Measuring Uncertainty in Monetary Policy Using Realized and Implied Volatility

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- Measuring the degree of uncertainty in the financial markets around future monetary policy rates and market interest rates is important because interest rate uncertainty affects the real economy through the investment and hiring decisions of firms.
- This article assesses uncertainty surrounding future policy rates set by the Bank of Canada using measures of *realized volatility* computed from the intraday prices of interest rate futures and *implied volatility* computed from the prices of options on interest rate futures.
- According to these measures, interest rate uncertainty decreased following major policy actions that the Bank took in response to the 2007–09 financial crisis.
- Findings also indicate that, on average, uncertainty decreases following the Bank's policy rate announcements.

Central banks monitor various financial variables, such as short-term interest rates and the prices of interest rate derivatives, to gauge market expectations of future monetary policy. The expectations extracted from these variables can then be used to complement other tools adopted by the Bank of Canada to assess the impact of monetary policy. The predicted *level* of future policy rates, captured by these measures of expectations, has a well-known impact on the real economic activity, but *uncertainty* about future monetary policy rates also affects economic activity through the investment and hiring decisions of firms (Bernanke 1983).

The most widely used measure of uncertainty around future policy rates is the dispersion of professional forecasts based on surveys. Although survey-based measures are good indicators of uncertainty, they have several limitations. First, since surveys are conducted infrequently, the uncertainty measures cannot be used to assess the immediate effect of central bank announcements or other macroeconomic events. Second, survey-based measures of uncertainty are based on the opinions of a small number of market participants and may not be reflective of the larger population. Third,

since survey respondents are professionals in the fields of economics and finance, their forecasts are potentially affected by reputational concerns. For example, respondents may be reluctant to deviate too far from consensus for fear of having a wrong forecast when others have the right one, thus harming their reputation. To overcome these limitations, we propose alternative measures based on the prices of interest rate futures and options.

This article describes two measures of the price volatility of interest rate futures that could be used as indicators of policy rate uncertainty: realized volatility, computed from the intraday prices of interest rate futures, and implied volatility, computed from the prices of options on interest rate futures. We construct our volatility measures using futures contracts on the average three-month bankers' acceptance rate (BAX) and options on BAX (OBX).

Using the two measures of policy rate uncertainty, we first analyze the effect of various policy actions taken by the Bank of Canada during and following the 2007–09 financial crisis, and then examine the effect of the Bank's policy rate announcements that took place on fixed announcement dates (FADs) over the 2002–13 period. We examine four crisis-related policy actions that the Bank took between 2007 and 2010: (i) the first introduction of term purchase and resale agreements (PRAs) for liquidity purposes in December 2007; (ii) the second introduction of term PRAs in March 2008; (iii) the inter-meeting cut in the policy rate in October 2008 that was coordinated with other major central banks; and (iv) the conditional commitment to keep the policy rate unchanged that lasted several months in 2009 and 2010.

This article explains how realized volatility and implied volatility can be used to measure policy rate uncertainty in various applications relevant to monetary policy. It first describes briefly how these measures of volatility are calculated and how they can be interpreted. The article then reports the results of empirical applications of the measures of uncertainty.[1]

◀ *Realized volatility and implied volatility can be used to measure policy rate uncertainty in various applications relevant to monetary policy*

Measures of Uncertainty Around Future Policy Rates

The price of interest rate futures reflects expectations of future interest rates, so when uncertainty around future interest rates is high, this price exhibits large variations over time. The most widely used measure of price variation is the standard deviation of daily price changes, referred to as historical volatility. However, since historical volatility is calculated using past daily prices, it is inherently backward-looking. This article uses two alternative measures of price variation:

(i) realized volatility—the volatility of intraday price changes,[2] and

(ii) implied volatility—the volatility of the underlying price process that is implied by the prices of options.

Although historical volatility and realized volatility are both backward-looking, realized volatility is computed with data from a single day and is therefore much more sensitive to the arrival of new information, whereas historical volatility is computed using only past prices.

