Interest rate pass-through:  
A nonlinear vector error-correction approach

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Abstract

This paper proposes a new econometric framework for estimating interest rate pass-through and provides a comprehensive analysis of Canadian consumer retail loan and deposit rate behaviour from 1983 to 2015. Interest rate pass-through from market rates to retail rates is analyzed using a nonlinear vector error-correction model. In contrast to empirical frameworks used in previous studies, this model allows for estimation of long-run pass-through coefficients, while simultaneously accounting for asymmetric adjustments and short-run dynamics. Pass-through was complete for all rates before the financial crisis although only after the mid 1990s for the 1 year mortgage rate. Since the end of the 2008-09 recession, pass-through remains complete in the mortgage market but has significantly declined for long-term deposit rates. Although some studies have documented a weakening of the transmission of monetary policy through the interest rate channel since the financial crisis in countries that resorted to unconventional monetary policy measures and experienced severe market turmoil, this is the first paper to document a decline in pass-through in a country that experienced no bank failures and did not resort to quantitative easing. This result suggests that the weakened transmission of monetary policy could be a global problem tied to near-zero interest rates.

JEL Codes: C32, E43, E52, G21  
Keywords: Interest rate pass-through, cointegration, asymmetric adjustment, nonlinear vector error correction model

1 Introduction

Banks play a critical role in the interest rate channel of monetary policy transmission. Most central banks’ main policy instrument is the target for the overnight rate, which directly affects only the shortest term interest rate. In competitive money markets, rates of securities of longer maturities usually respond quickly and completely to changes in the policy rate through the term structure of interest rates. However, consumer retail rates on loans and deposits are set by commercial banks who often have significant market power. As a result, the speed and degree of adjustment in this second step, known as the interest rate pass-through (IRPT), is subject to market frictions.

Quantifying IRPT is important to policy makers because it reflects the effectiveness of monetary policy transmission and allows for greater precision in forecasting policy outcomes. Yet despite its

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importance, there is no consensus in the literature on the appropriate model for its estimation. Choosing an econometric model is complicated by the need to simultaneously account for several key features of retail interest rates and their relationship to market rates. While different models can account for different features of the data, this paper proposes a model that can account for all of them in a unified framework.

The proposed model is used to estimate IRPT in Canada with weekly data from 1983 to 2015 on five deposit and three loan rates of maturities ranging from three months to five years. The sample is long enough to consider three distinct periods. In 1996, the Bank of Canada officially adopted a 2% inflation target and dropped the Bank Rate peg to the 3 month Treasury Bill.\(^1\) Thus, the first two periods are divided by a fundamental shift in the way that monetary policy was conducted, allowing for a comparison across regimes. The third period begins in 2009 after the end of the most recent recession which followed the global financial crisis. Analysis of this period looks at whether the transmission mechanism has weakened since the financial crisis.

For each of the rates two main hypotheses are tested. First, tests of the \textit{completeness hypothesis} reveal whether or not pass-through is complete, i.e. if retail rates fully adjust to changes in the market rate in the long-run. Second, tests of the \textit{symmetry hypothesis} reveal whether retail rates respond in the same way to upward and downward movements in the market rate. Pass-through has been complete among all of the deposit and loan rates in the first two periods (with the exception of the 1 year mortgage rate, for which pass-through was incomplete before 1996) but has noticeably declined for deposit rates of longer maturities since the financial crisis. Furthermore, there is evidence of asymmetric adjustment for all of the longer term rates. Interestingly, the asymmetry in adjustment of deposit rates favours the consumer in the first period, i.e. quick to increase and slow to decrease, but then switches to favour the bank in the second period. Meanwhile, mortgage rates exhibit downward rigidity in the first period and in the last period, but adjust symmetrically to market rates in the period that starts with the new monetary policy regime and ends with the onset of the financial crisis.

The literature on IRPT dates back to the early 1990s with the influential work of Cottarelli and Kourelis (1994) that tied differences in the degree of pass-through across countries to characteristics of their financial structures. The topic has been widely studied in Europe, especially since the introduction of the monetary union. De Bondt (2005) provides a comprehensive review of literature on individual European countries and performs a cross-country analysis to measure the impact of the monetary union on IRPT. Another strand of literature focuses entirely on the adjustment process. Hannan and Berger (1991) and Neumark and Sharpe (1992) find evidence of upward rigidity in US banking retail deposit rates and associate it with high levels of market concentration. Driscoll and Judson (2013) confirm this result with updated data.

Relatively few studies consider IRPT in Canada. Clinton and Howard (1994) provide a discussion of transmission from market rates to long-term retail rates, but they impose complete pass-through in their empirical specification. Scholnick (1999) considers a wider variety of interest

\(^1\)The Bank Rate is the rate that the Bank of Canada charges on short-term loans.
rates over a longer horizon and tests for adjustment asymmetries. He finds that despite the high
degree of market concentration in Canadian banking, only car loans and savings deposits exhibit
adjustment asymmetries that favour the banks. Finally, Allen and McVanel (2009) examine indi-
vidual bank mortgage rate data for a later period and find evidence of asymmetric adjustment in
the 3 and 5 year mortgage rates and mixed results for pass-through.

Recently, IRPT has once again come into the spotlight. In response to the financial crisis, most
central banks reduced their policy rates to their effective zero lower bound and many resorted to
unconventional monetary policies to further stimulate the economy. A number of studies document
the impact of financial turmoil and these new monetary policy tools on IRPT across Europe and
in the US: Karagiannis et al. (2010), Ahmad et al. (2013), Illes and Lombardi (2013), Mora (2014)
and Aristei and Gallo (2014). They report a decline in pass-through and evidence of asymmetric
adjustment. In contrast to the US and Europe, Canada experienced no bank failures during the
crisis. Furthermore, its policy rate quickly rebounded from the zero lower bound and it did not
resort to quantitative easing. Nevertheless, IRPT has significantly declined for some retail rates.

