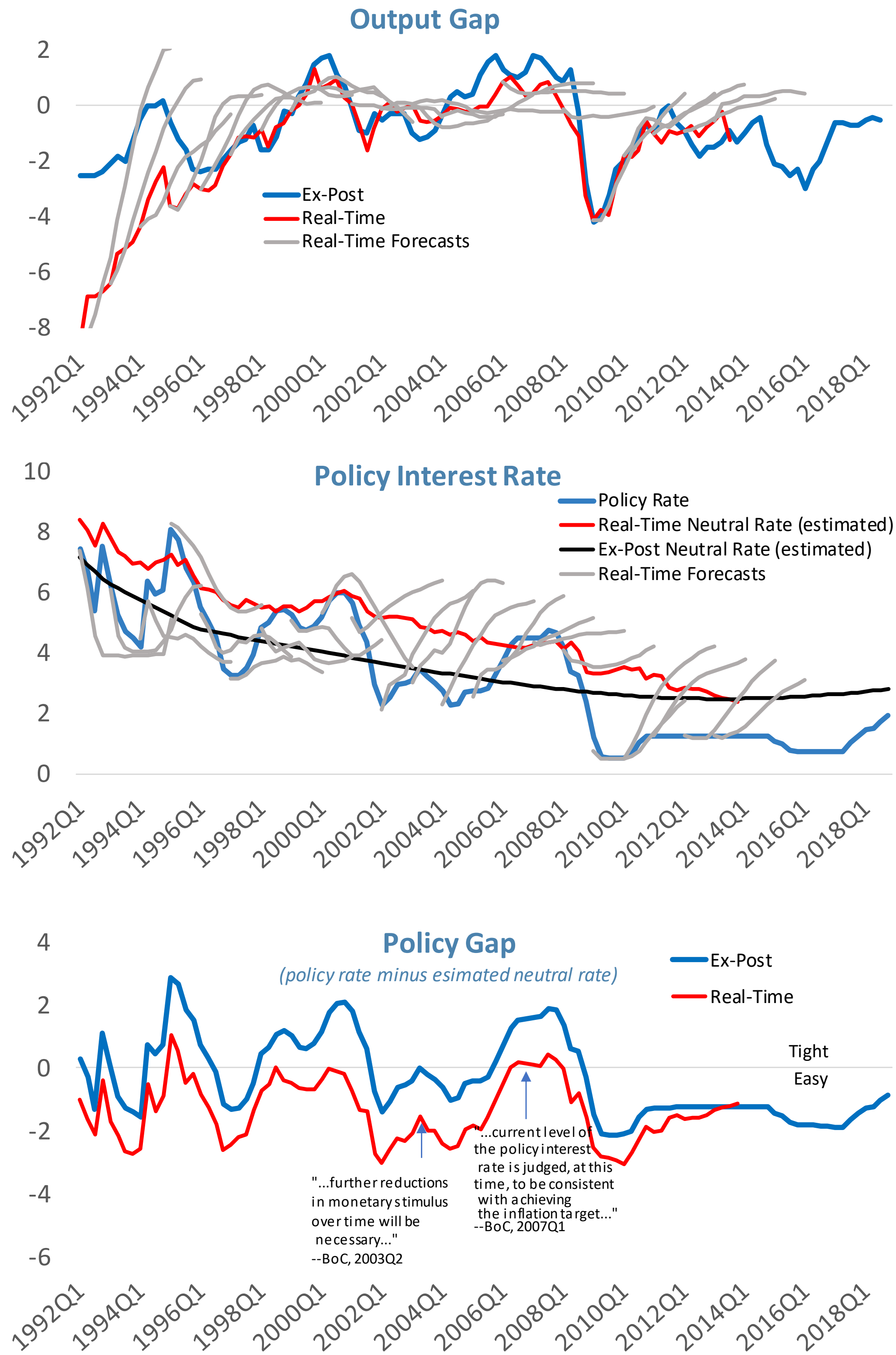
Estimates of the output gap and the neutral policy interest rate are crucial for making and communicating policy decisions in real time. Figure 7 shows the evolution of the output gap, the policy rate, and the neutral policy rate estimated using data from the whole sample and real-time estimates from Bank of Canada staff. Because the neutral policy rate is not available in the real-time database, the estimates of the neutral policy rate and the policy gap are made using the simple model described in section D.[9]

