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

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Interest rate pass-through: a nonlinear vector error-correction approach*

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Abstract

This paper analyzes pass-through from money market rates to consumer retail loan and deposit rates in Canada from 1983 to 2015 using a nonlinear vector error-correction model. This model permits estimation of long-run pass-through coefficients while simultaneously accounting for asymmetric adjustments and short-run dynamics. In contrast to empirical frameworks used in previous studies, it also allows testing of commonly made assumptions such as exogeneity of the market rate, making inference more robust. I find that 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 deposit rates. Furthermore, many rates adjust asymmetrically but the direction of rigidity differs among rates and time periods.

JEL Codes: C32, E43, E52, G21

Keywords: Interest rate pass-through; cointegration; asymmetric adjustment; nonlinear vector error-correction model.

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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 that 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.

The recent global financial crisis exposed the fragility of banking sectors across the world and heightened concerns about IRPT as central banks embarked on aggressive monetary policy easing. Not surprisingly, several studies (e.g. Karagiannis *et al.*, 2014; Aristei and Gallo, 2014; Illes and Lombardi, 2013; Mora, 2014; Hristov *et al.*, 2014) find evidence of a decline in pass-through across Europe and the US and associate it with changes in risk appetites, the size and structure of macroeconomic shocks, or funding uncertainty. In light of this evidence, an important question is whether this decline in pass-through is a global problem or one that is tied to areas that experienced the most severe turmoil. This paper contributes to this question by analyzing IRPT in Canada, a country with a relatively resilient banking sector that, in contrast to Europe and the US, experienced no bank failures or bailouts.[1]

Moreover, this paper also tackles another important issue. Despite its prominent role in the transmission process, there is no consensus in the literature on the appropriate model for estimating IRPT. Choosing an econometric model is complicated by the need to simultaneously account for several key features, such as cointegration and asymmetric movements, of retail interest rates and their relationship to market rates. While different models can

[1] Canadian banks were not immune to the financial crisis and benefited from increased liquidity provisions and from a government funded mortgage buyback program (Zorn *et al.*, 2009). Nevertheless, their losses were relatively low compared to those experienced in other countries (Crawford *et al.*, 2013).

account for different features of the data, this paper proposes using a flexible, nonlinear, vector error-correction model that can account for all of them in a unified framework. Other studies[2] have tried to capture these features using error-correction models with asymmetric adjustments, but they have done so in single-equation frameworks under the assumption of weak exogeneity of the market rate — an assumption that can lead to incorrect inference if it is not satisfied. In contrast, the nonlinear vector error-correction model permits explicit testing of this assumption and thus allows for more robust inference.

This model is applied to Canadian weekly data from 1983 to 2015 on five deposit rates 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 dropped the Bank Rate peg to the 3 month treasury bill and set it to the top of the operating band for the overnight target rate.[3] Thus, the first two periods are divided by a 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 recession that followed the global financial crisis. Analysis of this period looks at whether the transmission mechanism has weakened.

For each of the rates I test two main hypotheses. First, tests of the *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 *symmetry hypothesis* reveal whether retail rates respond in the same way to upward and downward movements in the market rate. I find that pass-through was 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 since the financial crisis. Furthermore, I find evidence of asymmetric adjustment for several rates across various periods. 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

[2]See for example Becker *et al.* (2012), Belke *et al.* (2013), Sander and Kleimeier (2004), Kleimeier and Sander (2006), among others.

[3]The Bank Rate is the rate that the Bank of Canada charges on overnight loans.

the bank in the second period. Meanwhile, all mortgage rates are downward rigid in the first period and become either upward rigid or adjust symmetrically — depending on the specification of the market rate — in the second period. In the last period, both the 3 and 5 year mortgage rates exhibit downward rigidity, although the evidence is stronger for the 5 year rate. Thus, the recent decline of pass-through to deposit rates and reemergence of rigidity in mortgage rates suggest that a weakened transmission through the interest rate channel may indeed be a global problem.

This paper relates to a large and growing literature on IRPT. Some of the more notable studies include the work of Cottarelli and Kourelis (1994), which ties differences in the degree of pass-through across countries to characteristics of their financial structures, and De Bondt (2005), which 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. For example, Berger and Hannan (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 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 individual bank mortgage rate data for a later period and find evidence of asymmetric adjustment favouring banks in the 3 and 5 year mortgage rates as well as complete pass-through.

This study makes three main contributions. The first is methodological: empirical analysis is conducted using a nonlinear vector error-correction model which generalizes previously used models and estimates pass-through while simultaneously allowing for asymmetric adjustments and short-run dynamics under less restrictive conditions. It also allows for explicit tests of some commonly made assumptions such as exogeneity of the market rate. 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 potential 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 empirical model, Section 4 presents the results and Section 5 contains some robustness analysis. Section 6 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, ρ is the markup[4] and β 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 β 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 the 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 favourable 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; Berger and Hannan, 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.[5] Consumers may be irresponsive 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. Furthermore, for the same market, Allen *et al.* (2014b) find evidence of price discrimination and Allen *et al.* (2014a) show that a decline in competition leads to an increase in mortgage rates. Both

[4]The IRPT literature often refers to ρ as the markup over marginal cost, but this ignores the fact that the marginal cost of handling loans and deposits is contained in ρ. More accurately, ρ 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).