This study contributes to the literature in three main ways. The first is methodological: em-
pirical analysis is conducted using a nonlinear vector error correction model which can overcome
several shortcomings of previously used models and estimate pass-through while simultaneously
allowing for asymmetric adjustments and short run dynamics. Since the asymptotic distributions
for conducting inference in this framework were only recently derived by Kristensen and Rahbek
(2013), this framework has yet to be used in the IRPT literature. Second, this paper extends the
work of Scholnick (1999) and Allen and McVanel (2009) on Canadian retail rates by looking at
the most recent time period since the financial crisis. It is also the first to test for completeness
of pass-through to Canadian deposit rates. Third, it contributes to the recent literature on post-
financial-crisis IRPT by showing that although Canadian financial markets were relatively resilient,
Canada was not immune to a weakening of the transmission mechanism of monetary policy.

The paper is structured as follows. The next section discusses IRPT and various market frictions
that can affect completeness and symmetry. Section 3 describes the data and methodology, Section 4
presents the results and Section 5 concludes.

2 Interest rate pass-through and market frictions

Analysis of IRPT is based on the Monti-Klein model of banking, which treats banks as profit
maximizing firms that take deposits, give loans, and put the balance on the interbank market
(Monti, 1972; Klein, 1971). Thus, in addition to the costs of managing loans and deposits, the
optimal retail rates are also influenced by the exogenously determined market rates. The main
pass-through equation, which is derived from maximizing the bank’s profit function, is specified as
follows

\[ r_t = \rho + \beta m_t, \]
where $m_t$ is the market rate, $r_t$ is the retail rate, $\rho$ is the markup\(^2\) and $\beta$ determines the degree of pass-through. Since monetary policy through the interest channel has the ultimate goal of influencing consumer spending and savings decisions, the pass-through parameter $\beta$ plays a critical role in determining the efficiency of transmission.

The pass-through equation represents an equilibrium outcome that is best modeled as a long-run relationship. Market rates fluctuate daily, but since it would be too costly for banks to respond to every one of these changes, short-run equilibrium deviations are likely to arise.

The short-run dynamics around adjustments to this long-run equilibrium contain important information about banking behaviour. For instance, a finding of complete pass-through does not necessarily imply that the market is free of frictions. Banks could, for example, be slower to respond to fluctuations in market rates that are less favorable to their profit margins. This is the case for US retail deposits rates which exhibit upward rigidity as confirmed by several studies (Neumark and Sharpe, 1992; Hannan and Berger, 1991; Driscoll and Judson, 2013).

Incomplete pass-through and asymmetric adjustments that favour banks are most often associated with market power and an inelastic demand. Consumers may be irresponsible to changes in retail banking rates if, for instance, switching costs are high. This situation may arise in the presence of information and search costs, which are likely to appear in markets where repeated transactions lead to long-term relationships (Sharpe, 1997). If search and switching costs are sufficiently high, consumers may be less inclined to look for better rates or change banks even if they find them. Allen et al. (2012) estimate these costs for consumers in the Canadian mortgage market and find that they are non-negligible.

Retail rate movements may also adjust to favour the consumer. Hannan and Berger (1991) discuss the case of negative consumer reactions to unstable prices and that they may be more pronounced when price fluctuations are unfavorable. If the banking sector is competitive, banks may adjust their retail rates to minimize negative reactions and maintain their consumers. This behaviour would manifest itself with upward rigidity of rates in the loan market and downward rigidity of rates in the deposit market.

Consumers may also respond negatively to near-zero deposit rates and withdraw their funds to invest in higher yielding assets. Therefore, banks may be reluctant to lower deposit rates beyond some minimal value for fear of losing depositors. In such a way, the low interest rate environment that followed the financial crisis may create downward rigidity in deposit rates.

On the loan side, upward rigidity can arise because of asymmetric information. When interest rates rise banks can encounter problems of adverse selection and moral hazard (Stiglitz and Weiss, 1981). Higher rates can attract riskier individuals and more speculative projects. In response, banks may be driven by a credit rationing motive that makes them slow to increase lending rates and quick to decrease them.

In summary, completeness of pass-through implies that banks fully adjust their retail rates to

\[ \rho - (1 - \beta)\bar{m} \]

when $\beta \neq 1$ (Allen and McVanel, 2009).

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\(^2\)The IRPT literature often refers to $\rho$ as the markup over marginal cost, but this ignores the fact that the marginal cost of handling loans and deposits is contained in $\rho$. More accurately, $\rho$ represents the markup over the market rate, which can be approximated by $\rho - (1 - \beta)\bar{m}$ when $\beta \neq 1$ (Allen and McVanel, 2009).
changes in the market rate in the long-run and the presence of asymmetries affects how quickly this adjustment takes place in different directions. Both completeness and symmetry may be violated in the presence of various market imperfections and the direction of asymmetry can shed light on the type of imperfection that is present in the market.

3 Data and methodology

This section describes the data on the interest rates and the selection of dates that split the sample into three main periods. It also discusses the empirical framework and how each of the research questions can be represented by testable hypotheses within the model.

3.1 Description and timing

The data contains several consumer loan and deposit rates: fixed rate mortgages and Guaranteed Investment Certificates (GICs) of 1, 3, and 5 year maturities, as well as fixed term deposits of 90 day and 5 year maturities. As is common in the IRPT literature, each loan and deposit rate is matched with an equal maturity government bond or treasury bill to proxy for banks’ cost of funding. Figures 1 and 2 plot the rates and show that they move closely together over the entire sample.

All data is taken from Statistics Canada CANSIM tables and is available from June 1982 for all rates. However, since this date is very close to the end of a severe recession with large market fluctuations, the first period is set to begin in January 1983, the first quarter of recovery (Cross and Bergevin, 2012). In the 1990s, the way that the Bank of Canada conducted monetary policy underwent several significant changes (Lundrigan and Toll, 1998). Most notably, the Bank of Canada phased out reserve requirements from 1992 to 1994 and adopted the corridor system in 1994. The corridor system establishes a 50 basis point operating band target for the overnight rate. In February 1996, the Bank of Canada officially set the Bank Rate to the upper bound of the corridor. Prior to this period, the Bank Rate had been pegged to the 3 month treasury bill plus 25 basis points. The Bank of Canada often intervened in the treasury bill market to influence the Bank Rate, but following this change it stopped open market operations and focused entirely on targeting the overnight rate. Since this marked a fundamental shift in the focus of monetary policy it comes as a natural break point to start the second period. The spread on the Bank rate and the overnight rate is shown in Figure 3, clearly depicting the change in monetary policy regimes.

