Preliminary version

Output Gaps and Inflation in Canada: An Examination with Real-Time data[1]

by

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Abstract

The authors use a new real-time database for Canada to study various output gap measures. This includes recently-developed measures based on models incorporating a large number of variables as inputs (and therefore requiring real-time data for many variables). They analyze output gap revisions, which they find to be biased towards too much excess supply following the 2008-2009 recession, and assess the usefulness of these gaps in forecasting total CPI inflation and three newly developed measures of core CPI inflation: CPI-median, CPI-trim and CPI-common. Their analysis includes an assessment of whether labour-input gaps, projected output gaps and simple combinations of output gap add useful information for forecasting inflation. Similarly to what was found by Orphanides and van Norden (2015) for the United States, the authors find that most output gaps do not appear to add useful information in forecasting Canada's total CPI inflation. An exception could be a simplified version of the Integrated Framework, which appears to contain some information including when combined with other methods. The labour input gap measures the authors consider do not perform better at forecasting total CPI inflation. Similarly, neither output nor labour input gaps appear useful to forecast CPI-median inflation. However, some individual gaps and combinations of gaps, historical or forecasted, seem to add useful information for forecasting CPI-trim and, in particular, CPI common. Adding forecasted output gaps does not improve the results in general.

[1] The views expressed in this paper are solely those of the authors and may differ from official Bank of Canada's views. No responsibility for them should be attributed to the Bank.

1. Introduction

In many central banks, the link between inflation and the output gap is central to the conduct of monetary policy. The basic idea is that when the level of real GDP exceeds its potential[2] (the output gap is positive), the economy is subject to inflationary pressures. In such circumstances, inflation-targeting monetary authorities tend to tighten their policy in order to keep forecasted inflation at target. Conversely, they tend to ease their policy when real GDP is below potential. [3]

However, the usefulness of output gaps to forecast inflation has been questioned in the literature. In particular, Orphanides and van Norden (2005) conclude that while ex post output gaps (i.e. output gaps estimated with the latest available vintage of data) appear to help predict inflation in the United States, real-time output gaps (i.e. output gaps estimated with the data available at the time inflation forecasts are produced) do not. Indeed they find that, in real-time, models including output gaps often do not perform better in forecasting inflation than simple models including only information about past inflation and generally do worse than simple bivariate forecasting models incorporating information about past inflation and output growth. They show that the difference of information content between ex post and real-time output gaps partly reflects the large and persistent revisions to output gap estimates. This failure of real-time output gaps is very significant, as policymakers use an assessment of the output gap in real time.

Edge and Rudd (2016) re-examine the issue in a study of the information content of real-time Federal Reserve staff output gaps. They find that, when compared with simple autoregressive models of inflation, these gaps do not help forecast inflation in the United States for the period since the mid-1990s. A difference with van Norden and Orphanides (2005) is that Edge and Rudd find that this is true of both real-time and revised (ex post) output gaps. Data revisions therefore do not seem to be the cause for the lack of information content of output gaps in their study.

The conclusion that real-time output gaps do not help forecast inflation is not limited to United States data. Indeed, Cayen and van Norden (2002) examine the issue with Canadian data and they, too,

[2] Potential output can be defined as the level of output that can be sustained in an economy without adding to inflationary pressures.

[3] This paper focuses on the links between output gaps and inflation. However, output gap measurement is important for a variety of policies. See, for instance, Ley and Mish (2014) for a discussion centered on fiscal policy.

conclude that most output gaps do not improve the inflation forecasts of simple autoregressive models of inflation. Champagne, Poulin-Bellisle and Sekkel (2016) assess the information content of the output gaps used in the Bank of Canada's staff projection (a mix of models and judgment) as well as a few other simple output gap measures, and arrive at the same conclusion. However, contrarily to Orphanides and van Norden (2005) and Cayen and van Norden (2002), but like Edge and Rudd (2016), they do not find that the information content of real-time output gaps is worse than that of output gaps measured with the latest vintage of the data.

Grigoli et al. (2015) study IMF staff output gap estimates and other output gap measures for a large number of countries and also conclude that output gaps do not provide useful information. In addition, they note that revisions to output gap measures tend to be particularly large following economic shocks, such as recessions, and that after negative shocks initial IMF output gap estimates are biased towards finding too much excess capacity. Martin, Munyan and Wilson (2015) and Dovern and Zuber (2017) find similar biases in output gaps estimated by other institutions.

Guérin, Maurin and Mohr (2015) revisit the issue with European data from the 2000s. They find that some output gaps can somewhat improve inflation forecasts when compared to simple models with lags of inflation. This is true in particular for two- and four-quarter ahead forecasts using output gaps calculated on the basis of simple unobserved component methods. They also find that simple combinations of output gaps tend to be less volatile than single models, but that they do not necessarily improve the inflation forecasting results.

The real-time data used in the studies discussed above have usually been limited to real GDP or to output gaps produced by policy institutions. To our knowledge, measures of output gaps generated with models that require many variables subject to data revisions, such as production-function or multivariate-filter measures, have not been analysed with real-time data.

In the present paper, we assess the information content of various output gap measures for Canada. This includes an assessment of the Extended Multivariate Filter (EMVF, also called "statistical method" in the Bank of Canada Monetary Policy Report (MPR)) and of a simplified version of the Integrated Framework (IF, also called "structural method" in the MPR).[4] These output gap measures have been

[4] Differences between the Integrated Framework (IF) and the simplified version of the IF (SIF) are discussed below. See Pichette et al (2015) for details about the EMVF and the IF.

used in policymaking but have not yet been assessed with real-time data. This is because such an assessment requires real-time data for a large number of variables and these were not available. For our project, we combine various real-time data sources, including a real-time database recently developed at the Bank of Canada, to enable such an examination. We assess the information content of simplified IF (SIF) and EMVF output gaps and compare these measures with various others, including a state-space approach adapted from the work of Blagrave et al (2015), which we call the IMF method, and a different state-space approach, also inspired by the IMF method, recently developed by Pichette, Robitaille and Bernier (forthcoming), that is called the Multivariate State-Space Framework (MSSF). We also include in the comparison simple mechanical filters that have often been considered in previous studies and the Bank of Canada staff output gap studied by Champagne, Poulin-Bellisle and Sekkel (2016).

Like Orphanides and van Norden (2005), we emphasize comparisons with simple models made of lags of inflation. We also investigate whether using simple real GDP growth rates instead of output gaps gives better inflation forecasts.[5]

As another experiment, we examine whether projected output gaps add useful information about future inflation. Output gaps forecasted for, say, $t+1$, might be helpful in forecasting $t+2$ inflation. Orphanides and van Norden (2005) limited their analysis to output gaps that could be estimated for the period up to the latest available quarter of real GDP, $t-1$, which is one quarter before the inflation forecast is made. To project our output gap measures we forecast the variables used as inputs in output gap models using Bank of Canada's staff monitoring and simple assumptions (where needed) about subsequent growth rates.[6]

While Orphanides and van Norden (2005) focused on total CPI to measure inflation, we consider forecasts of both Canadian total CPI inflation and of recently developed measures of Canadian core inflation: CPI-trim, CPI-median and CPI-common.[7] To our knowledge, this is the first paper providing an analysis of the usefulness of real-time output gaps to forecast Canada's newly developed measures of core inflation. We cannot take into account inflation data revisions for these core measures because

[5] St-Amant and van Norden (1998) argue that using output growth in this way can be interpreted as implicitly defining an estimated output gap as a one-sided filter of output growth with weights based on the estimated coefficients in the inflation forecasting model. See also van Norden (1995).

[6] We test the robustness of our conclusions to changes in these simple assumptions.

[7] See Bank of Canada (2016) for more details.

historical vintages are not available. We nevertheless take into account data revisions in the case of total CPI inflation, but these revisions are very small, only due to seasonality adjustment, and do not affect the results.

Why could output gaps be better at forecasting core CPI inflation than total CPI inflation? Because core measures should be less affected by short-run factors such as changes in commodity prices and idiosyncratic shocks (tax changes, weather effects on some prices, etc.). They should therefore be more clearly linked with longer-run determinants such as output gaps. And indeed it has been found, in analysis abstracting from data revisions, that the new measures of core CPI inflation (in particular CPI-common) are more correlated with output gap measures than total CPI inflation (Schembri, 2017). In this paper, we examine whether output gaps, estimated with real-time data, are better at forecasting the new core measures.

We also examine whether gaps based purely on labour market information, which we call labour input gaps, tend to provide better information about future inflation than output gaps. In addition, we examine the properties of simple combinations of output gaps and study whether they can improve inflation forecasts in Canada.

The rest of our paper proceeds as follows. We present our methodology in Section 2. In Section 3, we provide information about the output gap methods we consider and about the revisions affecting our data. Our results regarding the usefulness of output gaps to forecast inflation are presented in Section 4. We conclude in Section 5.

Our main findings can be summarised as follows:

- Similarly to Orphanides and van Norden (2005), we find that most output gaps do not add useful information in forecasting total CPI inflation. An exception could be SIF, which appears to contain some information including when combined with other methods. We obtain similar results with CPI-median (although in that case SIF does not do well). However, there is evidence that some output gaps or simple combinations of output gaps provide information about future CPI-trim and CPI-common.
- Unlike Orphanides and van Norden (2005), our results concerning the usefulness of output gaps to forecast inflation are similar when data revisions are not taken into account.

- Although output gaps estimated with the SIF tend to produce relatively low mean-square forecasting errors, the improvement relative to our benchmark is not statistically significant because the SIF is subject to substantial revisions.[8] Yet, these revisions have been smaller in recent years, partly due to improved data quality, and we expect that this will persist going forward.
- We do not find that labour input gaps perform better than output gaps at forecasting inflation. Also, adding forecasted output gaps does not improve the results in general.
- Our analysis of data revisions reveals that all measures tended to overestimate potential during the 2008-2009 recession and in subsequent years. This is consistent with the findings of Grigoli et al (2015),Martin, Munyan and Wilson (2015) and Dovern and Zuber (2017).