[5]However, high concentration can also be associated with more competitive pricing if it arises from more efficient banks replacing less efficient ones. These opposing views are referred to as the *structure-performance* and *efficient-structure* hypotheses, respectively (see for *e.g.* Berger and Hannan, 1989).

studies also discuss the presence of heterogeneity among consumers in their search efforts or negotiation abilities and how this can lead to price dispersion. Therefore, if average bargaining power is low, pass-through is likely to be incomplete or adjust in a way that favours the banks.

Retail rate movements may also adjust to favour the consumer. Berger and Hannan (1991) discuss the case of negative consumer reactions to unstable prices and that they may be more pronounced when price fluctuations are unfavourable. 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.

On the loan side, upward rigidity can also 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.

More recently, Ritz and Walther (2015) argue that the increased rigidity and decline in pass-through observed during the 2007–08 financial crisis can be explained by a rise in funding uncertainty. Competitiveness for deposit rates can increase sharply in the presence of funding uncertainty and if banks are highly risk averse, deposit rates can even be driven above their cost of funding. Furthermore, they show that retail rates become less responsive to changes in market rates and pass-through is dampened.

In summary, completeness of pass-through implies that banks fully adjust their retail rates to changes in the market rate in the long-run. 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 empirical model

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 contain weekly observations of 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.[6] Each loan and deposit rate is matched with an equal maturity government bond or treasury bill to proxy for banks' cost of funding. Figure 1 plots the rates and shows that they move closely together over the entire sample, with loan rates mostly above and deposit rates mostly below the market rate. Vertical lines are added at dates separating subsamples under consideration.

All data are taken from Statistics Canada[7] and are 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.[8] 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 major shift in

[6] In general, fixed term deposits are redeemable before maturity at a penalty while GICs are not.

[7] CANSIM Table 176-0078: Financial market statistics, as at Wednesday, Bank of Canada. Each series represents the most typical rate of those offered by major Canadian chartered banks.

[8] Recession dates are obtained from Cross and Bergevin (2012).

monetary policy it comes as a natural break point to start the second period. The second break point is set for the end of July 2007, the onset of the financial crisis. At this point, ratings agencies downgraded mortgage backed securities, Bear Stearns filed for bankruptcy, and markets began to slide. The last period starts in May 2009, at the beginning of the recovery.[9]

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[10] 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, the rates fail to reject the presence of a unit root with only one exception.[11]

Another series of interest is the difference between market and retail rates. If retail rates react to market rates with complete pass-through, then their difference should be stationary. Table 2 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

[9] Although other studies have tested for unknown breakpoints (*e.g.* Marotta, 2009), such tests have not been developed for the nonlinear model used in this paper and I rely on known events to select subsamples.

[10] The Bank of Canada began targeting inflation in 1991. By the mid 1990s inflation was successfully reduced to the target of 2% and inflation expectations fell in line soon after (Dodge, 2002). Thus, compared to the 1980's, the second period had lower and less volatile inflation.

[11] The ADF test rejects the unit root for the 3 year GIC in the last period, but the JN test suggests a unit root is present.

Table 1: Summary statistics

Rate		1983 − 1996				1996 − 2007				2009 − 2015			
		mean	sd	ADF	JN	mean	sd	ADF	JN	mean	sd	ADF	JN
FTD	3m	6.50	2.16	−1.13	0.00	2.00	1.02	−1.75	0.03	0.37	0.22	−1.74	0.41
TB	3m	8.74	2.44	−0.99	0.24	3.70	1.08	−1.31	0.21	0.76	0.28	−1.71	0.10
GIC	1y	8.12	2.20	−0.76	0.00	2.73	1.12	−1.38	0.24	0.83	0.32	−2.82	0.67
MR	1y	10.10	2.06	−1.13	0.00	5.94	1.02	−1.30	0.63	3.30	0.27	−1.88	0.00
TB	1y	9.10	2.26	−1.17	0.63	4.07	1.10	−1.50	0.47	0.96	0.25	−1.95	0.36
GIC	3y	8.85	1.99	−0.59	0.00	3.48	1.05	−1.63	0.16	1.26	0.18	−3.17*	1.64
MR	3y	10.87	1.83	−0.88	0.00	6.63	0.83	−1.82	1.08	3.97	0.35	−1.39	0.46
GB	3y	9.09	1.78	−1.13	0.30	4.53	1.00	−1.96	0.63	1.36	0.45	−1.29	0.62
GIC	5y	9.26	1.85	−0.66	0.00	4.02	1.00	−1.74	0.09	1.79	0.20	−2.85	3.93
FTD	5y	8.13	1.72	−0.97	0.07	3.84	1.01	−1.60	0.14	1.59	0.23	−2.61	3.12
MR	5y	11.25	1.71	−1.02	0.00	7.03	0.75	−2.01	0.79	5.25	0.35	−1.61	1.30
GB	5y	9.29	1.67	−1.07	0.13	4.83	0.94	−2.09	0.20	1.80	0.60	−1.05	0.27

Note: The table shows the mean and standard deviation in each period for each interest rate: fixed term deposit (FTD), treasury bill (TB), Guaranteed Investment Certificate (GIC), mortgage (MR), and government bond (GB). 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 $N = 330$ for 2009–2015. Statistical significance at the 5%, 1%, and 0.1% level is denoted by *, **, and ***, respectively.

spreads also exhibit some patterns. For instance, mortgage rates show that the markup over cost has been on the rise across the three periods. Deposit 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 Empirical model

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).