In addition, the Bank of Canada began officially targeting inflation in 1991 and it adopted the 2 per cent inflation target – from which it has not deviated since – at the end of 1995. Annual inflation is shown in Figure 4 and although inflation quickly declined soon after the Bank adopted inflation targeting, it took some time for inflation expectations to adapt to the new 2 per cent target (Perrier and Amano, 2000). The second period thus marks a transition in monetary policy objectives from inflation reduction to maintenance of low and stable inflation along with a new focus on the overnight money market.

The second break point is set for the end of July 2007, the onset of the financial crisis. At this

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\(^3\)Fixed term deposits are redeemable before maturity at a penalty while GICs are not.
point, ratings agencies downgraded mortgage backed securities, Bear Stearns filed for bankruptcy, and markets began to slide as indicated by the financial conditions index plotted in Figure 5(b). In August, rates for government securities began to plummet and continued to do so until the end of the recession (see Figures 1 and 2). The last period starts in May 2009, at the beginning of the recovery. GDP growth, shown in Figure 5(a), returned to positive territory and financial conditions, shown in Figure 5(b), improved significantly.

For a closer look at the data, Table 1 provides summary statistics for each of the rates across the three main time periods. In addition to means and standard deviations, the table contains two unit root test statistics: Augmented Dickey Fuller (ADF) and the Jansson-Nielsen (JN) “nearly efficient” likelihood ratio test (Jansson and Nielsen, 2012). Both the means and standard deviations of all rates decline over time. The decline from the first period to the second period reflects the change in the Bank of Canada’s stance on inflation targeting whereas the very low means and
volatility in the third period correspond to a new era of near zero interest rates following the financial crisis. Furthermore, with very few exceptions, the rates fail to reject the presence of a unit root. Table 2 reports the same summary statistics for the rates in first differences, which strongly reject the unit root, suggesting that they are difference-stationary.

Another series of interest is the difference between market and retail rates. If retail rates react to market rates according to the pass-through equation, then the distance between them should be stationary. Table 3 reports the summary statistics for the spreads of retail over market rates of matching maturities. These results should be interpreted with caution because analyzing the spreads and their properties abstracts from a lot of short and long run dynamics that are critical for an accurate description of the relationship among the variables. In general, the spreads appear to be stationary in the first two periods, which is suggestive of complete pass-through. However, in the period following the financial crisis several rates, in particular those with longer maturities,
appear to have non-stationary spreads. The means of the spreads also exhibit some patterns. For instance, mortgage rates show that the markup over cost has been on the rise across the three periods. Deposits rates, on the other hand, show a steady decrease in spreads for fixed terms and an increase followed by a decrease for GICs. An accurate analysis of these trends requires an appropriate econometric model, which is described in the next section.

### 3.2 Methodology

To estimate the pass-through equation, the empirical model must account for several key dynamics of the data. Most importantly, as discussed in Section 2, since the pass-through equation represents an equilibrium outcome, it is necessary to allow for short run deviation. The way that these short-run dynamics are specified is important for other research questions such as whether retail rates respond to market rates in the first place and, if they do, is their adjustment asymmetric. Estimation is further complicated by the fact that interest rates are non-stationary (see Table 1).

The typical approach in the literature takes one of three main forms. The simplest method
is a regression of change in market rates on change in retail rates (see for example Mora, 2014). Although this accounts for non-stationarity, it abstracts from all of the other features. Some authors, for example Scholnick (1999), use the cointegrated VAR (CVAR) model which is capable of estimating the long-run equilibrium between the two variables while simultaneously accounting for short-run dynamics. This framework, however, does not allow for nonlinearities such as asymmetric adjustments. To deal with this problem, others use a univariate error-correction model with dummy variables for positive and negative movements in the market rate. They either estimate it with nonlinear least squares (Karagiannis et al., 2010) or in two steps with OLS (Allen and McVanel, 2009). These models do not allow for short run persistence in the market rate and they assume that it does not respond to equilibrium fluctuations.

To deal with these empirical issues, the nonlinear vector error-correction model (VECM) is used. This model specifies a long-run equilibrium relationship with nonlinear adjustment coefficients without the assumption of strong exogeneity of the market rate. Estimation and analysis is based
on Kristensen and Rahbek (2013), who provide a rigorous discussion of testing and inference – as well as the asymptotic distributions for the relevant test statistics – within a general class of nonlinear VECMs.

Letting \( X_t = [r_t, m_t]' \) be a vector containing the retail and market rate, the nonlinear VECM is specified as follows,

\[
\Delta X_t = g(\beta' \tilde{X}_{t-1}) + \sum_{i=1}^{k} \Gamma_i \Delta X_{t-i} + \varepsilon_t, \tag{1}
\]

where the long-run stationary equilibrium corresponds to the pass-through equation and is given by,

\[
\beta' \tilde{X}_{t-1} = \begin{bmatrix} 1 & \beta & \rho \end{bmatrix} \begin{bmatrix} r_t \\ m_t \\ 1 \end{bmatrix} = r_t + \beta m_t + \rho. \tag{2}
\]

The \( \Gamma_i \)'s determine the short run dynamics while the function \( g(\cdot) \) captures the adjustment to equilibrium fluctuations. In contrast to the CVAR, this model allows for both linear and nonlinear adjustment coefficients,

\[
g(\beta' \tilde{X}_{t-1}) = \alpha \beta' \tilde{X}_{t-1} + \frac{\delta f(\beta' \tilde{X}_{t-1}; \psi)}{\text{Nonlinear}} \beta' \tilde{X}_{t-1}. \tag{3}
\]

The nonlinear adjustment is specified using a logistic function which can account for asymmetry in a general way,

\[
f(\beta' \tilde{X}_{t-1}; \psi) = [1 + \exp(\psi(\beta' \tilde{X}_{t-1}))]^{-1}. \tag{4}
\]