Bank of Canada staff have tended to overpredict the output gap and the policy interest rate. As discussed in Champagne (2018b), the magnitude of revisions to real-time estimates of the output gap have generally fallen over time. Consistent with the results from the forecast error decompositions displayed in figure 6, Bank of Canada staff appear to have tendency to overpredict the output gap when making their forecasts, particularly over 1993-1998 and 2011-2014. Staff have also had the tendency overpredict the policy interest rate. Real-time estimates from the simple model suggest that staff might have been systematically overestimating the neutral policy rate over history, and this could have contributed to projections of the policy rate that turned out to be too high ex-post. This is not surprising, given the large and largely unforeseen fall in global interest rates that has occurred over the past 30 years.

Overstating the level of the neutral policy rate would lead to very different perceptions of the policy stance (policy gap) in real time. Given real-time estimates of the neutral policy rate, the estimated policy gap is much lower than the gap estimated with all available data. Specifically, estimates from the simple model suggest that the monetary policy was likely perceived to be more accommodative than it was in real time. There also appears to be some support for this view in communications by Bank of Canada that were made in real time.

[9] The real-time estimates of the output gap, neutral policy rate, and policy gap are estimates for the current quarter in each forecast vintage (e.g. the real-time output gap in 2000Q1 is the estimated output gap in 2000Q1 from the 2000Q1 forecast vintage dataset).

Figure 7. Canada: Real-Time Output Gap and Policy Rate
(percent)



Source: Bank of Canada and staff estimates

The starting point of a forecast is crucial for determining the policy settings necessary to achieve an inflation objective. Given the lags in the transmission mechanism of monetary policy, central banks focus on inflation forecasts when determining their policy settings. For example, all else equal, estimates of the output gap that are too low will eventually lead a higher-than-expected inflation and may necessitate a higher-than-expected policy rate. Likewise, overestimating the neutral rate of interest in real time would lead to a monetary policy stance that would be perceived to be more accommodative than the actual policy stance in real time, and eventually lead to less monetary tightening than expected. In both these cases, uncertainty about the starting point is crucial in determining the appropriate monetary policy stance in real time, and highlight the risks associated with communication errors, policy reversals, and the potential for an erosion of policy credibility over time.

Do starting point errors impact inflation forecast errors in Canada? To answer this question, a simple model is estimated. Staff's core inflation forecast errors $e_{t+h}^{\pi^c}$ are explained by:

$$e_{t+h}^{\pi^c} = a + be_t^y + ce_{\mathrm{t}}^{(R-R^*)} + \varepsilon_t \tag{4}$$

where e_t^y is the starting-point error in estimating the output gap in real time, and $e_{\mathrm{t}}^{(R-R^*)}$ is the starting-point error in estimating the nominal policy gap in real time.[10] *a*, *b*, and *c* are constants and ε_t is an idiosyncratic shock. The significance of *b* and *c* indicate whether starting-point errors help to explain core inflation forecast errors. Estimates are made at three different forecast horizons for both the whole sample and the second half of the sample and are displayed in table 3.

Table 3. Canada: Explaining Staff's Core Inflation Forecast Errors

	One-Year-Ahead (h=4)			***Two-Years-Ahead (h=8)***			***Three-Years-Ahead (h=12)***		
Sample: 1992 to 2013	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Output Gap Error	0.17	0.17		0.29	0.30		0.17	0.16	
	[0.00]	[0.00]		[0.01]	[0.00]		[0.00]	[0.01]	
Policy Gap Error	0.16		0.25	0.18		0.34	-0.10		-0.01
	[0.24]		[0.09]	[0.27]		[0.03]	[0.29]		[0.40]
Constant	-0.27	-0.07	-0.24	-0.38	-0.15	-0.33	0.03	-0.09	0.05
Adj. R-Squared	0.22	0.21	0.05	0.44	0.42	0.06	0.17	0.17	-0.01
Sample: 1996 to 2013									
Output Gap Error	0.09	0.09		-0.03	0.03		0.08	0.08	
	[0.38]	[0.17]		[0.34]	[0.34]		[0.17]	[0.17]	
Policy Gap Error	0.26		0.27	0.35		0.33	-0.03		0.02
	[0.09]		[0.07]	[0.04]		[0.07]	[0.39]		[0.39]
Constant	-0.36	-0.05	-0.36	-0.49	-0.08	-0.49	-0.03	-0.07	-0.04
Adj. R-Squared	0.08	0.01	0.09	0.19	-0.01	0.19	0.02	0.03	-0.01