Table 2: Summary statistics of interest rate spreads: retail over market

	1983 – 1996				1996 – 2007				2009 – 2015			
Term	mean	sd	ADF	JN	mean	sd	ADF	JN	mean	sd	ADF	JN
3m†	−2.24	0.68	−4.26***	1.46	−1.70	0.37	−2.67	1.09	−0.39	0.12	−3.09*	0.54
1y	−0.98	0.48	−8.17***	1.92	−1.34	0.23	−6.44***	17.23***	−0.13	0.30	−2.77	3.74
3y	−0.24	0.56	−5.17***	9.93***	−1.06	0.25	−6.84***	19.10***	−0.10	0.36	−2.62	3.25
5y	−0.02	0.53	−4.94***	10.88***	−0.81	0.24	−7.04***	22.32***	−0.01	0.50	−1.78	0.99
5y†	−1.15	0.71	−4.18***	8.45***	−0.99	0.26	−6.34***	17.40***	−0.21	0.47	−1.96	1.48
1y‡	1.00	0.58	−6.62***	0.98	1.87	0.35	−3.82**	4.33	2.34	0.39	−2.97*	0.01
3y‡	1.78	0.55	−5.62***	0.57	2.09	0.39	−3.78**	2.95	2.60	0.25	−3.60**	6.02***
5y‡	1.96	0.51	−5.74***	0.36	2.20	0.39	−3.59**	0.80	3.45	0.40	−2.34	1.82

Note: The table shows the mean and standard deviation for each of the interest rate spreads 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 $N = 330$ for 2009–2015. Statistical significance at the 5%, 1%, and 0.1% level is denoted by *, **, and ***, respectively. † denotes term deposit spreads, and ‡ denotes mortgage spreads.

The typical approach in the literature takes one of three main forms. The simplest method is a regression of the change in market rates on the 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 single equation error-correction models (ECMs) with dummy variables (or smooth transition functions) for positive and negative movements in the market rate. They either estimate them with non-linear least squares (Karagiannis *et al.*, 2010) or in two steps with OLS (Allen and McVanel, 2009). However, inference is only valid in single equation analysis under a condition that is implicitly imposed but left untested: the weak exogeneity of the market rate (see Theorem 8.1 in Johansen, 1995).

To deal with these empirical issues, I use the nonlinear vector error-correction model (VECM). This model specifies a long-run equilibrium relationship with nonlinear adjustment coefficients without the assumption of exogeneity of the market rate. In fact, exogeneity of the market rate is a testable hypothesis within the model. 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 a retail and market rate, the nonlinear VECM is specified as follows,

$$\Delta X_t = g(\boldsymbol{\beta}'\tilde{X}_{t-1}) + \sum_{i=1}^{k} \boldsymbol{\Gamma}_i \Delta X_{t-i} + \varepsilon_t, \tag{1}$$

where ε_t is i.i.d. with $\mathrm{E}[\varepsilon_t] = 0$ and $\mathrm{E}[\varepsilon_t \varepsilon_t'] = \Omega$. The long-run stationary equilibrium corresponds to the pass-through equation and is given by,

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

The $\boldsymbol{\Gamma}$'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,

$$g(\boldsymbol{\beta}'\tilde{X}_{t-1}) = \boldsymbol{\alpha}\boldsymbol{\beta}'\tilde{X}_{t-1} + \underbrace{\boldsymbol{\delta} f(\boldsymbol{\beta}'\tilde{X}_{t-1}; \psi)}_{\text{nonlinear}} \boldsymbol{\beta}'\tilde{X}_{t-1}. \tag{3}$$

That is, both $\boldsymbol{\alpha}$ and $\boldsymbol{\delta} f(\boldsymbol{\beta}'\tilde{X}_{t-1}; \psi)$ determine how the variables in the system respond to equilibrium shocks (movements in $\boldsymbol{\beta}'\tilde{X}_{t-1}$). The nonlinear adjustment is specified using a logistic function which can account for asymmetry in a general way,