2. Methodology

Our approach builds on that of Orphanides and van Norden (2005). These authors' basic idea was to study whether output gaps could add useful information to simple forecasting models based on past inflation and to simple forecasting models based on past inflation and output growth. If output gaps cannot pass such minimal criteria, they are unlikely to help predict inflation.

We follow these authors' approach but add to it an examination of whether output gap projections, obtained with Bank of Canada's staff monitoring and (when needed) simple assumptions about subsequent growth of the variables entering in output gap models, could improve inflation forecasts. We also add preliminary examination of the information content of labour input gaps and of output gap combinations. In addition, while Orphanides and van Norden studied forecasts of total CPI inflation in the United States, we consider forecasts of not only Canadian total CPI inflation, but also of measures of Canadian core CPI inflation.

Let $\pi_t^h = \log(P_t) - \log(P_{t-h})$ denote inflation over h quarters ending in quarter t. We examine forecasts of inflation at various horizons (i.e., $h = 1$, $h = 2$, and $h = 4$). We assume that output gaps are estimated and projected on the basis of the information available towards the end of each quarter, shortly after the publication of Canadian National Accounts by Statistics Canada. This is when Bank of

[8] To assess statistical significance, we use an approach developed by Clark and McCracken (2009).

Canada staff present their assessment of the current state of the economy to the Bank's Governing Council.[9]

Our basic approach consists of three steps. First, like Orphanides and van Norden we estimate simple models of inflation of the form:

$$\pi_{t+h}^{h} = \alpha + \sum_{i=1}^{m} \beta_i \cdot \pi_{t-i}^{1} + e_{t+h}, \qquad (1)$$

where the number of lags, m, is determined with the Schwarz information criterion as estimated using the first available vintage (2007Q1). We re-estimate (1) in real-time, with data starting in 1992Q4,[10] in every quarter from 2007Q1 to 2017Q1 (we use an expanding window for the estimation) and use the resulting models to perform inflation forecasts. We use these forecasts as our main benchmarks in assessing models with output gaps. Our out-of-sample period starts in 2007Q1 because we do not have real-time data for some important variables before 2007.

Second, we examine forecasting models of the form:

$$\pi_{t+h}^{h} = \delta + \sum_{i=1}^{m} \eta_i \cdot \pi_{t-i}^{1} + \sum_{j=1}^{n} \gamma_j \cdot y_{t-j} + \varepsilon_{t+h}. \qquad (2)$$

The number of lags of inflation, m, is the same as in equation (1). n is the number of lags of the output gap, which is again determined with the Schwartz criterion as estimated with the first available vintage (2007Q1). As with equation (1), we re-estimate equation (2) in real-time in every quarter from 2007Q1 to the end of our sample and perform inflation forecasts. Equation (2) follows the approach used by Orphanides and van Norden (2005) to assess the information content of historical output gaps. In such models, the most recent estimate of historical output gap available is the same as the latest available quarter of real GDP at the time the forecasts are made. This means that the most recent historical output gap at the time a forecast of inflation is produced (t) is the previous-quarter output gap ($t-1$).[11]

[9] These projections are an input into the Bank of Canada monetary policy decisions. See Murray (2013) for a discussion about the process followed by the Bank for monetary policy decision making.

[10] Because this was the first quarter for which the Bank of Canada set a specific inflation target (Bank of Canada, 1991). A number of papers have found that the inflation process (mean, persistence, volatility) changed in Canada with the adoption of inflation targeting (Demers, 2003).

[11] Note however that forecasted information for up to 8 quarters is used in estimating the t-1 output in two cases: i) with annual model to complete a given year; ii) when using certain filters to address end-of-sample limitations.

Third, and unlike Orphanides and van Norden, we also consider cases where projected output gaps are included. This implies that we also examine forecasting models of the form:

$$\pi_{t+h}^{h} = \theta + \sum_{i=1}^{m} \varsigma_i \cdot \pi_{t-i} + \sum_{j=1}^{n} \psi_j \cdot y_{t-j} + \sum_{k=1}^{p} \varphi_k \cdot y_{t+h-k}^{*} + v_{t+h}. \quad (3)$$

The specification of equation (3) includes historical output gaps (y_t) and projected output gaps (y_t^*). Parameter p cannot exceed h and is determined with the Schwartz criterion as estimated with the first available vintage (2007Q1). The number of lags of inflation and of output gaps based on historical data is the same as in equations (1) and (2). To produce the projected output gaps, we use Bank of Canada staff monitoring of the variables entering in the estimation of output gaps (e.g., SIF output gap projections require forecasts about population growth, investment, interest rates, hours worked, etc.). This gives us estimates of these variables for periods t and $t+1$. For the subsequent quarters, we simply assume that the growth rates of the variables are equal to their historical mean.[12] It is important to note that these projected variables only take into account the information available at the time inflation forecasts were made. No information obtained after period t is included in these projections.

We estimate equations (1), (2) and (3) for different definitions of Canadian inflation: total CPI inflation (the Bank of Canada target) and the three measures of core inflation recently announced by the Bank of Canada (2016). We use ordinary least squares to estimate these equations.

To assess the models' forecast performance, we calculate and compare their root mean-square errors (RMSEs). Comparisons of forecasts with (2) and (1) give us information about whether output gaps estimated with historical data add information to simple models including only lags of inflation. Comparisons of (3) with 1) tell us whether adding projected output gaps helps improve inflation forecasts.

It is well-known that there is considerable uncertainty surrounding output gap estimates. Some researchers have found that combining output gaps can help reduce that uncertainty. For instance, Guérin, Maurin and Mohr (2015) find that simple combinations of output gaps can reduce the volatility of output gap estimates. We therefore perform an assessment of whether combining output gaps can

[12] We checked the robustness of our results to this simple assumption by using Bank of Canada staff projections, in addition to staff monitoring, instead of the simple assumption that the variables go back to their historical mean growth rates. We also considered a case where neither staff monitoring nor staff projections were used. In both cases, we obtained similar results.

help reduce uncertainty and improve inflation forecasts with Canadian data. For this, we consider two of the simple weighting schemes also used by Guérin, Maurin and Mohr (2015): a measure obtained as the simple arithmetic average of our output gaps, and a measure obtained as the median estimate of all our output gaps. We add to this an examination of the performance of the simple mean of the SIF and the EMVF (published on the Bank of Canada website), as well as the mean of the SIF and the MSSF (Pichette, Robitaille and Bernier, forthcoming). In addition, we use a simple data reduction technique giving us their common component.

Labour market variables tend to be less revised than variables related to GDP. It is therefore possible that labour input gaps (i.e. measures of the gap between potential and actual number of hours worked) should be used, instead of output gaps, in forecasting inflation. Three of our output gap measures incorporate labour input gap measures: the SIF, the EMVF and the MSSF. We use these in equations (2) and (3) to see whether they perform well at forecasting inflation.

Our conclusions about the usefulness of output gaps for forecasting inflation could potentially be different if we took into account other variables that may affect Canadian inflation. As a robustness check, we therefore estimate versions of equations (2) where we add variables often thought as influencing inflation in Canada. We focus on the exchange rate, commodity prices and unit labour costs – variables that have been found helpful to explain inflation in Canada (Schembri, 2017; Bank of Canada, 2017).

3. Output gaps

In this section, we first briefly describe the output gap methods we consider. Appendix A provides a list of the variables used for each method. We then discuss the real-time data we used to estimate the output gaps (Appendix A provides more detailed information) and the revisions to these output gaps.

3.1 Measures of output gap

Since 2014, one of the main methods used at the Bank of Canada to estimate and project potential output (and the output gap) has been the **Integrated Framework** (IF).[13] The IF is a production-function

[13] For a more detailed description, see Pichette et al (2015).

type of approach that decomposes potential output into trend labour input and trend labour productivity. Trend labour input is itself further decomposed into the working-age population, trend employment rate and trend average weekly hours. Estimates and projections of the working-age population are based on Statistics Canada data and Bank of Canada staff monitoring. Trend employment rate and trend average weekly hours are obtained with estimated models that take into account cohort (trend employment) and age-group (trend employment and trend weekly hours) fixed effects. These models also take into account variables such as interest rates, the job-offer rate, wealth, the education level, an employment disincentive index and the share of the service sector in the economy. Trend labour productivity is the sum of capital deepening (capital stock per hour worked) and trend total factor productivity (trend TFP). Trend TFP is measured with a mechanical filter and judgment.[14]

Because real-time data do not exist for some of the variables used in the IF, in this project we use a simplified version of it. There are three differences between the **simplified IF** (SIF) and the full model. First, while the model used by Bank staff has two interest rates (short and long), the SIF has the short-term interest rate only. Second, the SIF does not include wealth. Third, while the size of the service sector affects employment rates and average hours worked of specific age groups and genders differently in the full model, in the simplified version, the size of that sector enters as an aggregate variable. However, over the full sample, the simplified and the full IF provide very similar estimates (e.g. Figure B1 in Appendix B). We are therefore confident that the conclusions reach with the simplified version apply to the full model.

Another main method used at the Bank of Canada to estimate the output gap is the **Extended Multivariate Filter** (EMVF). The EMVF is a mix of mechanical filtering (Hodrick-Prescott filter), end-of-sample conditions and conditioning information applied to labour productivity and to components of labour input (participation rate, unemployment, average hours worked). This approach was first developed by Butler (1996), and it has been used at the Bank of Canada for many years as the main tool to measure past and present potential output. Pichette et al. (2015) proposed a modified version of the EMVF, which is now available on the Bank website. One feature of the EMVF is that rather than filtering output directly, it filters components of output (productivity, average hours worked, etc.), which implies

[14] Although not a structural method *sensu stricto*, the IF allows for some interpretation of potential output developments. For instance, it allows for some analysis of how demographic developments and shocks to physical capital investment can affect potential output.

that real-time data for all variables entering in the estimation of potential output need to be taken into account in constructing real-time output gaps.[15]

In this paper, we also examine **output gap estimates used in the Bank of Canada's staff economic projections**. This measure reflects the judgment of the staff and is based on a large set of information, including the IF (since 2014) and the EMVF, output gap measures based on other methods, various labour market indicators, and some survey indicators, such as the information gathered in the *Business Outlook Survey* on firms' ability to meet an unanticipated increase in demand and on the intensity of labour shortages.[16] The real-time properties of Bank Staff's output gaps are examined by Champagne, Poulin-Bellisle and Sekkel (2016).