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<tr>
<td></td>
<td>mean</td>
<td>sd</td>
<td>ADF</td>
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<td>FT 3m</td>
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</tr>
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<td>8.74</td>
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<td>-0.99</td>
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<td>10.10</td>
<td>2.06</td>
<td>-1.13</td>
</tr>
<tr>
<td>GB 1y</td>
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<td>2.26</td>
<td>-1.17</td>
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<tr>
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<td>-0.59</td>
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<tr>
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<td>10.87</td>
<td>1.83</td>
<td>-0.88</td>
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<td>-0.66</td>
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<td>1.72</td>
<td>-0.97</td>
</tr>
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<td>11.25</td>
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<td>-1.02</td>
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<td>GB 5y</td>
<td>9.29</td>
<td>1.57</td>
<td>-1.07</td>
</tr>
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</table>

Note: The table shows mean and standard deviation for each of the interest rates for the three periods. In addition, the Augmented Dickey-Fuller (ADF) is reported as well as the JN statistic. Each with lag \( k = 1 \). The sample sizes are \( N = 683 \) for 1983-1996, \( N = 600 \) for 1996-2007, and \( N = 304 \) for 2009-2015. Statistical significance at the 5%, 1%, and 0.1% level is denoted by *, **, and ***, respectively.
If \( \psi > 0 \), as the deviation from equilibrium becomes large and negative, \( f(\cdot) \) approaches 1 and as it becomes large and positive, \( f(\cdot) \) approaches 0. When \( \psi \) is small in magnitude, the size of the asymmetric adjustment depends on the size of the deviation from equilibrium. This could arise if, for example, banks only adjust their retail rates in response to large changes in the market rate.

Several hypotheses of interest can be tested within this framework. First, note that the CVAR is nested within model (1) as a special case when \( \delta = 0 \). Thus the hypothesis \( \mathcal{H}^{\delta}_{1,2} : \delta_1 = \delta_2 = 0 \) tests for the presence of asymmetric adjustments in the error correction. Failing to reject this hypothesis implies that adjustments are symmetric (symmetry hypothesis). Next, the null
hypothesis of complete pass-through is specified as a test on the long-run coefficients in $\beta$, namely $H^{\beta} : \beta = -1$. This hypothesis implies that a change in the market rate is fully transmitted to the retail rate in the long-run equilibrium (completeness hypothesis). Finally, the hypothesis $H^{\alpha,\delta}_i : \alpha_i = \delta_i = 0$, for $i \in \{1, 2\}$, tests for long-run exogeneity. If a variable does not respond to fluctuations in the long-run equilibrium then it is long-run exogenous. This weak form of exogeneity – the variable still responds to short-run fluctuations – can establish Granger causality. If the market rate is weakly exogenous and only the retail rate responds to equilibrium fluctuations, then we can say that changes in the market rate Granger-cause changes in the retail rate. Therefore, this hypothesis can reveal if the direction of transmission is consistent with the theory of pass-through.

4 Results

Each of the retail rates is estimated in a bivariate system with the market rate of matching maturity. Before conducting inference on the parameters of interest the model needs to be correctly specified with an appropriate lag augmentation and cointegrating rank. The rank $r$ determines the number of stationary cointegrating relations. If the rank is 0, then the two interest rates are not cointegrated. A rank of 1 implies that the market rate and retail rate form a long-run stationary equilibrium and a rank of 2 implies that they are both stationary.

The lag order $k$ is selected using a general-to-specific testing strategy. Starting with a maximum lag of $k = 5$, the significance of the coefficient with the highest lag $\Gamma_k$ is tested using a likelihood ratio (LR) test against the alternative model with $k - 1$ lags. This is done sequentially until the LR test rejects the model with $k^* - 1$ lags, leaving $k^*$ as the appropriate lag.

Rank selection follows the procedure outlined in Johansen (1995). Testing is once again done sequentially, starting with the null of no cointegration $H^r_0 : r = 0$. If this hypothesis is rejected, then the null of one cointegrating vector $H^r_1 : r = 1$ is tested. In both cases the alternative is the model with full rank $H^r_2 : r = 2$. The rank tests are conducted within the CVAR model because inference in nonlinear VECMs requires the long-run coefficient $\beta$ to be identified under the null (Kristensen and Rahbek, 2013).

Table 4 reports the results of rank tests for all of the bivariate systems. With the exception of the 1 year mortgage in the third period, all of the rates strongly reject the null of no cointegration and fail to reject the null of 1 cointegrating vector. However, since it is possible that different rates might have taken longer to stabilize after the financial crisis, the test for cointegration is also conducted for the period 2010-2015 for the 1 year mortgage rate. This result is reported in the last row of the table and also shows strong evidence of cointegration.

The rest of the hypothesis test results are discussed in detail for deposit rates in Section 4.1 and mortgage rates in Section 4.2. For each of the bivariate models, the testing procedure is conducted as follows. Using the rank and lag from Table 4, model (1) is estimated. The first test is for asymmetry, $H^{\delta}_{1,2}$, and if it is rejected then the rest of the hypotheses – completeness

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4More generally, the hypothesis is specified as $H^{\beta} : \beta_1 = -\beta_2$, but since the cointegrating vector is normalized on the retail rate for identification, these two specifications are equivalent.
Table 4: Rank test results

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<tbody>
<tr>
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<td>k</td>
<td>r = 0</td>
<td>r = 1</td>
<td>k</td>
<td>r = 0</td>
</tr>
<tr>
<td>FT 3m, TB 3m</td>
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<td>1.68</td>
<td>1</td>
<td>33.41***</td>
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<td>GIC 1y, TB 1y</td>
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<td>1.64</td>
<td>1</td>
<td>82.49***</td>
</tr>
<tr>
<td>GIC 3y, GB 3y</td>
<td>2</td>
<td>41.15***</td>
<td>1.94</td>
<td>1</td>
<td>85.68***</td>
</tr>
<tr>
<td>GIC 5y, GB 5y</td>
<td>2</td>
<td>31.53***</td>
<td>2.18</td>
<td>1</td>
<td>89.63***</td>
</tr>
<tr>
<td>FT 5y, GB 5y</td>
<td>2</td>
<td>28.19**</td>
<td>2.45</td>
<td>1</td>
<td>82.48***</td>
</tr>
<tr>
<td>MR 1y, TB 1y</td>
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<td>37.43***</td>
<td>2.32</td>
<td>1</td>
<td>26.35**</td>
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<td></td>
<td></td>
<td>0</td>
<td>21.83*</td>
</tr>
</tbody>
</table>