Implied volatility is a forward-looking measure of future interest rate volatility and thus reflects expectations of future interest rate volatility, while realized volatility is an ex post measure of current interest rate volatility that

1 For more information on how volatility was measured and the empirical tests, see Chang and Feunou (2013).

2 Measured as the square root of the sum of squared changes in high-frequency intraday prices.

estimates the interest rate uncertainty on a given day. Each measure has different applications. Realized volatility can be used to measure the actual change in interest rate uncertainty following a policy action, while implied volatility can be used to assess the effect of a policy announcement on the expected *future* interest rate volatility.

An increase in implied volatility can be due to either an increase in uncertainty or an increase in the risk premium required to compensate for interest rate uncertainty

A large proportion of time variations in both implied and realized volatility is determined by uncertainty around future interest rates. However, other factors also influence these measures. Implied volatility reflects both expected volatility and a volatility risk premium. An increase in implied volatility can therefore be due to either an increase in uncertainty or an increase in the risk premium required to compensate for interest rate uncertainty. Realized volatility is sensitive to noise in high-frequency prices caused by certain trading activities or restrictions, because the measure is computed using intraday prices. Since we cannot separate the effect of these factors from the measure reflecting only uncertainty, our results should be interpreted with these factors in mind.

In Canada, the collateralized overnight rate at which major financial institutions borrow and lend one-day funds among themselves is the main tool used by the Bank to conduct monetary policy. Since the Canadian overnight repo rate average (CORRA) tracks the central bank's policy rate closely, ideal instruments for our study would be futures and options on CORRA. However, futures on CORRA trade with limited liquidity, and options on CORRA have yet to be introduced. Instead, we use futures and options on the three-month bankers' acceptance rate—calculated from bid-side rates of the primary bankers' acceptance market and called the Canadian Dealer Offered Rate (CDOR)—to compute our volatility measures. This approach is consistent with the frequent use of eurodollar futures and options in related studies in the United States.[3]

Bankers' acceptances are tradable short-term corporate obligations that are backed by a line of credit and are therefore guaranteed by the accepting banks. Changes in bankers' acceptance rates are closely related to changes in overnight rates and are known to be good predictors of future policy rates (Johnson 2003). The CDOR is the key reference rate for short-term interbank funding in Canada, similar to the LIBOR (London Interbank Offered Rate) in the United States. Moreover, futures on the three-month bankers' acceptance rate, called BAX, are one of the most liquid instruments in the Canadian money market. Both BAX and options on BAX, which are less liquid, trade on the Montréal Exchange.

Realized volatility of BAX

The realized volatility of BAX is computed as the square root of the sum of squared changes in intraday BAX futures prices, observed at the interval of every five trades, roughly equivalent to every 20 minutes.

To illustrate how realized volatility captures uncertainty around future policy rates, **Chart 1** shows the implied yields[4] from intraday prices of a BAX contract on three consecutive days around 21 April 2009, the day the Bank lowered its policy rate from 0.50 per cent to 0.25 per cent and announced its conditional commitment to keep its policy rate at 0.25 per cent until the end of the second quarter of 2010. Panel b shows the implied yields of a BAX contract with a September 2009 expiry as of 21 April 2009, while panels a

3 See Abken (1995), Rigobon and Sack (2002), Neely (2005) and Bauer (2012).

4 The price of a BAX contract is quoted as 100 minus the annualized yield of a three-month Canadian bankers' acceptance rate. Thus, the implied yield is 100 minus the price of BAX.