[ ] HAC-adjusted p-value (Newey-West lag length is *h* - 1)

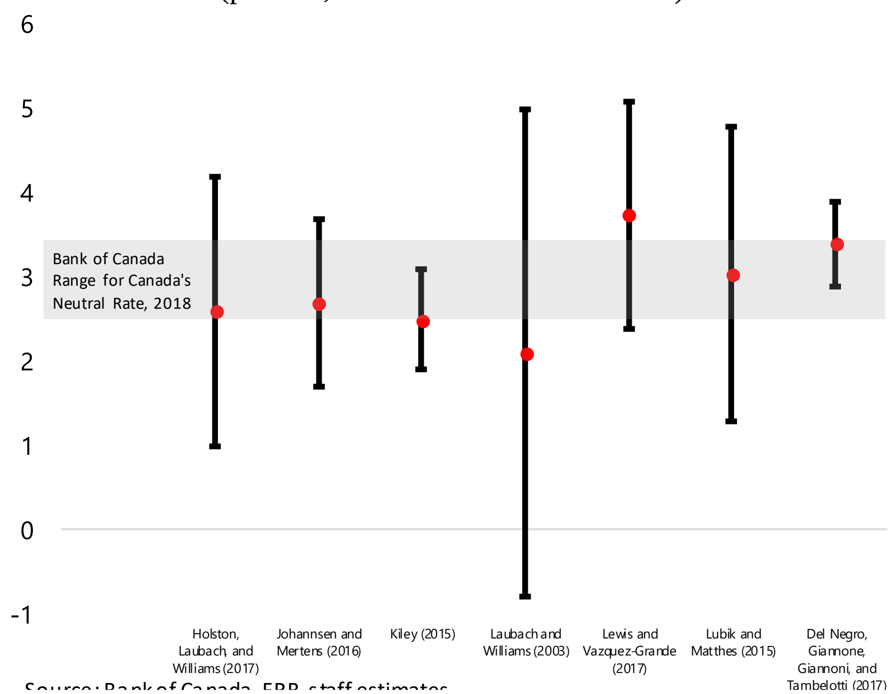
Source: Bank of Canada and staff estimates

[10] The output gap starting-point error is derived from Bank of Canada staff's real-time database. The nominal policy-gap starting-point error, on the other hand, is estimated using the neutral nominal rate derived from the data available in each real-time database.

Errors in estimating the neutral policy rate and the output gap in real time help to explain staff's inflation forecast errors. Over the whole sample, real time errors in estimating the output gap contribute to inflation forecast errors at all three forecasting horizons examined. Over the most recent sample, errors in estimating the policy-rate gap appear to be more useful at explaining forecast errors at horizons of one- and two-years ahead. Overall, the results show the importance of starting point estimates of the output gap and the policy rate gap when forecasting inflation and determining the appropriate monetary policy stance in real time.

Uncertainty about the neutral nominal policy rate is high, suggesting that a cautious approach to monetary policymaking is warranted. Figure 8 displays estimates of the neutral nominal policy rate in the U.S. and uncertainty around those estimates, and the range of estimates recently published by the Bank of Canada. As mentioned above, estimates of global neutral interest rates have been trending down for the past 30 years. Recent estimates for the U.S. and Canada suggest the rate is somewhere around 3 percent in each country, but there is a significant amount of uncertainty around these estimates; the uncertainty bands displayed in figure 8 for the U.S., for example, indicate only a 70 percent level of confidence.