Note: LR statistics are reported against the alternative of full rank, r = 2. Statistical significance at the 5%, 1%, and 0.1% level is denoted by *, **, and *** respectively. The last row performs an additional rank test for the 1 year mortgage for the period May 2010 to February 2015.

and weak exogeneity – are tested within the linear CVAR model.\(^5\) The test statistic used for all tests is the likelihood ratio and P-values are generated using the wild bootstrap. Although critical values are known for the CVAR and can be simulated for the nonlinear VECM, the bootstrap procedure is robust to heteroskedasticity (Boswijk et al., 2013). In general the bootstrap samples are generated using the residuals obtained under the null, but for the hypothesis of linearity this can be problematic (for details, see Kristensen and Rahbek, 2013) and therefore, the residuals under the alternative are used instead.\(^6\) If the roots of the characteristic polynomial for the coefficients specified under the null are inside the unit circle the hypothesis is rejected because these coefficients would generate explosive bootstrap samples. The number of bootstrap samples is 4999.

4.1 Deposit rates

The hypothesis test results for all of the deposit rates and each time period are shown in Table 5 and the coefficient estimates for the final restricted models are shown in Table 6. Due to the difference in asymptotic convergence rates of the adjustment coefficients and the coefficients of the cointegrating vector (Johansen, 1995), conditional hypotheses are also reported. In particular, hypotheses on the adjustment coefficients are nested in the model with restrictions imposed on the super-consistent long-run coefficients and complete pass-through is nested in the model of weak exogeneity of the market rate. The latter conditioning is reported since weak exogeneity restrictions can be considered as part of the model selection and based on this reasoning should be imposed before testing restrictions on other parameters. In all but one of the cases, the conclusions are the same from both the unconditional and conditional hypotheses. In addition, the joint test of

\(^5\)Estimation and inference for the CVAR uses software developed by Nielsen and Popiel (2014).

\(^6\)Kristensen and Rahbek (2013) also discuss an issue of obtaining negative likelihood ratio statistics for some samples. To get around this problem, the restricted likelihood is estimated first and the coefficients are used as starting values for maximizing the unrestricted likelihood.
Table 5: Deposit Rates - hypothesis test results

<table>
<thead>
<tr>
<th>Term</th>
<th>Time</th>
<th>$H_{1,2}^\delta$</th>
<th>$H_1^\beta$</th>
<th>$H_{1}^{\alpha,\delta}$</th>
<th>$H_2^{\alpha,\delta}$</th>
<th>$H_{1}^{\alpha,\delta}$</th>
<th>$H_2^{\alpha,\delta}$</th>
<th>$H_1^\beta$</th>
<th>$H_2^{\alpha,\delta} \cap H_2^{\beta}$</th>
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<tr>
<td>3m†</td>
<td>'83-'96</td>
<td>11.24</td>
<td>3.49</td>
<td>17.62***</td>
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<td>14.62**</td>
<td>0.14</td>
<td>3.61</td>
<td>3.63</td>
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<tr>
<td></td>
<td>'96-'07</td>
<td>8.97</td>
<td>2.87</td>
<td>–</td>
<td>7.47</td>
<td>–</td>
<td>5.10</td>
<td>0.50</td>
<td>7.97</td>
</tr>
<tr>
<td></td>
<td>'09-'15</td>
<td>124.05</td>
<td>7.28*</td>
<td>7.12</td>
<td>3.03</td>
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<tr>
<td>1y</td>
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<td>3.89</td>
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<td>0.00</td>
<td>98.26***</td>
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<td>0.28</td>
</tr>
<tr>
<td></td>
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<td>78.15***</td>
<td>1.32</td>
<td>1.04</td>
<td>2.02</td>
</tr>
<tr>
<td></td>
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<td>0.22</td>
<td>7.58*</td>
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<td>1.35</td>
<td>0.20</td>
<td>1.57</td>
</tr>
<tr>
<td>3y</td>
<td>'83-'96</td>
<td>61.14***</td>
<td>–</td>
<td>–</td>
<td>0.91</td>
<td>101.52***</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>'96-'07</td>
<td>27.44***</td>
<td>0.03</td>
<td>98.73***</td>
<td>0.73</td>
<td>102.25***</td>
<td>0.71</td>
<td>0.01</td>
<td>0.74</td>
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<tr>
<td></td>
<td>'09-'15</td>
<td>1.74</td>
<td>14.04**</td>
<td>18.27*</td>
<td>0.73</td>
<td>4.34</td>
<td>2.11</td>
<td>15.42***</td>
<td>16.15**</td>
</tr>
<tr>
<td>5y</td>
<td>'83-'96</td>
<td>16.03*</td>
<td>2.25</td>
<td>38.75***</td>
<td>1.21</td>
<td>11.57*</td>
<td>2.43</td>
<td>2.34</td>
<td>4.68</td>
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<tr>
<td></td>
<td>'96-'07</td>
<td>10.17*</td>
<td>7.75</td>
<td>76.31***</td>
<td>2.18</td>
<td>75.06***</td>
<td>0.71</td>
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<td></td>
<td>'09-'15</td>
<td>38.86</td>
<td>14.39*</td>
<td>19.29**</td>
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<td>0.26</td>
<td>13.66**</td>
<td>14.66*</td>
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<tr>
<td>5y†</td>
<td>'83-'96</td>
<td>16.24**</td>
<td>–</td>
<td>31.22**</td>
<td>7.24</td>
<td>24.41**</td>
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<td>23.35**</td>
<td>30.59**</td>
</tr>
<tr>
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<td>13.14*</td>
<td>7.60*</td>
<td>–</td>
<td>2.32</td>
<td>–</td>
<td>1.32</td>
<td>6.60*</td>
<td>8.91</td>
</tr>
<tr>
<td></td>
<td>'09-'15</td>
<td>19.53*</td>
<td>38.92*</td>
<td>–</td>
<td>5.30</td>
<td>–</td>
<td>0.91</td>
<td>33.80*</td>
<td>39.83*</td>
</tr>
</tbody>
</table>

Notes: This table reports the likelihood ratio test statistics for each of the hypotheses of interest. Unconditional hypotheses are tested against the unrestricted linear or non-linear CVAR depending on the result of hypothesis test $H_{1,2}^\delta$. Conditional hypotheses of impact coefficients are against the null of complete pass-through and the conditional hypothesis of complete pass through is against the null of weak exogeneity of the market rate. The joint hypothesis is unconditional. If the roots of the characteristic polynomial are inside the unit circle for a given hypothesis test of complete pass through is against the null of weak exogeneity of the market rate. The joint hypothesis is unconditional. If the roots of the characteristic polynomial are inside the unit circle for a given hypothesis test, the LR statistic is not reported. Statistical significance at the 5%, 1%, and 0.1% level is denoted by *, **, and *** respectively. The symbol † denotes term deposit.