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

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 ψ is large, $f(\cdot)$ behaves similarly to an indicator function and when ψ is small, the size of the asymmetric adjustment depends on the size of the deviation from equilibrium. This could arise if, for example, banks adjust their retail rates only 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 $\boldsymbol{\delta} = 0$. Thus the hypothesis $\mathscr{H}_{1,2}^{\delta}$: $\delta_1 = \delta_2 = 0$ tests for the presence of asymmetric adjustments in the error-correction. Failing to reject this hypothesis implies that adjustments are symmetric (*symmetry hypothesis*). Second, the null hypothesis of complete pass-through is specified as a test on the long-run coefficients in $\boldsymbol{\beta}$, namely $\mathscr{H}^{\beta} : \beta = -1$.[12] This hypothesis implies that a change in the market rate is fully transmitted to the retail rate in the long-run equilibrium (*completeness hypothesis*). Third, the hypothesis $\mathscr{H}_i^{\alpha,\delta} : \alpha_i = \delta_i = 0$, for $i \in \{1, 2\}$, tests for weak exogeneity. If a variable does not respond to fluctuations in the long-run equilibrium then it is weakly exogenous.[13] Fourth, the hypothesis $\mathscr{H}_i^{\alpha,\delta,\Gamma} : \alpha_i = \delta_i = \Gamma_{s,ij} = 0$, for $s = 1, \ldots, k$ and $i, j \in \{1, 2\}$ with $i \neq j$, tests whether the variable is strongly exogenous, *i.e.* driven entirely by its own dynamics, and can establish Granger causality. For example, if only the market rate is strongly exogenous then changes in the market rate Granger-cause changes in the retail rate.

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. With a slight abuse of notation, 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

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

[13] This weak form of exogeneity — the variable can still respond to short-run fluctuations — is required for valid inference on the long-run parameters $(\beta, \rho, \alpha, \delta, \psi)$ in single-equation ECMs. However, inference on the short-run coefficients $\{\boldsymbol{\Gamma}_i\}_{i=1}^{k}$ requires an additional assumption of Ω being diagonal (Urbain, 1992).

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 combination of Bayes information criteria (BIC) and serial correlation tests on the residuals. I start with the lag augmentation that minimizes the BIC for models estimated with $k = 0, \ldots, 5$ lags and, if needed, increase k until residuals fail to reject the null of no serial correlation.

Rank selection follows the procedure outlined in Johansen (1995). Testing is done sequentially, starting with the the null of no cointegration $\mathscr{H}_0^r : r = 0$. If this hypothesis is rejected, then the null of one cointegrating vector $\mathscr{H}_1^r : r = 1$ is tested. In both cases the alternative is the model with full rank $\mathscr{H}_2^r : r = 2$.

Rank and lag selection follow a general-to-specific testing procedure. Lags are chosen based on bivariate estimates of full rank models and then once a lag is chosen it is fixed for the rank tests. Rank tests are conducted within the CVAR model because inference in nonlinear VECMs requires the long-run coefficient $\boldsymbol{\beta}$ to be identified under the null (Kristensen and Rahbek, 2013). For consistency, the CVAR is also used for lag selection.

Table 3 reports the results of rank tests for all of the bivariate systems.[14] These results must be interpreted with caution since the estimated models abstract from potential nonlinearities ignored by the CVAR. Nevertheless, with the exception of very few cases, the models reject the null of no cointegration and fail to reject the null of 1 cointegrating vector. In three cases, the test fails to reject the null of no cointegration but since the test statistics are still relatively large this is likely due to the fact that the rank test has low power against the null, especially in smaller samples. In one case (3yr mortgage in 2000–2007), the null of one cointegrating vector is rejected but the test statistic (7.56) is just on the edge of significance with a P-value of 0.0995. Moreover, if rejection of cointegration occurs, it is never for the same rates in multiple periods. As a result, the rank tests provide strong enough evidence to proceed with estimating the bivariate systems in the nonlinear VECM with one cointegrating

[14]In addition to the three subsamples discussed in 3.1, a fourth period is estimated for mortgages as a robustness check for reasons discussed in 4.2.

Table 3: Rank test results

	1983 − 1996			1996 − 2007			2009 − 2015			2000 − 2007		
Variables	k	$r = 0$	$r = 1$	k	$r = 0$	$r = 1$	k	$r = 0$	$r = 1$	k	$r = 0$	$r = 1$
FTD 3m, TB 3m	2	21.29**	1.68	1	33.41***	2.81	1	15.13	3.49			
GIC 1y, TB 1y	2	104.70***	1.64	1	82.49***	2.75	0	28.80***	5.35			
GIC 3y, GB 3y	2	41.15***	1.94	1	85.68***	3.51	0	25.10***	1.79			
GIC 5y, GB 5y	2	31.53***	2.18	1	89.63***	4.38	0	26.48***	2.18			
FTD 5y, GB 5y	2	28.19***	2.45	1	82.48***	4.34	0	30.29***	1.82			
MR 1y, TB 1y	1	95.60***	2.12	2	19.38*	3.63	0	13.11	1.22	1	40.32***	5.02
MR 3y, GB 3y	2	50.15***	2.55	1	28.90***	5.39	0	30.84***	1.67	1	39.50***	7.56*
MR 5y, GB 5y	3	28.92***	2.86	3	16.93	6.79	0	24.13**	2.14	1	54.35***	6.68

Note: LR statistics are reported against the alternative of full rank, $r = 2$. Statistical significance at the 10%, 5% and 1% level is denoted by *, **, and ***, respectively.

vector.