Figure 8. Canada: Recent Estimates of Neutral Policy Rate (U.S.)
(percent, +/- one standard deviation)



Source: Bank of Canada and staff estimates

VII. Summary and Policy Messages

The Bank of Canada has an outstanding record in achieving its inflation objective. Since it began targeting inflation in 1993, the Bank of Canada has achieved great success in stabilizing inflation. Headline inflation has averaged close to the target of 2 percent, and inflation expectations have been firmly anchored through the ups and downs of the business cycle and bouts of external price shocks. Since 2000, inflation in Canada has averaged close to the rates seen in other advanced economies, and Canadian inflation outcomes have tended to be less volatile. Inflation is also less persistent than seen in other advanced economies, reflecting very stable inflation expectations and the strong credibility of the Bank of Canada.

Bank of Canada staff have a good track record at forecasting inflation, although there appears to be some room for improvement along several dimensions. Staff forecasts are less biased than forecasts from the other models, both for headline inflation and core inflation. On a mean-squared error basis, staff forecasts tend to be more accurate for headline inflation than the other methods examined up to two years ahead. However, at a horizon of three years, more simple forecasting models are at least as accurate (and, depending on the model, sometimes more accurate) than staff forecasts. While the improvements tend not to be statistically significant, the analysis shows that the core inflation forecasts of the Bank of Canada have tended to be less accurate than forecasts produced by both private sector forecasters and more simple forecasting models.

Not surprisingly, unforeseen shocks to non-core inflation (commodity prices etc.) are by far the largest contributors to Bank of Canada staff's overall inflation forecast errors. The largest forecast errors have occurred during episodes with particularly large fluctuations in (non-core) commodity and oil prices, particularly around the global downturn in the early 2000s, and around the global financial crisis and the early part of the recovery (2008-2011). While smaller in magnitude, core inflation forecast errors have tended have a negative impact on forecast accuracy in the latter part of the sample (2011 to 2015), reflecting a tendency of staff to overpredict core inflation.

Staff's core inflation errors have generally been quite low, but this seems to mask large and offsetting errors in forecasting the output gap and the policy interest rate. At longer forecasting horizons, errors in predicting the output gap and the policy rate play an increasingly important role in explaining inflation forecast errors. A simple model suggests that staff generally expected the output gap to be stronger and the policy interest rate more contractionary than was observed ex-post. The results also show that starting-point errors in estimating the neutral policy rate and the output gap in real time appear to contribute to staff's inflation forecast errors.

Uncertainty about the neutral nominal policy rate and the output gap in real time, suggests that the Governing Council's cautious approach to monetary policymaking is warranted. Looking back, the Governing Council has followed a more gradual approach to adjusting its policy settings than suggested by Bank of Canada staff. Given significant uncertainty around real-time estimates of the neutral policy rate and the output gap, this approach seems appropriate. Staff forecasts—including for the neutral nominal policy rate—serve as key inputs into the policy deliberations of the Governing Council. In this context, the evidence presented here suggests that the Council might also have been systematically overestimating the level of the neutral nominal policy rate over the sample examined and likely tended to misperceive the degree of policy space in real time, which could suggest deficiencies in the communication of the policy stance in real time.

The results of this paper suggest that are several areas in which the Bank of Canada could improve its inflation forecasting performance. Improving real-time estimates of the output gap and neutral nominal policy rate would help to enhance forecast accuracy, and in the communication of the policy stance. Of course, finding ways to further enhance monitoring and forecasting of non-core inflation developments would also help to improve overall inflation forecasting performance. Amid all these uncertainties, the Governing Council's gradual approach to setting monetary policy appears to have served it well.

VIII. REFERENCES

An, S and F. Schofheide (2007). "Bayesian Analysis of DSGE Models", Econometric Reviews, 26(2-4), 113-172.

Champagne, J, Poulin-Bellisle, G, and R. Sekkel (2018a). "Evaluating the Bank of Canada Staff Economic Projections Using a New Database of Real-Time Data and Forecasts", Bank of Canada Staff Working Paper, 52.

Champagne, J, Poulin-Bellisle, G, and R. Sekkel (2018b). "The Real-Time Properties of Bank of Canada's Staff Output Gap Estimates", Journal of Money, Credit and Banking, 50 (6), 1167-1188.