The IMF method, proposed by Blagrave et al. (2015), is a state-space model requiring information about only a few variables to estimate potential output (real GDP growth, CPI inflation, unemployment rate, and output and inflation expectations from consensus forecasts). In this method, real GDP is subject to three types of shocks: a level-shock to potential, a shock to potential growth, and a demand shock to the output gap. A Philips curve, an Okun's law and consensus forecasts for output growth and inflation are added to help identify potential output. Consensus forecasts are included to improve the precision of end-of-sample estimates, the basic idea being that a forecast that output growth will be strong could indicate that current output is below potential. A weak inflation forecast would have similar implications.

Since the IMF method requires information about only a few observed variables, it does not incorporate some of the main determinants of potential output. Building on this method, Pichette, Robitaille and Bernier (forthcoming) propose an alternative measure of potential output, the **Multivariate State-Space Framework (MSSF)**, constructed by decomposing potential into the product of trend productivity and trend labour input. Each component of GDP is modelled according to a stochastic process similar to the one assumed in the IMF method, with three types of shocks. The current version of the MSSF is an attempt to rewrite the EMVF. Therefore, the variables needed to construct the various vintages of this new approach are largely the same as for the EMVF.

[15] Pichette et al (2015) note various EMVF shortcomings, including the fact that, being a mix of mechanical filtering, conditioning information and end-of-sample conditions, it is difficult to interpret.

[16] For more details on these survey indicators, see Bank of Canada (2015).

We also consider two simple mechanical filters: the filter proposed by Hodrick and Prescott (1997) (**HP filter**, with a smoothing parameter set at 1,600) and the band-pass filter proposed by Christiano and Fitzgerald (2003) (**BP filter**).

Finally, a model including lags of real GDP growth instead of output gaps in the price equations is considered. This is consistent with an approach discussed by van Norden (1995) and St-Amant and van Norden (1998).

3.2 Data and output gap revisions

An important contribution of this paper is the development of a database that includes a large number of real-time variables. Data were collected from a variety of sources including a newly constructed Bank of Canada real-time database, historical staff projection and monitoring databases, and data obtained directly from Statistics Canada. Appendix A provides detailed information about the sources of our real-time data.

Since most of the data entering in the output gap estimations are subject to revisions, and in some cases, to very large revisions, it was essential to build this database. The capital stock (Chart A1) and the level and trend of the job offer rate (Chart A2 and Chart A3), which are used in the estimation of the IF output gap, are examples of variables that have been subject to significant revisions. Those large revisions throughout our sample contributed to large revisions to the SIF output gap. Data revisions originated from multiple sources ranging from new information gathered by Statistics Canada such as annual surveys and censuses, to methodological changes.

Table 1 summarizes some key statistical properties of cumulative revisions to the various measures of output gap after eight quarters. This guarantees that each observation has undergone at least eight revisions. This hypothesis, which is based on the idea that the data must be close to final after eight revisions, has been used in the literature (e.g., Jacobs and Sturm 2004).[17] The table shows the mean, the absolute mean, the standard deviation, the noise-to-signal ratio (which is the ratio of absolute mean revision to the absolute value of the output gap of the first release), the correlation between the output gap after eight revisions and the first release, and the frequency that the sign of the output gap changes

[17] For most approaches used, statistics after eight revisions are similar to those using the latest-available vintage.

between the first release and the data after eight revisions. Charts comparing the real-time estimates with the data after eight revisions and the latest vintage are shown in Appendix C.

For all approaches, output gap estimates are, on average, revised up, implying some downward biases in the first estimates. This could be due to the fact that real GDP has tended to be weak since the 2008-2009 Global Crisis; which came to be interpreted as lower potential (smaller gaps) by our methods. This is highlighted by the similarity between mean and absolute mean revisions, and it is particularly evident for the EMVF, which is significantly revised, consistently on the upside. This tendency to overestimate the size of excess supply following a recession is consistent with other papers' results (e.g. Grigoli et al, 2015).

The standard deviation provides a signal about the volatility of the revisions. Revisions to the SIF are the most volatile across all approaches. This partly reflects the large revisions to the data feeding in this method, including capital stock and job-offer rate data. However, revisions to some of these data may be smaller going forward. In particular, since 2016, Statistics Canada has been publishing new job vacancy data that are used in calculating the job-offer-rate and should be more reliable. [18]

The noise-to-signal ratio indicates that revisions are less important for the MSSF and the mean of MSSF and SIF. The correlation and the frequency of changes in the sign of the output gaps after eight revisions suggest that the MSSF and the staff projection gaps appears more likely to provide the same signal in real-time and eight quarters after their first estimates.

[18] In fact, we calculated that SIF revisions became smaller and less volatile after 2010, with the absolute mean and standard deviation of revision falling to 0.58 and 0.61, respectively.

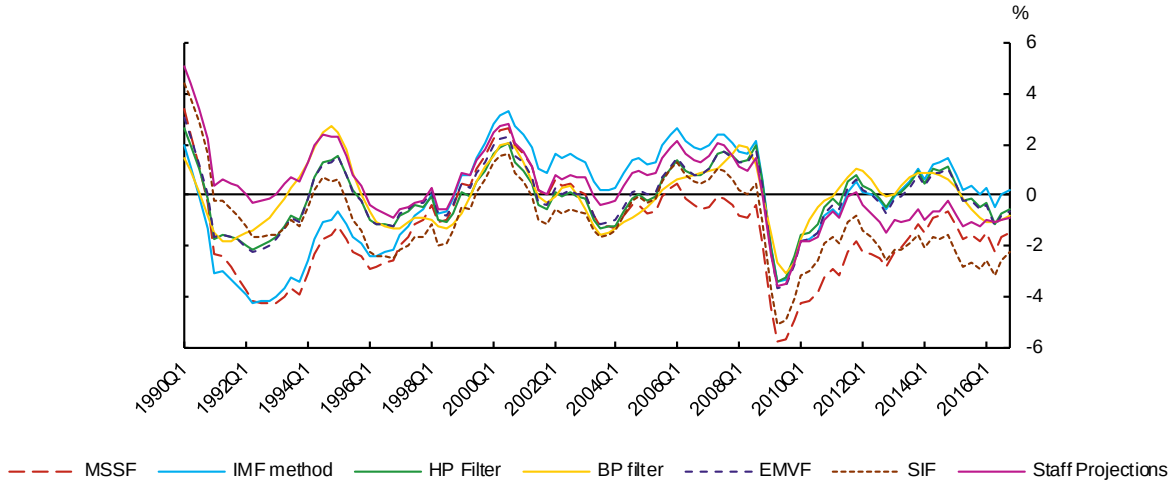
Table 1: Properties of revisions after 8 quarters (sample: 2006Q4 to 2014Q4)

	Mean	Absolute mean	Standard deviation	Noise-to-signal ratio	Correlation	Freq. of opposite signs
MSSF	0.36	0.45	0.37	18%	0.98	9%
IMF method	0.64	0.73	0.71	80%	0.94	18%
HP filter	0.44	0.62	0.68	115%	0.89	42%
BP filter	0.59	0.66	0.63	140%	0.88	52%
EMVF	0.97	0.97	0.55	115%	0.94	45%
SIF	0.52	1.23	1.43	88%	0.47	30%
Staff projection gaps	0.48	0.71	0.69	58%	0.88	6%
Mean of output gaps	0.57	0.58	0.59	58%	0.93	24%
Mean of EMVF and SIF	0.75	0.83	0.93	80%	0.76	33%
Mean of MSSF and SIF	0.44	0.63	0.75	32%	0.88	21%
Median of output gaps	0.69	0.69	0.57	88%	0.93	42%
Principal component	0.84	0.92	1.04	84%	0.94	24%

Chart 1 plots the output gap, estimated using the first six methods reported in Table 1. It shows the series constructed using the latest available vintage (2017Q1). It is worth noting that methods using mechanical filters (HP filter, BP filter and EMVF) produce output gaps that are less persistent. While the SIF and the MSSF show more excess supply since the 2008-2009 crisis, the IMF method and the MSSF indicate that the 1990's recession was somewhat deeper than suggested by the other estimates.

Chart 1: **Output gap estimates using the latest available vintage (2017Q1)**

Quarterly data



Source: Bank of Canada calculations

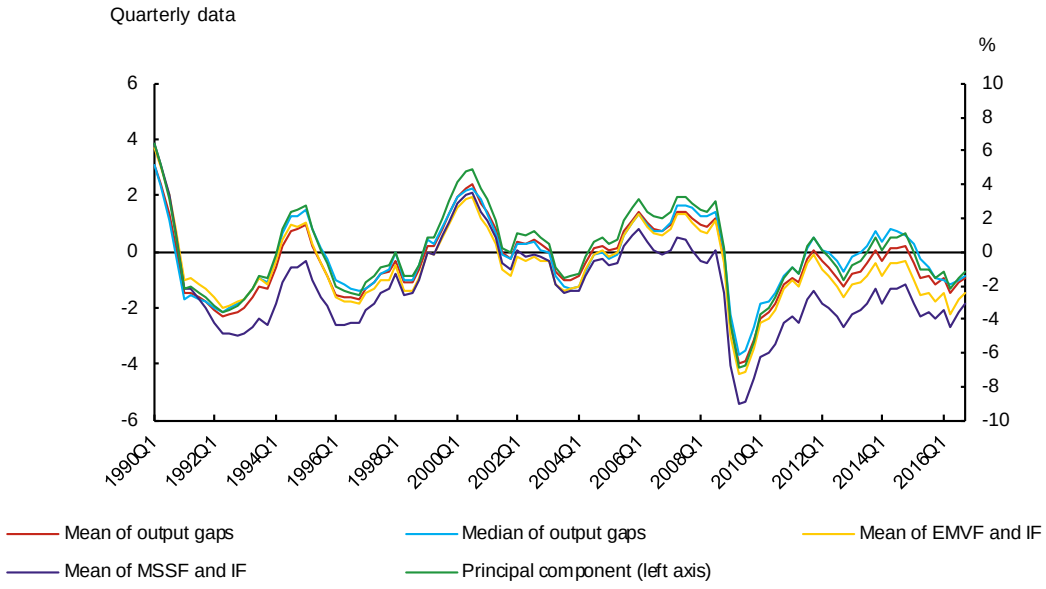
Last observation: 2016Q4

In the estimation of the equations, we use real-time seasonally-adjusted total CPI inflation. Revisions to total CPI inflation on a quarter-over-quarter basis are minor and are due to seasonality. Total CPI inflation on a year-over-year basis is never revised because it is not seasonally adjusted and as such,

real-time data are identical to the latest available vintage. On the other hand, for the newly constructed measures of core inflation used in our analysis (Chart D1), we focus on the latest-available data since we only have a few vintages to work with.[19]