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 bivariate model, the testing procedure is conducted as follows. Using the rank and lag from Table 3, model (1) is estimated. The first test is for asymmetry, $\mathscr{H}^{\delta}_{1,2}$, and if it is rejected then the rest of the hypotheses — *completeness* and exogeneity — are tested within the linear CVAR model.[15] 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.[16] 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

[15] Estimation and inference for the CVAR uses software developed by Nielsen and Popiel (2014).

[16] 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. I thank Dennis Kristensen for providing me with the code for the simulation study in Kristensen and Rahbek (2013).

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 4 and the coefficient estimates for the final restricted models are shown in Table 5. 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 exogeneity of the market rate. The latter conditioning is reported since 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. The ability to test both conditional and unconditional hypotheses is another major advantage over the single-equation ECM — in fact, in three cases the results from the unconditional and conditional hypotheses are different. In addition, the joint test of complete pass-through and exogeneity of the market rate is reported in the last column because it is the model that is selected most often. Missing test statistics imply that the null hypothesis generated explosive roots.

As expected, for all terms and time periods, $\mathscr{H}_1^{\alpha,\delta}$ is strongly rejected while $\mathscr{H}_2^{\alpha,\delta,\Gamma}$ fails rejection, implying that the market rate is strongly-exogenous and the retail rate responds to fluctuations in the long-run equilibrium as well as short-run dynamics of the market rate. In two cases, weak exogeneity of the market rate $\mathscr{H}_2^{\alpha,\delta}$ is rejected but since the conclusions from both the conditional and unconditional hypotheses are the same for these two cases, the strong exogeneity restriction is imposed.

For the shortest term rate, both the *completeness* and *symmetry* hypotheses fail rejection for all time periods.[17] Although *completeness* conditional on strong exogeneity of the

[17] Although the LR statistic for the symmetry hypothesis is very large in magnitude (137.14) 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 4: Hypothesis test results for deposit rates

			Unconditional				Conditional		Joint
Rate	Time	$\mathscr{H}_{1,2}^{\delta}$	$\mathscr{H}^{\beta}$	$\mathscr{H}_1^{\alpha,\delta}$	$\mathscr{H}_2^{\alpha,\delta}$	$\mathscr{H}_2^{\alpha,\delta,\Gamma}$	$\bar{\mathscr{H}}_2^{\alpha,\delta,\Gamma}$	$\bar{\mathscr{H}}^{\beta}$	$\mathscr{H}_2^{\alpha,\delta,\Gamma} \cap \mathscr{H}^{\beta}$
FTD 3m	'83-'96	11.24	3.49	17.62***	0.01	6.19	6.34	3.62*	9.80
	'96-'07	8.97	2.87	–	7.47*	7.79	5.43	0.50	8.29
	'09-'15	137.14	3.04	8.10**	0.09	2.06	2.71	3.64	5.70
GIC 1y	'83-'96	3.89	0.28	97.54***	0.00	5.40	5.40	0.28	5.68
	'96-'07	5.46	0.69	75.81***	0.98	1.15	1.50	1.04	2.19
	'09-'15	20.69**	15.04**	–	3.90	3.90	3.07	14.22**	18.12**
GIC 3y	'83-'96	61.65***	–	–	0.53	2.27	–	–	–
	'96-'07	27.44***	0.03	97.91***	0.73	0.82	0.80	0.01	0.83
	'09-'15	1.79	–	20.17***	0.92	0.92	2.08	17.83***	18.76***
GIC 5y	'83-'96	16.56**	2.85	40.68***	1.74	3.14	4.68	4.38*	7.54
	'96-'07	10.17*	4.41*	85.28***	3.86	5.45	3.94	2.90	8.35
	'09-'15	44.08	17.54***	21.55**	1.11	1.11	0.38	16.81***	17.92***
FTD 5y	'83-'96	16.24***	–	31.22***	7.23*	7.84	–	–	–
	'96-'07	13.14**	7.60**	–	2.32	3.44	2.44	6.59**	10.04
	'09-'15	21.34*	–	–	5.42	5.42	1.85	37.34**	42.77**

Notes: This table reports the likelihood ratio test statistics for each of the hypotheses of interest in the following order: (1) $\mathscr{H}_{1,2}^{\delta}$ tests for the presence of asymmetric adjustments in the error-correction; (2) $\mathscr{H}^{\beta}$ tests for complete pass-through; (3)–(4) $\mathscr{H}_i^{\alpha,\delta}$ for $i \in \{1,2\}$ tests for weak exogeneity of the market rate and retail rate, respectively; (5) $\mathscr{H}_2^{\alpha,\delta,\Gamma}$ tests for strong exogeneity of the market rate; (6) $\bar{\mathscr{H}}_2^{\alpha,\delta,\Gamma}$ tests for strong exogeneity conditional on complete pass-through; (7) $\bar{\mathscr{H}}^{\beta}$ tests for complete pass-through conditional on strong exogeneity of the market rate; and (8) $\mathscr{H}_2^{\alpha,\delta,\Gamma} \cap \mathscr{H}^{\beta}$ tests the joint hypothesis of complete pass-through and strong exogeneity of the market rate. Results are based on 4,999 bootstrap samples. Statistical significance at the 10%, 5%, and 1% level is denoted by *, **, and ***, respectively. If the roots of the characteristic polynomial are inside the unit circle for a given hypothesis, the LR statistic is not reported.

market rate is rejected at a low level of significance in period one, the joint hypothesis test matches the result from the unconditional hypothesis, suggesting that pass-through is indeed complete. Although a similar situation arises for the 5 year GIC in the first period, the coefficient estimate of β in that case is actually greater than 1. Nevertheless, these two instances demonstrate the importance of using a flexible model that can allow for unconditional tests of *completeness*.[18] The additional joint and unconditional hypotheses can

[18]For the 3 month term deposit, *completeness* is also rejected conditional on weak exogeneity (not re-

provide more information and sometimes even lead to different conclusions than those that would be obtained from a single-equation ECM.