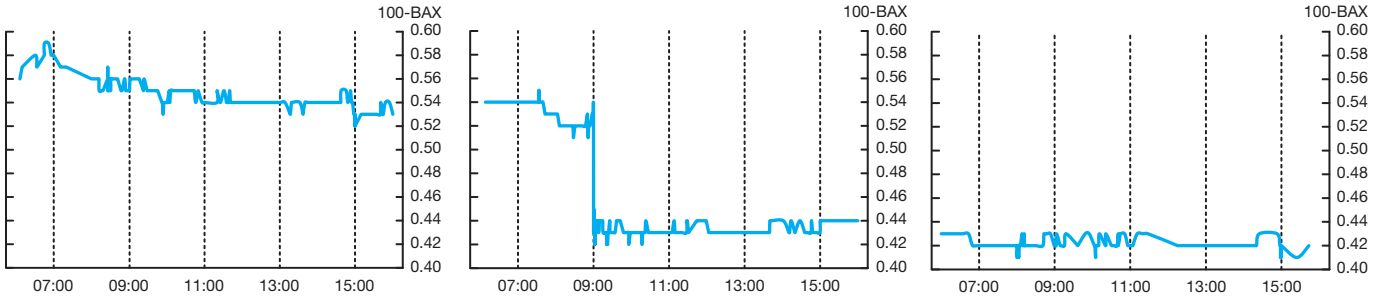
Chart 1: Intraday BAX prices

Expiry: 14 September 2009

a. 20 April 2009: realized volatility = 0.69

b. 21 April 2009 fixed announcement date: realized volatility = 1.17

c. 22 April 2009: realized volatility = 0.40



Source: Montréal Exchange

and c show the implied yields of the same BAX contract one day before and one day after 21 April, respectively. There is a large drop in the implied yield at 09:00 on 21 April 2009, the time of the Bank's policy rate announcement. This pattern is typical of FADs, reflecting a shift in expectations immediately following a policy announcement. Any large change (either up or down) in the BAX price leads to distinctly larger-than-average relative volatility on the FADs. We explore this issue in more detail in the section on policy rate announcements.

Implied volatility of BAX

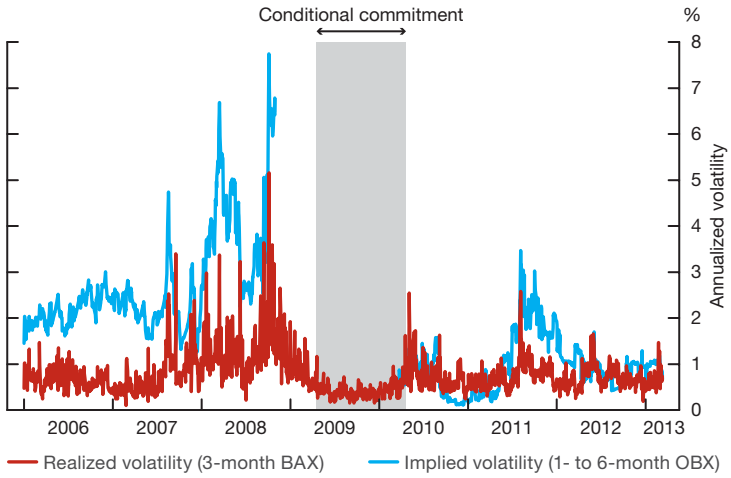
We compute the implied volatility of BAX from OBX option prices using an option valuation formula based on the Vasicek interest rate model (Vasicek 1977).[5] Since the expiry dates of the options that are traded vary, the implied volatility can, in theory, be computed at different maturities and used as a measure of policy rate uncertainty at different horizons. However, the relatively low liquidity of OBX prevents us from computing the implied volatility of BAX for different maturities consistently over time. We therefore compute an average implied volatility for each day, using all options with maturities from one to six months.[6]

Chart 2 shows the daily time series for our measure of implied volatility. Note that the implied volatility cannot be computed between November 2008 and mid-March 2010, since there was no trading in OBX contracts during that period. This temporary halt in trading began in October 2008 at the peak of the financial crisis in the United States, possibly as a result of the increased margin requirements caused by the high volatility of the underlying interest rates and risk premiums at that time. This halt was not a result of actions taken by the exchange or the regulators. Trading in OBX resumed in mid-March 2010, about one month before the removal of the conditional commitment.