Different combinations of the various output gap estimates (MSSF, IMF method, HP filter, BP filter, EMVF, SIF, and staff projection gaps) are shown in Chart 2. Common movements from the aforementioned output gap estimates are extracted using a data-reduction technique – principal component analysis (PCA). Only the first principal component is reported here, as it is the one that maximizes its contribution to the variance of the set of output gap estimates. On average in the different vintages, the first principal component accounts for 83% of the total variance.[20]

Chart 2: **Output gap combinations using the latest available vintage (2017Q1)**



Source: Bank of Canada calculations

Last observation: 2016Q4

[19] Both year-over-year and quarter-over-quarter measures of core inflation are revised. For CPI-trim and CPI-median, revisions are due to seasonality, as they are based on seasonally adjusted components. In the case of CPI-common, revisions are due to the statistical technique used, as the factor model is estimated over all available historical data.

[20] The principal component cannot be interpreted as an output gap per se since it is expressed in standardized units. It is thus presented on a different axis.

4. Inflation forecasting results

This section presents empirical results to assess whether the output gap improves forecasts of inflation at various horizons h. This is done through a real-time out-of-sample forecasting exercise, in which each equation is estimated for a sample spanning the 1992Q4 to 2006Q4 period using the real-time vintage (i.e., 2007Q1), and a forecast is produced for 2007Q1+h. One observation is then added to the estimation period and the subsequent vintage of data is used to estimate the forecasting model and to compute the out-of-sample forecast. This process is repeated up to the moment where we obtain a forecast for 2016Q4. A key point in a typical real-time forecasting exercise is the choice of "actual data" from which forecast errors are calculated. As mentioned in the previous section, revisions to total inflation are minor, diminishing the importance of this choice. Table 2 compares the performance of real-time out-of-sample forecasts of total inflation using the latest available vintage as actuals.[21] A simple model with only lags of inflation – equation (1) – is taken as a benchmark. It is compared to the previously described output gap estimates to forecast inflation, which rely on historical output gap data only – equation (2) – or on a mix of historical and projected output gap data – equation (3). A comparison is also conducted with models including lags of inflation and real GDP growth. Statistical significance between the root-mean-square error (RMSE) of equation (1) and equations (2) and (3) is assessed using an approach developed by Clark and McCracken (2009). This test compares the forecasting performance of nested models in the presence of data revisions.[22]

The first thing apparent from the table is that most approaches for estimating output gap do not provide accuracy gains compared to the benchmark model. The SIF estimates of the output gap most often give the lowest RMSEs, but improvements against the model with only lags of inflation are never significant. This lack of statistical significance may be due to the large revisions affecting SIF gaps (Table 1). These tend to be penalised by the significance test. However, combining the SIF with the MSSF appears to bring statistically significant improvement to one- and two-quarter ahead forecasts, both with and without forecasted gaps in the latter case. The fact that combining these methods greatly reduces the size and volatility of gap revisions (Table 1), when compared with SIF gaps, likely accounts for the

[21] Similar results were obtained using the first data released of total inflation as "actual data."

[22] Technical details are available in the Appendix E.

statistically significant results.[23] With the exception of the SIF/MSSF combination, the inclusion of both historical and projected output gaps and the use of combinations of methods do not seem to improve inflation forecasts compared to the benchmark. Nor does replacing output gap by GDP growth, as a measure of business cycles, appear to improve forecasts.

Table 2: Comparison of total inflation forecasts at various horizons

Model	Equation 2			Equation 3		
	$h = 1$	$h = 2$	$h = 4$	$h = 1$	$h = 2$	$h = 4$
MSSF	1.02	1.03	1.19	1.01	1.02	1.16
IMF method	1.00	1.01	1.11	0.98	0.97	1.07
HP filter	1.00	1.00	1.05	0.98	0.95	1.00
BP filter	0.99	1.13	1.00	0.98	1.26	1.06
EMVF	1.00	1.00	1.07	0.99	0.97	1.04
SIF	0.95	0.95	1.01	0.93	0.88	0.87
Staff projection gaps	0.99	0.99	1.06	0.97	0.95	0.99
GDP growth	1.01	0.98	0.92	1.00	0.98	0.92
Mean of output gaps	0.99	0.99	1.08	0.96	0.94	0.99
Mean of EMVF and SIF	0.97	0.96	1.03	0.94	0.90*	0.90
Mean of MSSF and SIF	0.97***	0.96***	1.06	0.95	0.92***	0.96
Median of output gaps	0.99	0.99	1.08	0.98	0.95	1.01
Principal component	0.99*	0.99	1.07	0.97	0.94	0.99
Labour input gap - MSSF	1.01	1.02	1.22	0.99	0.97	1.20
Labour input gap - SIF	1.03***	1.05	1.17	1.02	1.00	1.21
Labour input gap - EMVF	1.01	1.01	1.18	0.98	0.95	1.17

Notes:
1) The table reports the RMSE ratio between the forecasts obtained from equations 2 and 3 and equation 1 (benchmark model).
2) Results for the test of equal forecast accuracy are reported as follows: *** p-value < 0.01; ** p-value < 0.05; * p-value < 0.1.
3) The sample size varies according to the forecasting horizon: $h = 1$, 2007Q2-2016Q4; $h = 2$, 2007Q3 - 2016Q4; $h = 4$, 2008Q1-2016Q4.

Results for CPI-median (Table 3) are similar to those for total CPI; but in this case the only exception is the inclusion of the IMF-method historical estimates of the output gap to forecast four quarters ahead. Otherwise, output gaps do not appear to provide useful information. RMSE ratios are high and the results are not significantly different from the ones with lags of inflation only.

[23] The matrix $\boldsymbol{F}$, calculated in the context the test developed by Clark and McCracken (2009), plays an important role in the significance of the mean of SIF and MSSF. As explained in Appendix E, the size of this matrix is often associated with the size of the revisions.

Table 3: Comparison of core inflation (CPI-median) forecasts at various horizons

Model	Equation 2			Equation 3		
	$h=1$	$h=2$	$h=4$	$h=1$	$h=2$	$h=4$
MSSF	1.04	1.05	1.07	1.03	1.06	1.07
IMF method	0.97	0.96	0.93***	0.96	0.96	0.93
HP filter	1.03	1.04	1.01	1.01	1.02	0.98
BP filter	1.05	1.05	1.11	1.08	1.17	1.10
EMVF	1.07	1.09	1.07	1.07	1.11	1.11
SIF	1.02	1.05	0.99	1.05	1.10	1.06
Staff projection gaps	1.00	0.99	0.95	0.98	0.99	0.93
GDP growth	1.04	1.01	0.99	1.06	1.07	0.98
Mean of output gaps	1.02	1.04	1.00	1.03	1.04	0.99
Mean of EMVF and SIF	1.02	1.04	0.98	1.04	1.07	1.01
Mean of MSSF and SIF	1.02	1.04	1.02	1.03	1.06	1.02
Median of output gaps	0.99	0.99	0.96	1.00	0.99	0.97
Principal component	1.03	1.04	1.01	1.03	1.05	1.00
Labour input gap - MSSF	0.99	0.99	1.00	0.96	0.96	1.02
Labour input gap - SIF	1.02	1.06	1.09	1.02	1.11	1.25
Labour input gap - EMVF	0.99	0.99	1.00	0.95	0.94	0.99

Notes:
1) The table reports the RMSE ratio between the forecasts obtained from equations 2 and 3 and equation 1 (benchmark model).
2) Results for the test of equal forecast accuracy are reported as follows: *** p-value < 0.01; ** p-value < 0.05; * p-value < 0.1.
3) The sample size varies according to the forecasting horizon: $h=1$, 2007Q2-2016Q4; $h=2$, 2007Q3 - 2016Q4; $h=4$, 2008Q1-2016Q4.

Results are different in the cases of CPI-common and CPI-trim (Tables 4 and 5). Most RMSE ratios are below one, in particular for models and combinations including SIF gaps and for staff projection gaps. For CPI-common, some results associated with the use of historical data only – equation (2) – to forecast two quarters ahead are statistically significant. This includes models with the MSSF's labour input gap and the EMVF gap.

Table 4: Comparison of core inflation (CPI-common) forecasts at various horizons

Model	Equation 2			Equation 3		
	$h=1$	$h=2$	$h=4$	$h=1$	$h=2$	$h=4$
MSSF	0.91	0.89	0.95	0.99	0.92	0.94
IMF method	0.91	0.84	0.83	1.02	0.89	0.84
HP filter	0.86	0.87*	0.95	0.95	0.91	0.96
BP filter	0.90	0.90	0.93	0.94	0.95	0.92
EMVF	0.85	0.82***	0.92	0.96	0.89	0.93
SIF	0.87	0.74	0.72	1.00	0.80	0.72
Staff projection gaps	0.83	0.77	0.75	0.94	0.85	0.75
GDP growth	1.02	1.03	0.87	1.07	0.98	0.86
Mean of output gaps	0.84	0.78	0.81	0.94	0.84	0.81
Mean of EMVF and SIF	0.82	0.73	0.73	0.96	0.80	0.73
Mean of MSSF and SIF	0.84	0.76	0.77	0.94	0.81	0.78
Median of output gaps	0.84	0.85	0.82	0.94	0.88	0.81
Principal component	0.83	0.79	0.83	0.93	0.84	0.83
Labour input gap - MSSF	0.91	0.87***	0.90	0.93	0.92	0.91
Labour input gap - SIF	0.99	0.92	0.96	1.05	1.00	1.05
Labour input gap - EMVF	0.88*	0.91	0.94	0.91	0.97	0.94

Notes:
1) The table reports the RMSE ratio between the forecasts obtained from equations 2 and 3 and equation 1 (benchmark model).
2) Results for the test of equal forecast accuracy are reported as follows: *** p-value < 0.01; ** p-value < 0.05; * p-value < 0.1.
3) The sample size varies according to the forecasting horizon: $h=1$, 2007Q2-2016Q4; $h=2$, 2007Q3 - 2016Q4; $h=4$, 2008Q1-2016Q4.