The rest of the rates strongly reject both *completeness* and *symmetry* in at least one period. Table 5 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 1. 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 unconditional hypothesis of *completeness* is also rejected for the 5 year GIC in period 1, but the unrestricted coefficient estimate of β is above 1 and not significantly different from 1 according to the conditional and joint hypothesis test results. The same cannot be said about the last period. For all of the deposit rates with maturities of 1 year and greater, pass-through has significantly declined since the financial crisis.

Sluggish behaviour for these deposit rates appears to be common throughout the entire sample. Even though pass-through was complete in the first two periods, several of these rates responded differently to equilibrium fluctuations based on the direction of the movement in the market rate. According to the functional form of the nonlinear adjustment shown in (4), the signs on the coefficients of ψ and δ_1 reveal the direction of the asymmetry in response to an equilibrium shock. The equilibrium relation, $\boldsymbol{\beta}'\tilde{X}_t = r_t + \beta m_t + \rho$, becomes positive when the market rate m_t decreases and negative when it increases. As a result, when $\psi > 0$, $f(\boldsymbol{\beta}'\tilde{X}_{t-1};\psi) \to 1$ as m_t declines and $f(\boldsymbol{\beta}'\tilde{X}_{t-1};\psi) \to 0$ 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 ψ and

ported).

Table 5: Coefficient estimates for deposit rates

Rate	Time	β	ρ	α_1	α_2	δ_1	δ_2	ψ
FTD 3m	'83-'96	−1.000	2.333	−0.037	0.000			
	'96-'07	−1.000	1.757	−0.041	0.000			
	'09-'15	−1.000	0.398	−0.042	0.000			
GIC 1y	'83-'96	−1.000	1.019	−0.173	0.000			
	'96-'07	−1.000	1.344	−0.156	0.000			
	'09-'15	−0.599	−0.687	−1.811	0.000	1.785	0.000	51.459
GIC 3y	'83-'96	−1.058	1.702	−0.019	0.000	−0.930	0.000	135.063
	'96-'07	−1.000	0.863	−0.558	0.000	0.487	0.000	351.102
	'09-'15	−0.287	−0.857	−0.122	0.000			
GIC 5y	'83-'96	−1.000	0.670	−0.022	0.000	−0.323	0.000	11043.313
	'96-'07	−1.000	0.740	−0.277	0.000	0.195	0.000	6.761
	'09-'15	−0.275	−1.289	−0.113	0.000			
FTD 5y	'83-'96	−1.398	3.522	−0.451	0.000	0.442	0.000	43.032
	'96-'07	−1.081	1.299	−0.261	0.000	0.173	0.000	9.647
	'09-'15	−0.202	−1.398	−0.484	0.000	0.470	0.000	12.022

Notes: This table reports the coefficient estimates from the final restricted models: β and ρ are the coefficients for pass-through and markup presented in (2); α_i and δ_i are the linear and nonlinear adjustment coefficients, respectively, presented in (3) — subscript 1 is for the retail rate and 2 is for the market rate — and ψ is the parameter determining the behaviour of the logistic function in (4).

δ_1 have opposite signs, then the dynamic is reversed and the adjustment asymmetry favours the consumer.[19]

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

$$f(-1; 135.063) = [1 + \exp(135.063(-1))]^{-1} \approx 1.$$

[19]Note that if α_i and δ_i have the opposite sign then δ_i must be smaller in magnitude than α_i for variable i to adjust toward equilibrium following a shock. Otherwise, it may diverge.

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

$$[\hat{\alpha}_1 + \hat{\delta}_1 f(\boldsymbol{\beta}' \tilde{X}_t; \hat{\psi})]\hat{\boldsymbol{\beta}}' \tilde{X}_t = (-0.019 - 0.930)(-1) = 0.949.$$

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

$$[\hat{\alpha}_1 + \hat{\delta}_1 f(\hat{\boldsymbol{\beta}}' \tilde{X}_t; \hat{\psi})]\hat{\boldsymbol{\beta}}' \tilde{X}_t = (-0.019)(1) = -0.019.$$

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 periods 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 and the 1 year GIC began exhibiting downward rigidity following the financial crisis. 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. 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.