APPENDIX I. DEFINITIONS AND MODEL

A. Definitions

(log) Real GDP	Y_t
(log) Potential real GDP	Y_t^*
Output Gap (%)	$y_t = 100 * (Y_t - Y_t^*)$
(log) CPI (same for core and non-core)	P_t
Inflation (quarterly, annualized, %)	$\pi_t = 400 * (P_t - P_{t-1})$
Inflation (year-on-year, %)	$\pi_t^4 = 1/4(\pi_t + \pi_{t-1} + \pi_{t-2} + \pi_{t-3})$
Inflation Target (year-on-year, %)	π_t^*
Neutral Real Interest Rate (annual, %)	r_t^*
Policy Interest Rate (annual, %)	R_t
Neutral Policy Interest Rate (annual, %)	$R_t^* = r_t^* + \pi_t^*$
Real Interest Rate (annual, %)	$r_t = R_t - E_t\pi_{t+1}$
Idiosyncratic Shock to x	ε_t^x

B. Model

IS Curve

$$y_t = \rho_1 E_t y_{t+1} + \rho_2 y_t + \rho_3(r_t - r_t^*) + \varepsilon_t^y$$

Phillips Curve (core inflation)

$$\pi_t^c = E_t \pi_{t+1}^c + \gamma y_t + \varepsilon_t^{\pi^c}$$

Non-Core Inflation

$$\pi_t^x = \omega \pi_{t-1}^x + (1-\omega)\pi_t^* + \varepsilon_t^{\pi^x}$$

Overall Inflation

$$\pi_t = \alpha \pi_t^c + (1-\alpha)\pi_t^x$$

Monetary Policy

$$R_t = \xi_1 R_{t-1} - (1-\xi_1)(R_t^* + \xi_2(\pi_{t+4}^4 - \pi_{t+4}^*) + \xi_3 y_t) + \varepsilon_t^R$$

C. Trends

Potential Output

$$Y_t^* - Y_{t-1}^* = Y_{t-1}^* - Y_{t-2}^* + \varepsilon_t^{Y^*}$$

Real Interest Rate

$$r_t^* = r_{t-1}^* + \varepsilon_t^{r^*}$$

Inflation Target

$$\pi_t^* = \pi_{t-1}^* + \varepsilon_t^{\pi^*}$$

D. Parameters[1]

	Prior Distribution (mean, std.)	*Posterior Mean*	*90 Percent Confidence*
ρ_1	$\Gamma(0.1,0.05)$	0.04	[0.01 ,0.06]
ρ_2	$\Gamma(0.5,0.05)$	0.71	[0.66 ,0.77]
ρ_3	$\Gamma(0.5,0.025)$	0.39	[0.36 ,0.42]
γ	$\Gamma(0.2,0.025)$	0.13	[0.10 ,0.15]
ω	$\beta(0.5,0.1)$	0.69	[0.61, 0.75]
α	Calibrated	0.85	
ξ_1	$\beta(0.9,0.025)$	0.74	[0.71 ,0.79]
ξ_2	$\Gamma(3,0.1)$	3.05	[2.88 ,3.22]
ξ_3	$\Gamma(0.2,0.025)$	0.23	[0.18 ,0.27]
Standard Deviations			
ε^y	$\Gamma^{-1}(1,\infty)$	0.59	[0.44 ,0.71]
ε^{π^c}	$\Gamma^{-1}(1,\infty)$	0.55	[0.44 ,0.66]
ε^{π^x}	$\Gamma^{-1}(1,\infty)$	6.18	[5.22 ,7.56]
ε^R	$\Gamma^{-1}(1,\infty)$	0.42	[0.34 ,0.48]
ε^{Y^*}	$\Gamma^{-1}(1,\infty)$	0.15	[0.13 ,0.19]
ε^{r^*}	$\Gamma^{-1}(1,\infty)$	0.02	[0.02 ,0.03]
ε^{π^*}	$\Gamma^{-1}(1,\infty)$	0.03	[0.02 ,0.04]

[1] Parameters estimated using Metropolis-Hastings, 1,000,000 draws, with a 50 percent burn.