In the case of CPI-trim, the MSSF, the staff projection gaps, the mean and the median of all gaps, as well as the principal component are significant at certain horizons for equation (2), while it is the case for the HP filter, the mean of all gaps and the principal component for equation (3).

Table 5: Comparison of core inflation (CPI-trim) forecasts at various horizons

Model	Equation 2			Equation 3		
	$h = 1$	$h = 2$	$h = 4$	$h = 1$	$h = 2$	$h = 4$
MSSF	0.97*	0.94***	0.94***	0.98	0.96	0.92
IMF method	0.95	0.93	0.91	0.95	0.93	0.87
HP filter	0.98	0.97	0.97	0.95	0.93	0.93***
BP filter	0.99	0.95	1.00	1.01	1.05	0.99
EMVF	0.98	0.95	0.94	0.97	0.95	0.93
SIF	0.95	0.94	0.91	0.97	0.96	0.92
Staff projection gaps	0.94	0.92***	0.90	0.91	0.89	0.82
GDP growth	1.01	1.00	0.95	1.06	1.04	0.96
Mean of output gaps	0.94	0.91	0.89***	0.93	0.89	0.83***
Mean of EMVF and SIF	0.92	0.88	0.84	0.92	0.89	0.79
Mean of MSSF and SIF	0.92	0.87	0.83	0.93	0.88	0.80
Median of output gaps	0.95***	0.93***	0.92	0.93	0.89	0.86
Principal component	0.95	0.92	0.90***	0.93	0.90	0.84**
Labour input gap - MSSF	0.98	0.97	0.97	0.93	0.93	0.98
Labour input gap - SIF	1.11	1.16	1.21	1.09	1.21	1.39
Labour input gap - EMVF	0.98*	0.97	0.97	0.90	0.90	0.93

Notes:
1) The table reports the RMSE ratio between the forecasts obtained from equations 2 and 3 and equation 1 (benchmark model).
2) Results for the test of equal forecast accuracy are reported as follows: *** p-value < 0.01; ** p-value < 0.05; * p-value < 0.1.
3) The sample size varies according to the forecasting horizon: $h = 1$, 2007Q2-2016Q4; $h = 2$, 2007Q3 - 2016Q4; $h = 4$, 2008Q1-2016Q4.

We performed pseudo out-of-sample forecasts of total inflation and core inflation. The pseudo out-of-sample forecasting exercise is similar to the real-time one, except that in the first, all recursive estimations are conducted using the same vintage of data – the latest available vintage (2017Q1). Although the forecasting performance of different models should always be compared using real-time out-of-sample procedures, pseudo out-of-sample forecasts have long been used and they can be compared to those of the literature. Consistent with real-time out-of-sample forecasts, pseudo out-of-sample forecasts of total inflation failed to provide evidence of the usefulness of output gaps to forecast total CPI.[24] This is in contrast with results from Orphanides and van Norden (2005) and Cayen and van Norden (2002), but in line with Edge and Rudd (2016), who do not find that the information content of real-time output gaps is worse than that of output gaps measured with final data. Like the real-time out-of-sample forecasts, the pseudo out-of-sample ones suggest that some output gap estimates may be more useful to forecast CPI-common and CPI-trim than total inflation.

[24] Results of the pseudo out-of-sample forecasting exercise are not shown in this paper, but they are available upon request.

Overall, our results are mixed: while output gaps do not add useful information in forecasting total CPI and CPI-median inflation, some of them may improve forecasts of CPI-common and CPI-trim inflation.

Like Guérin, Maurin and Mohr (2015), we find that the gaps that are the least revised are not necessarily the ones resulting in the best RMSE compared to the benchmark equation. Output gap estimates from methods that are revised using new information, even substantially, may do better in terms of RMSE than those from methods that provide persistent inaccurate assessment. However, the test of predictive accuracy developed by Clark and McCracken (2009) penalizes variables that are heavily revised, which makes it more difficult for them to be found statistically significant. Ultimately, the MSSF, the staff projection gaps and the mean of the SIF and the MSSF, which were the least revised output gaps, the ones that provide statistically significant accuracy gains in forecasting inflation.

In general, we do not find that labour input gaps perform better than output gaps at forecasting inflation. We find that simple combinations, such as means or medians of output gaps, tend to do relatively well, but these methods do not always outperform single output gaps. We do not find that adding projected output gap improves the results.

As a robustness check, we also estimated versions of equation (2) where we added other variables that have been found helpful to explain inflation in Canada (Schembri, 2017; Bank of Canada, 2017): the exchange rate, commodity prices and unit labour costs. Including these variables left our main results qualitatively unchanged.

4. Conclusion

The link between inflation and the output gap is central to the conduct of monetary policy. However, the output gap is unobservable, and highly uncertain. This paper examines whether output gaps, measured in real-time, help improve forecasts of inflation when compared with simple models with lags of inflation. It makes three key contributions: i) it uses a novel database including a large number of variables that enables the construction of real-time output gap estimates based on various models, including models incorporating a large number of variables as inputs, ii) it assesses the ability of different measures of output gap and labour gap, as well as combinations of output gaps to improve forecasts of inflation, and iii) it is the first paper analyzing the usefulness of output gaps to forecast new core CPI measures.

We find that most output gap estimates do not appear to be better than lagged inflation for forecasting total CPI inflation and CPI-median. However, there are some indications that the SIF, in particular when combined with the MSSF, might provide helpful leading information for total CPI inflation.

We find that some output gaps appear to contain useful information about future CPI-common and CPI-trim inflation. SIF and its combination with the EMVF or the MSSF, and staff projection gaps perform relatively well at forecasting CPI-common. However, a statistically significant improvement is only obtained with the EMVF and the MSSF's labour input gap. Similarly, some combinations of output gaps perform relatively well with CPI-trim and statistically significant results are found for various models.

We also find that, in general, equations with projected output gaps and equations with labour input gaps do not perform better at forecasting inflation than equations with lagged output gaps.

The SIF does relatively well in general in terms of pure forecasting accuracy. This is interesting given that it is its output gap estimates that have been revised the most over our forecasting period. However, the importance of its revisions probably explains why it was not found to provide significant improvement over our benchmark. This situation may unwind, since the SIF should be less revised going forward, as has been the case since 2010.

Our analysis of data revisions also reveals that all measures tended to overestimate potential during the Global recession and in subsequent years. This is consistent with findings from other studies such as Grigoli et al (2015),Martin, Munyan and Wilson (2015), and Dovern and Zuber (2017) who also find that potential tends to be overestimated following recessions. Developing output gap measures that do better following recessions should be a subject for future research.

References

Bank of Canada, 1991, "Press Release: Targets for Reducing Inflation," *Bank of Canada Review*, February, http://www.bankofcanada.ca/wp-content/uploads/2011/12/bocreview-mar1991.pdf.

Bank of Canada, 2015, "Backgrounder on the Question in the Business Outlook Survey Concerning the Intensity of Labour Shortages," April, http://www.bankofcanada.ca/wp-content/uploads/2015/04/backgrounder-question-bos-intensity-labour-shortages.pdf.

Bank of Canada, 2017, *Monetary Policy Report*, July.

Bank of Canada, 2016, "Renewal of the Inflation-Control Target: Background Information," October, http://www.bankofcanada.ca/wp-content/uploads/2016/10/background_nov11.pdf

Blagrave, P., R. Garcia-Saltos, D. Laxton and Fan Zhang, 2015, "A Simple Multivariate Filter for Estimating Potential Output," IMF Working Papers 15/79, International Monetary Fund.

Butler, L. 1996. "A Semi-Strutural Method to Estimate Potential Output: Combining Economic Theory with a Time-Series Filter. The Bank of Canada's New Quarterly Projection Model, Part 4." Technical Report No. 77. Ottawa: Bank of Canada.

Cayen, J.-P., and S. van Norden, 2002, "La fiabilité des estimations de l'écart de production au Canada," Staff Working Paper 02-10, Bank of Canada.

Champagne, J., G. Poulin-Bellisle and Rodrigo Sekkel, 2016, "The Real-Time Properties of the Bank of Canada's Staff Output Gap Estimates," Staff Working Paper 2016-28, Bank of Canada.

Christiano, L. J. and T. J. Fitzgerald, 2003, "The band pass filter," *International Economic Review*, 44(2), 435-465.

Clark, T. and M. McCracken, 2009, "Tests of Equal Predictive Ability With Real-Time Data," *Journal of Business & Economic Statistics*, American Statistical Association, vol. 27(4), pages 441-454.

Dovern, J. and C. Zuber, 2017 "The Effect of Recessions on Potential Output Estimates: Size, Timing, and Determinants," Annual Conference 2017 (Vienna): Alternative Structures for Money and Banking 168180, Verein für Socialpolitik / German Economic Association.

Edge, R. M. and J. B. Rudd, 2016, "Real-time Properties of the Federal Reserve's Output Gap," *Review of Economics and Statistics,* 98 (4), 785–791.

Grigoli, F., A. Herman, A. J. Swiston and G. Di Bella, 2015, "Output Gap Uncertainty and Real-Time Monetary Policy," IMF Working Papers 15/14, International Monetary Fund.