As expected, $H_2^{\alpha,\delta}$ is not rejected for all terms and time periods, implying that the market rate is long-run exogenous and only the retail rate responds to fluctuations in the long-run equilibrium. For the shortest term rates (3 month and 1 year), both the completeness and symmetry hypotheses fail rejection for all time periods. For the 3 month term deposit in the last period, the unconditional hypotheses suggest that both the market and retail rates are weakly exogeneous and that pass-through is incomplete. This conclusion not only does not make economic sense but it is also inconsistent with the rank test results because if both impact coefficients are 0, then so is the rank. Fortunately, the conditional hypotheses results suggest that pass-through is indeed complete and

---

7Although the LR statistic for the symmetry hypothesis is very large in magnitude (124.05) for the 3 month term deposit in the last period, the nonlinear model under the alternative has explosive roots and the bootstrap distribution has a very fat tail. The same occurs for the 5 year GIC in the last period.
Table 6: Coefficient estimates - deposit rates

<table>
<thead>
<tr>
<th>Interest Rate</th>
<th>Time</th>
<th>$\beta_2$</th>
<th>$\rho$</th>
<th>$\alpha_1$</th>
<th>$\alpha_2$</th>
<th>$\delta_1$</th>
<th>$\delta_2$</th>
<th>$\psi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>FT 3m</td>
<td>'83-'96</td>
<td>-1.000</td>
<td>2.333</td>
<td>-0.037</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>'96-'07</td>
<td>-1.000</td>
<td>1.757</td>
<td>-0.041</td>
<td>0.000</td>
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</tr>
<tr>
<td></td>
<td>'09-'15</td>
<td>-1.000</td>
<td>0.402</td>
<td>-0.046</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIC 1yr</td>
<td>'83-'96</td>
<td>-1.000</td>
<td>1.019</td>
<td>-0.173</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>'96-'07</td>
<td>-1.000</td>
<td>1.344</td>
<td>-0.156</td>
<td>0.000</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>'09-'15</td>
<td>-1.000</td>
<td>0.144</td>
<td>-0.083</td>
<td>0.000</td>
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<tr>
<td>GIC 3yr</td>
<td>'83-'96</td>
<td>-1.061</td>
<td>1.710</td>
<td>-0.024</td>
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<td>-1.019</td>
<td>0.000</td>
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<tr>
<td></td>
<td>'96-'07</td>
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<td>0.863</td>
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<td>0.487</td>
<td>0.000</td>
<td>351.052</td>
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<tr>
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<tr>
<td>GIC 5yr</td>
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<td>0.780</td>
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<td>0.000</td>
<td>-0.449</td>
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<td>113.331</td>
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<td></td>
<td>'96-'07</td>
<td>-1.000</td>
<td>0.740</td>
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<td>0.195</td>
<td>0.000</td>
<td>6.761</td>
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<tr>
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<td>'09-'15</td>
<td>-0.262</td>
<td>-1.314</td>
<td>-0.114</td>
<td>0.000</td>
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</tr>
<tr>
<td>FT 5yr</td>
<td>'83-'96</td>
<td>-1.398</td>
<td>3.530</td>
<td>-0.443</td>
<td>0.000</td>
<td>0.434</td>
<td>0.000</td>
<td>157.258</td>
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<tr>
<td></td>
<td>'96-'07</td>
<td>-1.081</td>
<td>1.299</td>
<td>-0.261</td>
<td>0.000</td>
<td>0.173</td>
<td>0.000</td>
<td>9.647</td>
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<tr>
<td></td>
<td>'09-'15</td>
<td>-0.204</td>
<td>-1.394</td>
<td>-0.481</td>
<td>0.000</td>
<td>0.461</td>
<td>0.000</td>
<td>12.282</td>
</tr>
</tbody>
</table>

that the retail rate is endogenous. The joint hypothesis, which fails rejection, also supports this finding.

In contrast to the shorter term rates, movements in deposit rates with terms of 3 years and longer reject the symmetry hypothesis in most periods. Furthermore, the completeness hypothesis is also rejected several times, especially in the period following the financial crisis. Table 6 allows for a better analysis of the implications of these findings. Although the hypothesis of complete pass-through is rejected for the 3 year GIC in period 1 and for the 5 year fixed term in periods 1 and 2, the coefficient estimates in the cointegrating relation actually imply a pass-through that is greater than one. Therefore, even though the stronger two-sided hypothesis is rejected, it is clear from the coefficient estimates that pass-through is still complete for these two rates in the first two periods. The same cannot be said about the last period. For all of the deposit rates with maturities of 3 years and greater, pass-through has significantly declined since the financial crisis.

Sluggish behaviour for these longer-term rates appears to be common throughout the entire sample. Even though pass-through was complete for long-term deposit rates before the financial crisis, they responded differently to equilibrium fluctuations based on the direction of the movement in the market rate. The signs on the coefficients of $\psi$ and $\delta_1$ reveal the direction of the asymmetry. Recall the functional form of the nonlinear adjustment shown in (4). The equilibrium relation, $\beta'\tilde{X}_t = r_t + \beta m_t + \rho$, becomes positive when the market rate $m_t$ decreases and negative when it increases. As a result, when $\psi > 0$, $f(\beta'\tilde{X}_{t-1}; \psi) \to 1$ as $m_t$ declines and $f(\beta'\tilde{X}_{t-1}; \psi) \to 0$ as $m_t$ rises.
When both $\psi > 0$ and $\delta_1 > 0$, the retail deposit rate responds more strongly to a market rate decrease than to an increase. This type of asymmetry is consistent with a profit motive on the side of the bank since it implies that they are reluctant to pay more for deposits when their cost of funding decreases, but are quick to pay less when it increases. If $\psi$ and $\delta_1$ have opposite signs, then the dynamic is reversed and the adjustment asymmetry favours the consumer.\footnote{Note that if $\alpha_i$ and $\delta_i$ have the opposite sign then $\delta_i$ must be smaller in magnitude than $\alpha_i$ for variable $i$ to adjust toward equilibrium following a shock. Otherwise, it may diverge.}