In 2005, the Canadian Deposit Insurance Corporation raised the limit on insurable deposits from \$60,000 to \$100,000.[20] This change made retail deposits more popular and could have increased banks' market power as a result. To explore whether this change had an

[20] The change was passed in Part 15 of the 2005 Federal Budget as an ammendment to pragraph 12(c) of the Canadian Deposit Insurance Act (for details see http://laws-lois.justice.gc.ca/eng/annualstatutes/2005_30/page-26.html).

impact on the observed upward rigidity in deposit rates in the second period, I repeat the analysis with the period ending at the end of 2004. The conclusions from the hypothesis as well as the parameter estimates are very similar to those obtained from the full subsample.[21] This suggests that the change in the deposit insurance limit was not a major factor in the presence of rigidities.

In the period following the financial crisis, deposit rates became substantially more sluggish. However, even though a decline in pass-through is most often associated with banks exploiting their pricing power for higher profits, the coefficient estimates in the last period suggest a different dynamic. Using the mean values for the market rate from Table 1, the markups, approximated by $\rho - (1 - \beta)\bar{m}$, for the 1, 2, and 3 year GIC and 5 year fixed term deposit are -0.302, 0.113, 0.016, and 0.038, respectively. These markups are very low relative to the other time periods and even negative in the case of the 1 year GIC. As a result, it is likely that the sluggish behaviour is driven by a response to funding uncertainty as described by Ritz and Walther (2015).

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 1 year GIC and 5 year fixed term, however, even though pass-through is incomplete, upward rigidity appears to dominate the adjustment process.

4.2 Mortgage rates

Turning to the loan side of the market, this section considers mortgage rates. Before discussing the results, I first provide some relevant historical context. In the 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

[21] The results are not reported but available upon request.

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 percent, the discounting in the early part of the second period poses some potential problems for estimation.

Since the data contain 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 2. 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 2).

Table 6 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 exogenous for almost all maturities and time periods. For the 1 year mortgage, even though weak exogeneity is rejected for the market rate, strong exogeneity is not rejected and therefore imposed. However, the conditional hypothesis test for completeness yields the same result as the unconditional one. For the 5 year mortgage rate, the retail rate fails to reject weak exogeneity. However, this hypothesis is rejected conditional on complete pass-through and therefore not imposed.[22]

In contrast to deposit rates, mortgage rates had complete pass-through before the crisis and have maintained it since the end of the recession. Moreover, the 1 year mortgage rate was the only rate to exhibit incomplete pass-through in the earliest period. This product saw a large level of activity in the first period, but as inflation and interest rates fell in the

[22]The test statistics for the hypothesis $\mathscr{H}_1^{\alpha,\delta} \cap \mathscr{H}^{\beta} | \mathscr{H}^{\beta}$ are omitted from the result tables, but are available upon request.

Table 6: Hypothesis test results for mortgage rates

Rate	Time	$\mathscr{H}_{1,2}^{\delta}$	Unconditional $\mathscr{H}^{\beta}$	$\mathscr{H}_1^{\alpha,\delta}$	$\mathscr{H}_2^{\alpha,\delta}$	$\mathscr{H}_2^{\alpha,\delta,\Gamma}$	Conditional $\bar{\mathscr{H}}_2^{\alpha,\delta,\Gamma}$	$\bar{\mathscr{H}}^{\beta}$	Joint $\mathscr{H}_2^{\alpha,\delta,\Gamma} \cap \mathscr{H}^{\beta}$
MR 1y	'83-'96	43.65***	48.70***	–	8.52**	8.53	2.52	42.70***	51.23***
	'96-'07	9.82	0.06	10.91**	0.04	0.61	0.57	0.03	0.63
	'00-'07	8.94*	0.17	33.73***	0.07	0.11	0.14	0.20	0.31
	'09-'15	5.09	0.45	7.20**	2.96	2.96	2.54	0.03	2.99
MR 3y	'83-'96	34.27***	0.03	78.45***	0.54	0.76	0.75	0.02	0.78
	'96-'07	4.79	3.95	18.05***	1.25	1.34	0.10	2.71	4.05
	'00-'07	2.16	0.24	21.85***	0.02	1.53	1.51	0.22	1.75
	'09-'15	35.94***	4.44	53.60**	1.20	1.20	0.88	4.13	5.33
MR 5y	'83-'96	15.27***	0.46	39.43***	0.26	0.38	0.35	0.43	0.81
	'96-'07	6.03	0.06	2.52	0.11	4.60	5.32	0.78	5.38
	'00-'07	1.15	0.01	34.90***	0.43	1.89	1.91	0.03	1.92
	'09-'15	61.71***	17.93**	–	0.27	0.27	0.19	17.59**	18.12*