Guay, A. and P. St-Amant, 2005, "Do the Hodrick-Prescott and Baxter-King Filters Provide a Good Approximation of Business Cycles?" *Annals of Economics and Statistics*, GENES, issue 77, pages 133-155.

Guérin, P., Maurin, L. and M. Mohr, 2015, "Trend-Cycle Decomposition of Output and Euro Area Inflation Forecasts: A Real-Time Approach Based on Model Combination," *Macroeconomic Dynamics,* 19, pages 363–393.

Hodrick, R, and E. C. Prescott, 1997, "Postwar U.S. Business Cycles: An Empirical Investigation," *Journal of Money, Credit, and Banking,* 29(1), pages 1–16.

Jacobs, J.P.A.M. and J.-E. Sturm, 2004, "Do IFO Indicators Help Explain Revisions in German Industrial Production?" CESifo Working Paper No. 1205.

Jolliffe, I. 2002. Principal Component Analysis. 2nd ed. New York: Springer.

Ley, E., and F. Misch, 2013, "Real-Time Macro Monitoring and Fiscal Policy," Policy Research Working Paper 6303 (Washington: World Bank).

Melolinna, M. and M. Tóth, 2016, "Output gaps, inflation and financial cycles in the United Kingdom," Bank of England working paper 585, Bank of England.

Martin, R., T. Munyan, and B. A. Wilson, 2015, "Potential Output and Recessions: Are We Fooling Ourselves?" International Finance Discussion Papers 1145. Board of Governors of the Federal Reserve System.

Murray, J, 2013, "Monetary Policy Decision Making at the Bank of Canada," *Bank of Canada Review*, Autumn.

Orphanides, A. and S. van Norden, 2005, "The Reliability of Inflation Forecasts Based on Output Gap Estimates in Real Time," *Journal of Money, Credit and Banking*, Blackwell Publishing, vol. 37(3), 583-601, June.

Pichette, L., P. St-Amant, B. Tomlin and K. Anoma, 2015, "Measuring Potential Output at the Bank of Canada: the Extended Multivariate Filter and the Integrated Framework," Staff Discussion paper, Bank of Canada, 2015-1.

Pichette, L., M.-N. Robitaille and M. Bernier, 2017, "An Alternative Estimate of the Canadian Potential Output," CEA Modelling, April.

Schembri, L., 2017, "Getting to the Core of Inflation," Remarks to the Department of Economics, Western University, London, Ontario, February. http://www.bankofcanada.ca/wp/content/uploads/2017/02/remarks-090217.pdf

St-Amant, P. and S. van Norden, 1998, "Measurement of the Output Gap: A Discussion of Recent Research at the Bank of Canada," Staff Technical Report 79, Bank of Canada.

Stock, J. H. and M. Watson, 2004, "Combination Forecasts of Output Growth in a Seven-Country Data Set," *Journal of Forecasting* 23: 405–30.

van Norden, S., 1995, "Why Is It So Hard to Measure the Current Output Gap?," http://econwpa.repec.org/eps/mac/papers/9506/9506001.pdf

Appendix A: Details about the data

Data sources description:

- VINT: The Bank of Canada started collecting vintages of various series in the early 2000s. These series are stored in a special database and are accessible to the Bank staff. Most of the real-time data used in the paper come from this source.
- IMP_VINT: In addition to the VINT database mentioned previously, the Bank of Canada recently created a second database that contains hundreds of new real-time series.
- MON: Bank of Canada short-term forecast databases.
- STAT CAN: Data provided from Statistics Canada through a special request.
- NR: The data are not revised.

Models:

Multivariate State-Space Framework (MSSF)

	Definition	Source	Real-time data source
Employment	Employment (x1000); Both sexes; 15 years and over; Seasonally adjusted	Statistics Canada - Labour force survey estimates	VINT & MON
Gross domestic product	Gross domestic product at market prices (x1,000,000); Expenditure-based; Chained (2007) $	Statistics Canada - National Gross Domestic Product by Income and by Expenditure Accounts (IEA)	MON
Gross domestic product (consensus forecast)	Consensus forecasts of gross domestic product (the next five years)	Consensus Economics	NR
Inflation	Total consumer price index inflation (annual)	Statistics Canada - Consumer Price Index	MON
Inflation (consensus forecast)	Consensus forecasts of total consumer price index inflation (the next year)	Consensus Economics	NR
Labour productivity	Total gross domestic product divided by total hours worked		
Gross domestic product	Gross domestic product at market prices (x1,000,000); Expenditure-based; Chained (2007) $	Statistics Canada - National Gross Domestic Product by Income and by Expenditure Accounts (IEA)	MON
Total hours worked	Total actual hours worked for all jobs, Seasonally adjusted	Statistics Canada - Labour force survey estimates	VINT & MON
Average hours worked	Total hours worked divided by employment		
Employment	Employment (x1000); Both sexes; 15 years and over; Seasonally adjusted	Statistics Canada - Labour force survey estimates	VINT & MON
Total hours worked	Total actual hours worked for all jobs, Seasonally adjusted	Statistics Canada - Labour force survey estimates	VINT & MON

International Monetary Fund (IMF)

	Definition	Source	Real-time data source
Unemployment rate	Number of people unemployed (labour force minus employed) divided by labour force	Statistics Canada - Labour force survey estimates	VINT & MON

Labour force	Total labour force (x1000); Both sexes; 15 years and over; Seasonally adjusted	Statistics Canada - Labour force survey estimates	VINT & MON
Employment	Employment (x1000); Both sexes; 15 years and over; Seasonally adjusted	Statistics Canada - Labour force survey estimates	VINT & MON
Gross domestic product	Gross domestic product at market prices (x1,000,000); Expenditure-based; Chained (2007) $	Statistics Canada - National Gross Domestic Product by Income and by Expenditure Accounts (IEA)	MON
Gross domestic product (consensus forecast)	Consensus forecasts of gross domestic product (the next five years)	Consensus Economics	NR
Inflation	Total consumer price index inflation (annual)	Statistics Canada - Consumer Price Index	MON
Inflation (consensus forecast)	Consensus forecasts of total consumer price index inflation (the next year)	Consensus Economics	NR

Hodrick-Prescott filter (HP filter)

	Definition	Source	Real-time data source
Gross domestic product	Gross domestic product at market prices (x1,000,000); Expenditure-based; Chained (2007) $	Statistics Canada - National Gross Domestic Product by Income and by Expenditure Accounts (IEA)	MON

Band-Pass filter (BP filter)

	Definition	Source	Real-time data source
Gross domestic product	Gross domestic product at market prices (x1,000,000); Expenditure-based; Chained (2007) $	Statistics Canada - National Gross Domestic Product by Income and by Expenditure Accounts (IEA)	MON

Extended Multivariate Filter (EMVF)

	Definition	Source	Real-time data source
Average hours worked	Total hours worked divided by employment		
Total hours worked	Total actual hours worked for all jobs, Seasonally adjusted	Statistics Canada - Labour force survey estimates	VINT & MON
Employment	Employment (x1000); Both sexes; 15 years and over; Seasonally adjusted	Statistics Canada - Labour force survey estimates	VINT & MON
Gross domestic product	Gross domestic product at market prices (x1,000,000); Expenditure-based; Chained (2007) $	Statistics Canada - National Gross Domestic Product by Income and by Expenditure Accounts (IEA)	MON
NAIRU			
Employment disincentive index	Employment insurance disincentive index assuming constant unemployment rate of 7.5% for all regions	Department of Finance Canada	NR
Payroll taxes (excluding CPP)	Payroll taxes (excluding CPP) as a share of wages, salaries, and supplementary income		
Employer and employee contribution to employment insurance	Employer and employee contributions to employment insurance (x1,000,000); Seasonally adjusted at annual rates	Statistics Canada - National Gross Domestic Product by Income and by Expenditure Accounts (IEA)	IMP_VINT & VINT
Employers' contributions to worker's compensation	Employers' contribution to workers' compensation (x1,000,000); Seasonally adjusted an annual rates	Statistics Canada - National Gross Domestic Product by Income and by Expenditure Accounts (IEA)	IMP_VINT & VINT
Compensation of employees paid by resident entities	Compensation of employees paid by resident entities (x1,000,000); Seasonally adjusted at annual rates	Statistics Canada - National Gross Domestic Product by Income and by Expenditure Accounts (IEA)	IMP_VINT & VINT

Provincial payroll taxes	Provincial payroll taxes (x1,000,000); Seasonally adjusted at annual rates	Statistics Canada - National Gross Domestic Product by Income and by Expenditure Accounts (IEA)	IMP_VINT & VINT
Employer and employee contributions to industrial employees' vacations	Employer and employee contributions to industrial employees' vacations (x1,000,000); Seasonally adjusted at annual rates	Statistics Canada - National Gross Domestic Product by Income and by Expenditure Accounts (IEA)	IMP_VINT & VINT
Unemployment rate	Number of people unemployed (labour force minus employed) divided by labour force		
Labour force	Total labour force (x1000); Both sexes; 15 years and over; Seasonally adjusted	Statistics Canada - Labour force survey estimates	VINT & MON
Employment	Employment (x1000); Both sexes; 15 years and over; Seasonally adjusted	Statistics Canada - Labour force survey estimates	VINT & MON
Working-age population	Number of persons of working age, 15 years of age and over (x1000)	Statistics Canada - Labour force survey estimates	IMP_VINT & VINT & MON

Simplified Integrated Framework (SIF)