Surprisingly, we observe both of these cases for the 3 and 5 year GICs. Consider a 100 basis point increase in the three year government bond in the first period at time $t$. The nonlinear adjustment function $f(\beta'\tilde{X}_t; \psi)$, evaluated with the coefficient estimates for this deviation is

$$f(-1; 140.448) = [1 + \exp(140.448(-1))]^{-1} \approx 1.$$  

Thus the short run adjustment to equilibrium for the retail rate in period $t + 1$ is,

$$[\alpha_1 + \delta_1 f(\beta'\tilde{X}_t; \psi)]\beta'\tilde{X}_t = (-0.024 - 1.019)(-1) = 1.043.$$  

For a 100 basis point movement of the market rate in the other direction, the reaction of the retail rate is significantly different. Now $\beta'\tilde{X}_t = 1$, $f(\beta'\tilde{X}_t; \psi) \approx 0$ and

$$[\alpha_1 + \delta_1 f(\beta'\tilde{X}_t; \psi)]\beta'\tilde{X}_t = (-0.024)(1) = -0.024.$$  

In each of the cases, the equilibrium correction is in the right direction, i.e. retail rates follow movements in market rates, but the magnitude is greatly reduced when the retail rate decreases. In the next period, the exact opposite behaviour takes place: for a 100 basis point increase in the retail rate, the 3 year GIC adjusts by 0.071 and for a decrease by -0.558.

This change in the direction of rigidity across period 1 and 2 is also present in the 5 year GIC. The 5 year fixed term deposit, however, has maintained upward rigidity for all three periods. As discussed in Section 2, downward rigidity in deposit rates is consistent with banks trying to keep consumers content in the face of higher levels of competition. The GICs are an important source of funding for mortgages because they match them in term (Clinton and Howard, 1994). However, the second period saw a significant rise in securitization of mortgages and the growth of mortgage-backed securities (Traclet, 2005, 2010; Crawford et al., 2013). The fact that banks became less reliant on GICs could explain this transition from asymmetric adjustment that favours the consumer to one that favours the bank.

Although a decline in pass-through is most often associated with banks exploiting their pricing power for higher profits, the coefficient estimates for the period following the financial crisis suggest a different dynamic. Using the mean values for the market rate from Table 1, the markups, $\rho - (1 - \beta)\bar{m}$, for the 3 year GIC, 5 year GIC, and 5 year fixed term deposit are 0.162, 0.073, and 0.102, respectively. These markups are very low relative to the other time periods and close in magnitude to the markups for the shorter-term rates with complete pass-through. As a result,
it is likely that the sluggish behaviour is driven by a response to some lower bound as oppose to a profit motive. In particular, banks may be facing upward pressure to keep long-term deposit rates positive despite very low market rates because otherwise they would risk losing this source of funding. This behaviour is consistent with the negative consumer reaction hypothesis.

Moreover, the upward pressure on long-term deposit rates may explain the failure to reject symmetry for the 3 and 5 year GICs in this period. These rates have generally been quick to fall and slow to rise but given this additional force preventing them from adjusting downward they are now rigid in both directions. This lack of movement results in an incomplete pass-through and a drastically reduced markup. For the 5 year fixed term, upward rigidity appears to dominate the adjustment process but the markup is affected in the same way as for the GICs.

4.2 Mortgage rates

In the late 1990s Canadian chartered banks started facing increasing competition in the mortgage market from virtual banks and mortgage brokers (Traclet, 2005). While these competitors offered their lowest rate upfront, chartered banks adopted a different strategy, namely discounting. Banks would offer their customers a mortgage rate below the posted rate. This practice grew steadily over time and by the early 2000s it was common for consumers to expect discounts when taking on a mortgage from a chartered bank. Day and Tkacz (2005) point out that while discounts steadily increased, so did posted rates, so that the actual transaction rate remained steady over the time period. Although the market share of these competitors remained modest at only a few per cent, the discounting in the early part of the second period poses some potential problems for estimation.

Since the data contains posted rates and not transaction rates, there is a positive trend in the spread between market and retail rates in the late 1990s, which corresponds to the first part of the second sample period. This spread is plotted in Figure 6. As discussed by Day and Tkacz (2005) and as can be seen from the figure, this trend stabilized in late 2000. Although this trend is not very strong, tests are also performed using a smaller sub-period that begins in December 2000 (denoted by the vertical black line in Figure 6). All of the conclusions from the full second period are robust to the smaller stable sub-period.
estimate of $\beta$ is imposed since both the unconditional and joint hypothesis test fail to reject and because the unconditional parameter period. Although the asymmetry does not appear in the middle period, the longer term rates in period 1. Likewise, the 3 and 5 year mortgages exhibit asymmetric adjustments in the earliest and banks were yet to face the steeper competition that arrived in the late 1990s. 

In the 1 year mortgage in the earliest period could be tied to the fact that it was a popular product gained more popularity Clinton and Howard (1994). Thus, the finding of incomplete pass-through activity in the first period, but as inflation came down in the mid 1990s the longer term mortgages crisis and have maintained it since the end of the recession. The 1 year mortgage saw a large level of

The coefficient estimates of the restricted models shown in Table 8

Table 7 presents the results from the hypothesis tests. As was the case for deposit rates, the retail loan rates are endogenous while their market counterparts are weakly exogenous for all maturities and time periods. Furthermore, pass-through appears to be complete for almost all of the rates and time periods. Specifically, completeness is rejected in two instances, both of which involve the 1 year mortgage. The coefficient estimates of the restricted models shown in Table 8 reveal that pass-through was more than complete in the sub-sample of period 2, but incomplete in period 1.