5 Since Vasicek's interest rate model allows negative interest rates, the implied volatility that we compute does not take into account the fact that the interest rate cannot fall below zero.

6 Chang and Feunou (2013) provide details on how the implied volatility is calculated.

Chart 2: Implied volatility and realized volatility of BAX



Sources: Montréal Exchange and Bank of Canada

Last observation: 13 March 2013

Impact of Bank of Canada's Policy Actions on Uncertainty

Conditional commitment in 2009 and 2010

The Bank's conditional commitment in 2009 and 2010 reduced a large amount of uncertainty around future policy rates for a specific period of time

The Bank's conditional commitment that lasted several months in 2009 and 2010 had clear implications for policy rate uncertainty, since the commitment reduced a large amount of uncertainty around future policy rates for a specific period of time. On 21 April 2009, the Bank lowered its policy rate from 0.50 per cent to 0.25 per cent and announced that, "Conditional on the outlook for inflation, the target overnight rate can be expected to remain at its current level until the end of the second quarter of 2010 in order to achieve the inflation target."[7] The commitment was eventually removed on 20 April 2010, and the policy rate was subsequently raised back to 0.50 per cent on the following FAD on 1 June, one month earlier than indicated in the initial conditional commitment. The introduction of the conditional commitment coincided with the decision to lower the interest rate to the effective lower bound of 0.25 per cent, at which point interest rates could be moved only upward. In principle, both the reduction of the policy rate to the effective lower bound and the conditional commitment would reduce uncertainty about future policy rates. This section assesses whether uncertainty did in fact decrease during the conditional commitment period.

Chart 2 shows the realized volatility and the implied volatility from January 2006 to March 2013. We choose the three-month maturity for realized volatility because the average maturity of options used in the computation of implied volatility is around three months. Since the asset underlying both BAX futures and OBX options is the three-month CDOR, the time horizon of uncertainty for both measures of volatility reflects uncertainty around the policy rate approximately three to six months ahead.[8]

7 See the Bank of Canada press release at http://www.bankofcanada.ca/2009/04/publications/press-releases/fad-press-release-2009-04-21/.

8 For example, we compute the realized volatility in January 2013 using the BAX contract expiring in March 2013. The final settlement price of this contract is the three-month CDOR on 18 March 2013. Since the three-month CDOR in March reflects expected policy rates between March and June (plus a small spread), the price of the March-expiry BAX in January also reflects these expected policy rates. Therefore, the horizon of uncertainty of the realized volatility computed in January using the prices of BAX expiring in March is between three and six months.

As expected, during the period of the conditional commitment, uncertainty about future policy rates was extremely low, as indicated by the low level of realized volatility. Furthermore, although a measure of implied volatility is not available throughout the conditional commitment period, its level at the time when trading resumed is significantly lower than it was when trading halted in late 2008. This low level is consistent with the decreased uncertainty exhibited by the low level of realized volatility throughout the conditional commitment period.

The timing of the resumption of trading in OBX contracts also provides an interesting insight into the market's expectations regarding the timing of the removal of the conditional commitment. Trading of OBX contracts with a 14 June 2010 expiry date resumed in mid-March 2010, one month before the removal was announced. The fact that options started trading even though they had an expiry date before the end date of the commitment suggests that the market anticipated a possible early removal of the commitment before the actual announcement was made.

The Bank's removal of the conditional commitment resulted in a large increase in the level of both implied and realized volatility

The Bank's removal of the conditional commitment resulted in a large increase in the level of both implied and realized volatility relative to that observed during the conditional commitment period. While realized volatility increased to a level comparable with that observed before the crisis, implied volatility remained much lower compared with both the crisis period and the pre-crisis period. The extremely low level of implied volatility is a result of both little interest rate uncertainty, as reflected in low realized volatility, and a small volatility risk premium, which is measured as the difference between implied volatility and realized volatility. The near-zero volatility risk premium indicates that investors in the post-crisis period did not require a high premium for bearing the risk of interest rate volatility, possibly because any indication of the interest rate moving away from the effective lower bound, and thus increasing interest rate volatility, was linked to an improving rather than deteriorating economic outlook during this period.