	Definition	Source	Real-time data source
Average hours worked	Total hours worked divided by employment		
Total hours worked	Total actual hours worked for all jobs, Seasonally adjusted	Statistics Canada - Labour force survey estimates	VINT & MON
Employment	Employment (x1000); Both sexes; 15 years and over; Seasonally adjusted	Statistics Canada - Labour force survey estimates	VINT & MON
Education	Ratio of university degree holders to working age population		
University degree holders	University degree holders	Statistics Canada - Labour force survey estimates	IMP_VINT & VINT
Working-age population	Number of persons of working age, 15 years of age and over (x1000)	Statistics Canada - Labour force survey estimates	IMP_VINT & VINT
Employment disincentive index	Employment insurance disincentive index assuming constant unemployment rate of 7.5% for all regions	Department of Finance Canada	NR
Enrollment rate	Full-time students ages 15-24 years divided by total population ages 15-24 (students + non-students)		
Full-time students (15-24)	Full-time students; 15-24 years; Unadjusted for seasonality	Statistics Canada - Labour force survey estimates	VINT
Total non-students (15-24)	Non-students; 15-24 years; Unadjusted for seasonality	Statistics Canada - Labour force survey estimates	VINT
Total students (15-24)	Students; 15-24; Unadjusted for seasonality	Statistics Canada - Labour force survey estimates	VINT
Nominal interest rate	Bank of Canada bank rate (ninety day interest rate)	Bank of Canada	MON
Trend inflation	The trend in the consumer price index inflation rate	Internal	MON
Trend nominal interest rate	The trend in the nominal interest rate	Internal	MON
Job offer rate			
Help-wanted index	Help-wanted index measures changes in the demand for labour relative to a base-year	Statistics Canada - Help-wanted index survey	NR
Labour shortage	Production difficulties skilled labour shortage from the Business Conditions Survey	Statistics Canada - Business Conditions Survey for the Manufacturing Industries	IMP_VINT
CFIB – job vacancy rate	Canadian Federation of Independent Business job vacancy rates	Canadian Federation of Independent Business Economics	NR
SEPH – job vacancy rate	Survey of Employment, Payrolls and Hours, job vacancy statistics; Job vacancy rate (%); Unadjusted for seasonality	Statistics Canada – Job Vacancy Rate	VINT
Labour input	Total actual hours worked for all jobs, Seasonally adjusted	Statistics Canada - Labour force survey estimates	VINT & MON

Share of service-producing sector	Ratio of employment in the service-producing sector to total employment		
Employment	Employment (x1000); Both sexes; 15 years and over; Seasonally adjusted	Statistics Canada - Labour force survey estimates	VINT & MON
Service-producing sector employment	Employment (x1000); Service-producing sector; Both sexes; 15 years and over	Statistics Canada - Labour force survey estimates	IMP_VINT & VINT
Working-age population	Number of persons of working age, 15 years of age and over (x1000)	Statistics Canada - Labour force survey estimates	IMP_VINT & VINT
Average hours worked, single age groups	Average hours worked by employee; Males, females, and both sexes; Single-age group (%)	Statistics Canada - Labour force survey estimates (special request)	STAT CAN
Employment rate, single age groups	Employment rate; Males, females, and both sexes; Single-age group	Statistics Canada - Labour force survey estimates (special request)	STAT CAN
Working-age group, single age groups	Number of persons of working age; Males, females, and both sexes; Single-age group (x1000)	Statistics Canada - Labour force survey estimates (special request)	STAT CAN
Total non-residential investment	Total non-residential investment (x1,000,000); Chained (2007) dollars	Statistics Canada - Stock and Consumption of Fixed Non-residential Capital	STAT CAN & IMP_VINT & VINT
Business fixed investment	Business Fixed Investment; Chained (2007) Dollars; Seasonally adjusted at annual rate	Statistics Canada - National Gross Domestic Product by Income and by Expenditure Accounts (IEA)	MON
Capital cost	Capital cost (dollars x 1,000,000); Business sector	Statistics Canada - Productivity Measures and Related Variables (National and Provincial)	STAT CAN & VINT
Government consumption	The sum of government consumption expenditure and government gross fixed capital formation		MON
Government consumption expenditure	General governments final consumption expenditure (x 1,000,000); Chained (2007) dollars; Seasonally adjusted at annual rates	Statistics Canada - National Gross Domestic Product by Income and by Expenditure Accounts (IEA)	MON
Government gross fixed capital formation	General governments gross fixed capital formation (x 1,000,000); Chained (2007) dollars; Seasonally adjusted at annual rates	Statistics Canada - National Gross Domestic Product by Income and by Expenditure Accounts (IEA)	MON
Nominal gross domestic product	Gross domestic product (dollars x 1,000,000); Business sector; Value-added	Statistics Canada - Productivity Measures and Related Variables (National and Provincial)	STAT CAN & VINT
Gross domestic product	Gross domestic product at market prices (x1,000,000); Expenditure-based; Chained (2007) $	Statistics Canada - National Gross Domestic Product by Income and by Expenditure Accounts (IEA)	MON
Net capital stock	Geometric (infinite) end-year net stock; Chained (2007) dollars; Total assets (x 1,000,000)	Statistics Canada - Stock and Consumption of Fixed Non-residential Capital	STAT CAN & IMP_VINT & VINT

Staff projection gaps

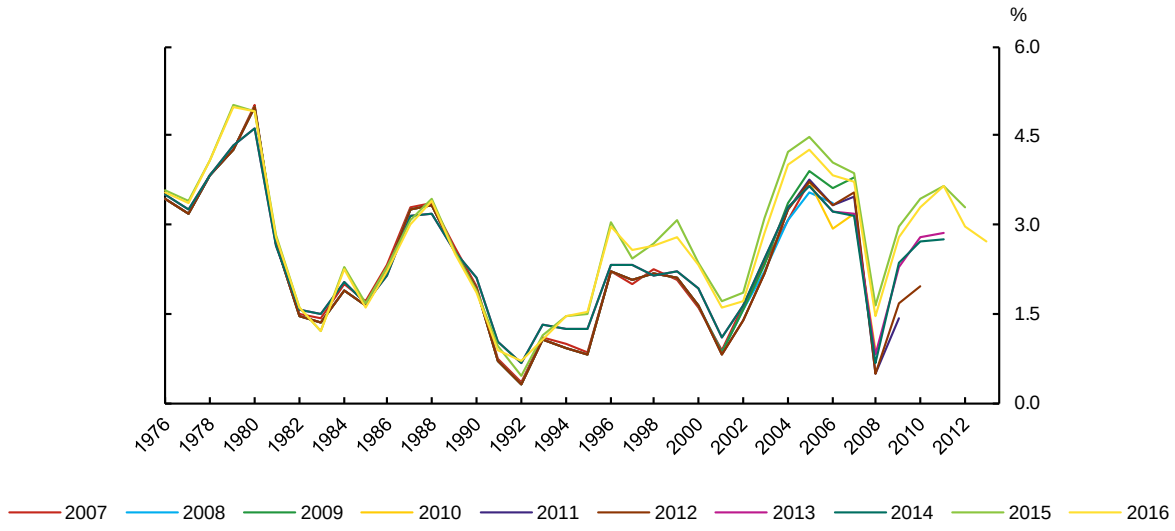
	Definition	Source	Real-time data source
Output gap	-	Internal	MON

Gross domestic product growth (GDP growth)

	Definition	Source	Real-time data source
Gross domestic product	Gross domestic product at market prices (x1,000,000); Expenditure-based; Chained (2007) $	Statistics Canada - National Gross Domestic Product by Income and by Expenditure Accounts (IEA)	MON

Chart A1: Large revisions to the growth rate of the capital stock

Year-over-year growth rate, annual data

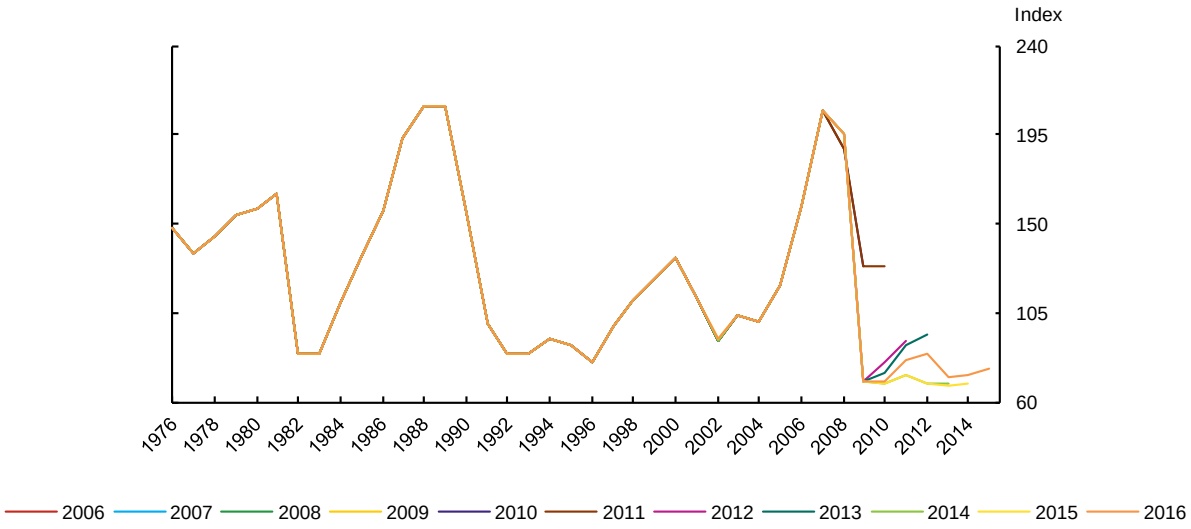


Source: Statistics Canada and Bank of Canada databases

Last observation: 2013

Chart A2: Large revisions to the job offer rate

Annual data

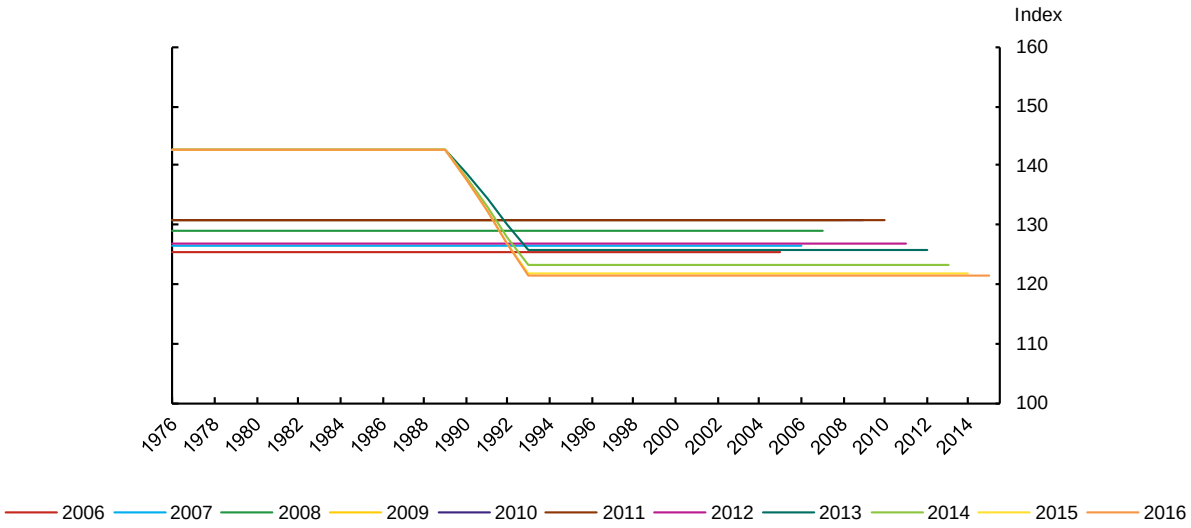


Sources: Statistics Canada, Conference Board of Canada, Canadian Federation of Independent Businesses, and Bank of Canada calculations