In contrast to deposit rates, mortgage rates had significantly complete pass-through before the crisis and have maintained it since the end of the recession. The 1 year mortgage saw a large level of activity in the first period, but as inflation came down in the mid 1990s the longer term mortgages gained more popularity Clinton and Howard (1994). Thus, the finding of incomplete pass-through in the 1 year mortgage in the earliest period could be tied to the fact that it was a popular product and banks were yet to face the steeper competition that arrived in the late 1990s.

Perhaps not surprisingly, linear adjustment is also strongly rejected for the 1 year mortgage in period 1. Likewise, the 3 and 5 year mortgages exhibit asymmetric adjustments in the earliest period. Although the asymmetry does not appear in the middle period, the longer term rates

\footnote{Although complete pass-through is rejected conditionally for the 5 year mortgage in the last period the restriction is imposed since both the unconditional and joint hypothesis test fail to reject and because the unconditional parameter estimate of $\beta$ is greater than 1.}
Table 8: Coefficient estimates - Mortgage Rates

<table>
<thead>
<tr>
<th>Interest Rate</th>
<th>Time</th>
<th>$\beta_2$</th>
<th>$\rho$</th>
<th>$\alpha_1$</th>
<th>$\alpha_2$</th>
<th>$\delta_1$</th>
<th>$\delta_2$</th>
<th>$\psi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>MR 1y</td>
<td>’83-’96</td>
<td>-0.809</td>
<td>-2.110</td>
<td>-0.029</td>
<td>0.000</td>
<td>-0.531</td>
<td>0.000</td>
<td>29.843</td>
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<tr>
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<td>’96-’07</td>
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<td>-1.894</td>
<td>-0.051</td>
<td>0.000</td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td>’01-’07</td>
<td>-1.100</td>
<td>-1.735</td>
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<td>0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>’10-’15</td>
<td>-1.000</td>
<td>-2.124</td>
<td>-0.045</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MR 3y</td>
<td>’83-’96</td>
<td>-1.000</td>
<td>-1.184</td>
<td>-0.038</td>
<td>0.000</td>
<td>-0.425</td>
<td>0.000</td>
<td>13.180</td>
</tr>
<tr>
<td></td>
<td>’96-’07</td>
<td>-1.000</td>
<td>-2.116</td>
<td>-0.047</td>
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<tr>
<td></td>
<td>’01-’07</td>
<td>-1.000</td>
<td>-2.333</td>
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<tr>
<td></td>
<td>’09-’15</td>
<td>-1.000</td>
<td>-2.311</td>
<td>-0.033</td>
<td>0.000</td>
<td>-0.541</td>
<td>0.000</td>
<td>65.188</td>
</tr>
<tr>
<td>MR 5y</td>
<td>’83-’96</td>
<td>-1.000</td>
<td>-1.536</td>
<td>-0.041</td>
<td>0.000</td>
<td>-0.221</td>
<td>0.000</td>
<td>8.517</td>
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<td></td>
<td>’96-’07</td>
<td>-1.000</td>
<td>-2.224</td>
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<td></td>
<td>’01-’07</td>
<td>-1.000</td>
<td>-2.442</td>
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<tr>
<td></td>
<td>’09-’15</td>
<td>-1.000</td>
<td>-2.752</td>
<td>-0.011</td>
<td>0.000</td>
<td>-0.875</td>
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<td>330.672</td>
</tr>
</tbody>
</table>

reject linearity once again in the most recent period. Furthermore, in all of the cases, the nonlinear coefficients show that mortgage rates respond more strongly to market rate increases than decreases.

The downward rigidity in mortgage rates is consistent with the presence of switching costs discussed in Section 2. However, banks may also be slow to decrease rates because of the way that the mortgage contracts are formed. There is often a significant time lag between when the loan is approved and when it is actually issued. During this time the bank is committed to the interest rate, but the consumer is not committed to the loan (Clinton and Howard, 1994). If rates decline before the mortgage is issued, the bank can renegotiate a new rate with the consumer. But if rates increase, the bank must still offer the lower rate agreed upon approval. Therefore, the presence of downward rigidity in the mortgage market could be a symptom of higher risk for delaying a rate increase.

5 Conclusion

This paper provides a comprehensive analysis of the transmission process from market rates to retail loan and deposit rates in Canada. In contrast to previous studies on Canadian retail rates, it is the first to test completeness and symmetry for both deposit and loan rates in a unified framework. Furthermore, the empirical model used for estimation and inference overcomes several shortcomings of commonly used models in the IRPT literature. The nonlinear VECM estimates the long-run equilibrium pass-through equation while accounting for short-run dynamics, asymmetric adjustments, as well as persistence in both the retail and market rate.

The results identify incomplete pass-through and asymmetric adjustment for various loan and deposit rates in different time periods. In the period of 1983-1996, before the Bank of Canada set the Bank Rate to the upper bound of the corridor for managing the overnight rate, pass-through was incomplete only for the 1 year mortgage rate, however, all mortgage rates were rigid downwards.
On the deposit side, asymmetries were present in rates of longer maturities but the direction of rigidity differed across products. Changes in GICs favoured the consumer while changes in the fixed term deposit favoured the bank. Before the onset of the financial crisis, in the period 1996-2007, pass-through was complete for all rates and asymmetric adjustment – in the form of downward rigidity – only appeared in the movements of long term deposits. Finally, in the most recent period 2009-2015, pass-through has significantly declined for long term deposits and asymmetric adjustment has reappeared for mortgage rates.

Although these results are not surprising given the high level of market concentration in the Canadian banking industry, they provide important information that is relevant for a better understanding of the transmission mechanism of monetary policy through the interest rate channel. If the Bank of Canada moves to increase rates in the future, we can expect mortgage rates to respond quickly and fully and deposit rates to adjust partially and sluggishly.

In contrast to the US and Europe, the pass-through from market to retail loan rates in Canada was resilient to the financial crisis. However, the presence of asymmetries and the decline in pass-through to deposit rates suggest that overall the transmission mechanism of monetary policy through the interest rate channel has weakened. While previous studies have focused on countries that experienced bank failures and resorted to unconventional monetary policies, this paper shows that a weakening of transmission can arise in a country that experienced neither. Instead, incomplete pass-through since the financial crisis could be a global phenomena related to historically low interest rates. Thus extending the analysis to other countries is a natural next step for future research.

References


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