Announcement effects of crisis-related policy actions

Announcements of other crisis-related policies led to large decreases in implied volatility

Unlike the conditional commitment, the implication of other crisis-related policies on policy rate uncertainty is not clear a priori. This section examines the impact of these policy actions on uncertainty, as reflected in the change in the implied volatility on the days when policy announcements were made. We examine three crisis-related policy announcements made by the Bank in 2007 and 2008: (i) the first introduction of term PRAs for liquidity purposes in December 2007; (ii) the second introduction of term PRAs in March 2008; and (iii) the intermeeting cut in the policy rate in October 2008 that was coordinated with other major central banks. All of these announcements led to large decreases in implied volatility, ranging between 12 and 51 basis points (**Table 1**).

By far, the largest drop in implied volatility—51 basis points—occurred on 8 October 2008, when, in an intermeeting announcement, the policy rate was cut by 50 basis points, in conjunction with similar moves announced by other central banks. This rate reduction occurred around the height of the crisis, when the implied volatility of BAX had reached its highest level in our sample period, as shown in **Chart 2**. The result is consistent with Bauer (2012), who finds that many of the important announcements made by the Federal Reserve during the financial crisis also led to a larger-than-average drop in the implied volatility of eurodollar futures options. The strong market

Table 1: Implied volatility following crisis-related Bank of Canada policy announcements

Date	Policy announcement	Daily change in implied volatility (basis points)
12 December 2007	First term purchase and resale agreements (PRAs) announced for liquidity purposes (in coordination with similar actions by the Bank of England, the European Central Bank, the Federal Reserve and the Swiss National Bank) (not a FAD[a])	-12
11 March 2008	Second term PRAs announced for liquidity purposes, coordinated with other G-10 central banks (not a FAD)	-25
8 October 2008	Intermeeting cut in target rate, coordinated with other major central banks (not a FAD)	-51
	Average—all days	0
	Average—FADs	-5
	Average—non-FADs	1

a. FAD: fixed announcement date, the Bank of Canada's pre-scheduled policy rate announcement date

reaction indicates that this coordinated action by the central banks was effective at reducing uncertainty around the policy rate and the risk premium associated with the uncertainty at that time.

The Bank announced the term PRA facility on 12 December 2007 as part of a broader initiative that included similar programs announced by other central banks worldwide to alleviate pressures in short-term funding markets.[9] Enenajor, Sebastian and Witmer (2010) find evidence that the term PRA announcements did indeed reduce bank short-term funding costs in Canada. Zorn, Wilkins and Engert (2009) also suggest that the availability of the Bank's extraordinary liquidity facilities such as the term PRAs may have mitigated stresses in the bank funding market in Canada. Since the introduction of a term PRA facility is not directly related to the policy rate, a large decrease in implied volatility observed on the PRA announcement days seems to be related to a lower risk premium rather than lower uncertainty around future policy rates. A lower risk premium is consistent with reduced stress in the short-term bank funding market found in the previous studies.