Last observation: 2016

Chart A3: Large revisions to the trend of the job offer rate

Annual data

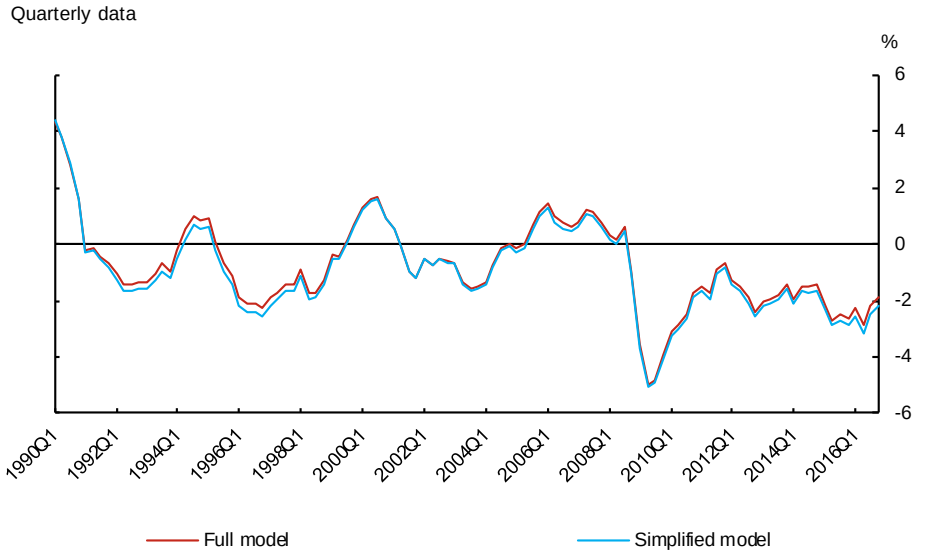


Source: Bank of Canada calulations

Last observation: 2016

Appendix B: Simplified and full Integrated Framework

Chart B1: The simplified and full versions of the IF give very similar output gaps



Source: Bank of Canada calculations

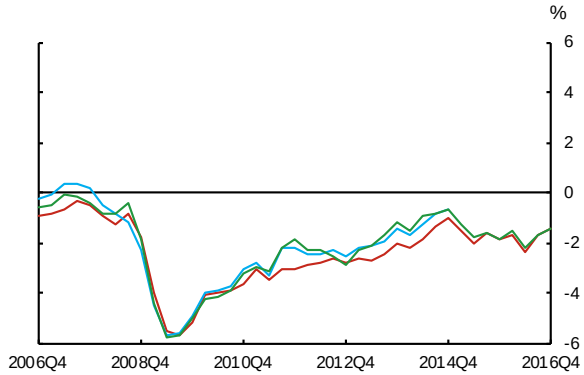
Last observation: 2016Q4

Appendix C: Output gap estimates

IMF

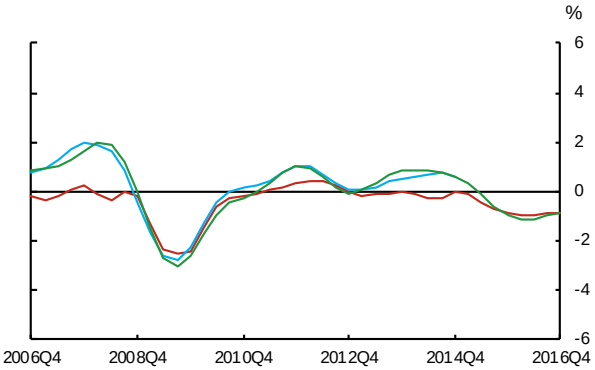
Source: Bank of Canada calculations Last observation: 2016Q4

MSSF



Source: Bank of Canada calculations Last observation: 2016Q4

BP-filter

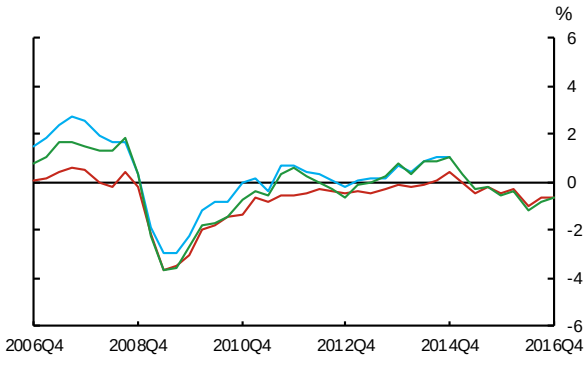


Source: Bank of Canada calculations Last observation: 2016Q4

HP-filter

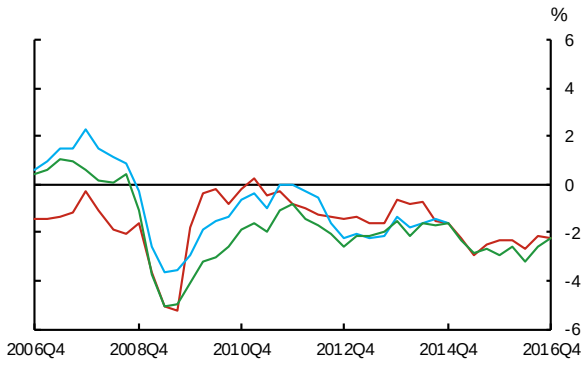
Source: Bank of Canada calculations Last observation: 2016Q4

EMVF



Source: Bank of Canada calculations Last observation: 2016Q4

SIF



Source: Bank of Canada calculations Last observation: 2016Q4

Appendix D: New measures of core inflation

Chart D1: **New measures of core inflation, year-over-year**

Quarterly data

Sources: Statistics Canada and Bank of Canada calculations

Last observation: 2016Q4

Appendix E: Clark and McCracken test for comparing forecasting performance

This Appendix details the Clark and McCracken (2009) test for nested models estimated with real-time data. We use this test to compare the forecasting performance of equations (2) and (3) with that of a simple equation made of only lags of inflation – equation (1).

Let two forecast models, $y_{s+\tau}(t) = \boldsymbol{x}'_{\boldsymbol{1,s}}(t)\boldsymbol{\beta_1}(t) + u_{1,s+\tau}(t)$ (model 1) and $y_{s+\tau}(t) = \boldsymbol{x}'_{\boldsymbol{s,t}}(t)\boldsymbol{\beta_2}(t) + u_{2,s+\tau}(t)$ (model 2), with $y_s(t)$ is the value of the time t vintage of the observation s realization of y, where $t \geq s$. The observables are subject to revision over a finite number of periods, r. When the revision process is completed, we drop the notation indexing the vintage and simply let $y_s(t) = y_s$. k_1 is the number of parameters from equation 1 and k_2 is the number of parameters from equation 2. Since the two models are nested, $k_{22} = k_2 - k_1$ is the number of excess parameters.

The Clark and McCracken test statistic S for comparing predictive accuracy of nested models with real-time data is given by:

$$S = \sqrt{(P - \tau - 1)}\,\frac{MSE_1 - MSE_2}{\sqrt{\Omega}}$$

Where $P - \tau - 1$ is the number of forecasts, τ is the forecast horizon, MSE_i is the mean square error of model i, and Ω is the long-run variance of the scaled forecasting loss differential, which is estimated as follows:

$$\Omega = 2\big(1 - \pi^{-1} ln(1+\pi)\big)\boldsymbol{F}(-\boldsymbol{JB_1J'} + \boldsymbol{B_2})\boldsymbol{S_{hh}}(-\boldsymbol{JB_1J'} + \boldsymbol{B_2})\boldsymbol{F'}.$$

In this equation:

$$\pi = \frac{P}{R},$$

R is the sample size at the initial forecast origin,

$$\boldsymbol{J'} = (\boldsymbol{I_{k_1 \times k_1}}, \boldsymbol{0_{k_1 \times k_{22}}}),$$

$$\widehat{\boldsymbol{\beta}}_{\boldsymbol{i}} = (T^{-1}\textstyle\sum_{s=1}^{T-max(\tau,r)} \boldsymbol{x_{i,s}x'_{i,s}})^{-1},$$

$$T = R + P - \tau,$$

and

$$\widehat{\boldsymbol{F}} = 2[P^{-1} \times \textstyle\sum_{s=R}^{T} \hat{u}_{2,s+\tau}(t)\,\boldsymbol{x'_{2,s}}(t)].$$

Various scenarios make the matrix $\boldsymbol{F} = \boldsymbol{0}$, thus permitting the use of conventional tests. For example, this is the case when there are no revisions. The long-run covariance $\hat{S}_{hh}$ of $h_{s+\tau}$ is estimated using the Newey West's (1987) HAC estimator with a bandwidth of 2τ.

$$\hat{h}_{s+\tau} = \big(y_{s+\tau} - \boldsymbol{x'_{2,s}}\hat{\beta}_{2,T}\big)\boldsymbol{x_{2,s}}$$