Policy rate announcements on fixed announcement dates

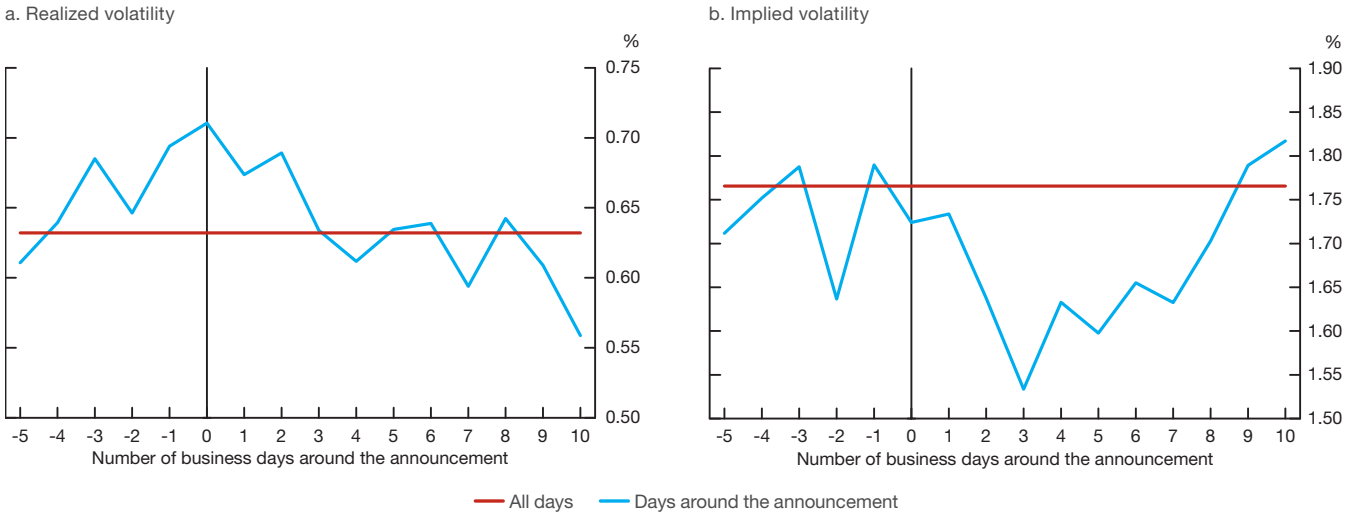
Many central banks make their policy rate announcements only on pre-scheduled dates to reduce uncertainty about the timing of changes to the policy rate, a practice that is consistent with increased transparency in central bank communications.[10] After each policy rate announcement, central banks are interested in assessing the impact of their decision on the market. Typically, the financial variables they monitor include yields on various fixed-income securities and foreign exchange rates. However, these variables do not indicate whether a particular decision has increased or decreased uncertainty around future policy rates.

To determine whether uncertainty increased or decreased, we look at whether any pattern emerges in the measures of realized and implied volatility around the days of the policy rate announcements. Since the policy rate is fixed until the next FAD, typically six to eight weeks away, we would

9 See the Bank of Canada press release at http://www.bankofcanada.ca/2007/12/bank-canada-temporarily-expands-list-securities/.

10 For further discussion on the impact of fixed announcement dates and forward-looking guidance on uncertainty, see Parent, Munro and Parker (2003) and Fay and Gravelle (2010).

Chart 3: Average level of realized and implied volatility of BAX around policy rate announcement days



Sources: Montréal Exchange and Bank of Canada

expect any measure of uncertainty over a shorter horizon to drop sharply after each announcement. However, if the horizon extends beyond the following announcement day, as is the case for realized volatility and implied volatility, which have horizons of three to six months, uncertainty can either increase or decrease after a policy rate announcement.

Chart 3 shows the average levels of realized volatility and implied volatility between five business days before and ten business days after policy rate announcements. For this analysis, we compute realized volatility using only trade prices after 09:15 to remove the effect of large changes in BAX prices observed immediately following the policy rate announcements (**Chart 1**). The analysis is based on 90 FADs between January 2002 and March 2013 for realized volatility, and 58 FADs between January 2006 and March 2013 for implied volatility.

The realized volatility is higher than average (with statistical significance) on the FAD and the day before the FAD. It then decreases gradually over the next two weeks. However, this analysis shows that realized volatility is significantly lower than average on only two days within the two-week window, seven and ten business days after the FAD. Thus, based on realized volatility, we find only weak evidence that uncertainty decreases following a policy rate announcement.

The results for implied volatility provide much stronger evidence that uncertainty decreases on average following a policy rate announcement. A regression analysis of the level of implied volatility shows that it is significantly lower than average between two and seven business days after an announcement. A regression analysis of the change in implied volatility shows that statistically significant drops in implied volatility occur on an announcement day and two business days after an announcement. The decrease in implied volatility two business days after an announcement can be explained by the fact that, during a large part of the sample period, the Bank released its *Monetary Policy Report* two days after every other policy rate announcement.[11]

11 Between October 2010 and December 2012, the Bank published its *Monetary Policy Report* one day after its January, April, July and October FAD announcements, and since January 2013, it has published the *Report* concurrently with these FAD announcements.

Our results show that, on average, the Bank's policy rate decisions reduced uncertainty around future policy rates in our sample period. A statistically significant reduction in uncertainty is observed on the days of a policy rate announcement and the release of the *Monetary Policy Report*. The effect of the reduction in uncertainty, however, seems to be temporary, lasting for seven business days, on average. This gradual increase in uncertainty following the initial decrease after a policy rate announcement is reasonable, given that new information and new events tend to increase uncertainty.

Our results show that, on average, the Bank's policy rate decisions reduced uncertainty around future policy rates

Conclusion

Realized volatility computed from the intraday prices of interest rate futures and implied volatility computed from interest rate futures options are useful indicators of uncertainty around future central bank policy interest rates. Based on implied volatility computed from OBX options, we show that, on average, policy rate announcements by the Bank of Canada reduced uncertainty around future policy rates. We also examine the effect of major policy actions that the Bank took in response to the 2007–09 financial crisis. We find that realized volatility was extremely low during the conditional commitment period in 2009 and 2010. Also, the introduction of term PRAs and the intermeeting cut in the policy rate coordinated with other major central banks both resulted in a large drop in implied volatility on the announcement days, indicating that these announcements reduced uncertainty around future policy rates and/or reduced risk premiums on interest rate uncertainty.

Literature Cited

Abken, P. A. 1995. "Using Eurodollar Futures Options: Gauging the Market's View of Interest Rate Movements." Federal Reserve Bank of Atlanta *Economic Review* 80 (2): 10–30.

Bauer, M. D. 2012. "Monetary Policy and Interest Rate Uncertainty." Federal Reserve Bank of San Francisco *Economic Letter* No. 2012-38.

Bernanke, B. S. 1983. "Irreversibility, Uncertainty, and Cyclical Investment." *Quarterly Journal of Economics* 98 (1): 85–106.

Chang, B. Y. and B. Feunou. 2013. "Measuring Uncertainty in Monetary Policy Using Implied Volatility and Realized Volatility." Bank of Canada Working Paper No. 2013-37.

Enenajor, E., A. Sebastian and J. Witmer. 2010. "An Assessment of the Bank of Canada's Term PRA Facility." Bank of Canada Working Paper No. 2010-20.

Fay, C. and T. Gravelle. 2010. "Has the Inclusion of Forward-Looking Statements in Monetary Policy Communications Made the Bank of Canada More Transparent?" Bank of Canada Discussion Paper No. 2010-15.

Johnson, G. 2003. "Measuring Interest Rate Expectations in Canada." *Bank of Canada Review* (Summer): 17–27.

Neely, C. J. 2005. "Using Implied Volatility to Measure Uncertainty About Interest Rates." Federal Reserve Bank of St. Louis *Review* 87 (3): 407–25.

Parent, N., P. Munro and R. Parker. 2003. "An Evaluation of Fixed Announcement Dates." *Bank of Canada Review* (Autumn): 3–11.

Rigobon, R. and B. Sack. 2002. "The Impact of Monetary Policy on Asset Prices." *Journal of Monetary Economics* 51 (8): 1553–75.

Vasicek, O. 1977. "An Equilibrium Characterization of the Term Structure." *Journal of Financial Economics* 5 (2): 177–88.

Zorn, L., C. Wilkins and W. Engert. 2009. "Bank of Canada Liquidity Actions in Response to the Financial Market Turmoil." *Bank of Canada Review* (Autumn): 3–22.