Notes: This table reports the likelihood ratio test statistics for each of the hypotheses of interest in the following order: (1) $\mathscr{H}_{1,2}^{\delta}$ tests for the presence of asymmetric adjustments in the error-correction; (2) $\mathscr{H}^{\beta}$ tests for complete pass-through; (3)–(4) $\mathscr{H}_i^{\alpha,\delta}$ for $i \in \{1,2\}$ tests for weak exogeneity of the market rate and retail rate, respectively; (5) $\mathscr{H}_2^{\alpha,\delta,\Gamma}$ tests for strong exogeneity of the market rate; (6) $\bar{\mathscr{H}}_2^{\alpha,\delta,\Gamma}$ tests for strong exogeneity conditional on complete pass-through; (7) $\bar{\mathscr{H}}^{\beta}$ tests for complete pass-through conditional on strong exogeneity of the market rate; and (8) $\mathscr{H}_2^{\alpha,\delta,\Gamma} \cap \mathscr{H}^{\beta}$ tests the joint hypothesis of complete pass-through and strong exogeneity of the market rate. Results are based on 4,999 bootstrap samples. Statistical significance at the 10%, 5%, and 1% level is denoted by *, **, and ***, respectively. If the roots of the characteristic polynomial are inside the unit circle for a given hypothesis, the LR statistic is not reported.

mid 1990s the longer term mortgages gained more popularity (Clinton and Howard, 1994). Thus, the finding of incomplete pass-through 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 the earliest period. Likewise, the 3 and 5 year mortgage rates exhibit asymmetric adjustments in the earliest period. The sign on the impact coefficient is negative implying that rates responded more strongly to market rate increases than decreases. This downward rigidity 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

Table 7: Coefficient estimates for mortgage rates

Rate	Time	β	ρ	α_1	α_2	δ_1	δ_2	ψ
MR 1y	'83-'96	−0.815	−2.073	−0.045	0.000	−0.621	0.000	592.827
	'96-'07	−1.000	−1.909	−0.043	0.000			
	'00-'07	−1.000	−2.286	−0.557	0.000	0.508	0.000	113.473
	'09-'15	−1.000	−2.127	−0.015	0.000			
MR 3y	'83-'96	−1.000	−1.122	−0.035	0.000	−0.500	0.000	247.241
	'96-'07	−1.000	−2.116	−0.047	0.000			
	'00-'07	−1.000	−2.333	−0.127	0.000			
	'09-'15	−1.000	−2.310	−0.027	0.000	−0.548	0.000	65.381
MR 5y	'83-'96	−1.000	−1.371	−0.028	0.000	−0.318	0.000	11027.140
	'96-'07	−1.000	−2.300	−0.028	0.000			
	'00-'07	−1.000	−2.442	−0.204	0.000			
	'09-'15	−1.547	−1.288	−0.005	0.000	−0.786	0.000	29.326

Notes: This table reports the coefficient estimates from the final restricted models: β and ρ are the coefficients for pass-through and markup presented in (2); α_i and δ_i are the linear and nonlinear adjustment coefficients, respectively, presented in (3) — subscript 1 is for the retail rate and 2 is for the market rate — and ψ is the parameter determining the behaviour of the logistic function in (4).

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.

In the middle period, there is only one case where the conclusions differ for the shorter stable subsample 2000–2007. Although *completeness* is not rejected in both subsamples for the 1 year mortgage, *symmetry* is rejected in the shorter subsample. Interestingly, the adjustment process exhibits upward rigidity. This could be either due to asymmetric information and the banks' reluctance to increase rates for fear of attracting riskier projects, or competitive behaviour aimed to attract more consumers. Since the other mortgage rates adjust symmetrically in this period, the latter explanation is more likely.

Although pass-through is complete for all rates in the final period, downward rigidity

Table 8: Rank test results with interest rate swaps as proxy for bank funding costs

	1996 − 2007			2000 − 2007			2009 − 2015		
Variables	k	$r = 0$	$r = 1$	k	$r = 0$	$r = 1$	k	$r = 0$	$r = 1$
MR 1y, TB 1y				1	44.58***	4.72	0	13.02	1.37
MR 3y, GB 3y	2	24.46*	7.25	1	51.23***	8.02*	0	24.26*	1.93
MR 5y, GB 5y	2	22.34*	8.11*	1	72.29***	6.99	0	21.95*	2.53

Note: LR statistics are reported against the alternative of full rank, $r = 2$. Statistical significance at the 10%, 5% and 1% level is denoted by *, **, and ***, respectively.

reappears in the 3 and 5 year mortgage rates. Therefore, the adjustment of mortgage rates has also become more sluggish since the financial crisis but, unlike the deposit rates, we can expect them to fully adjust in the long run to movements in the market rates.

5 Robustness

In this section I consider alternative interest rates as proxies for banks' cost of funding in the decision to set mortgage rates. Since banks face a maturity mismatch between these assets and their mostly short-term liabilities (deposits), they may want to hedge their positions by exchanging the cash-flow from a fixed rate contract (mortgage) to one based on a floating rate, *i.e.* by entering a swap agreement.[23] Therefore, I re-estimate the models matching each of the mortgage rates with the same maturity swap rate which converts the fixed rate into a floating 3 month rate.[24] Since data is not available for the full first period, I focus only on the two most recent periods.[25] The spreads are shown in Figure 3 and the estimation results are in Tables 8–10.

In general, the rank test results, shown in Table 8, and hypothesis test results, shown in Table 9, are very similar to what was found in the main analysis in Section 4. Once again the weak exogeneity of the retail rate is rejected for all rates and time periods.[26] Meanwhile, the

[23]Note that this balance sheet risk is not present for long-term deposit rates and as a result matching maturity government bonds or treasury bills are appropriate proxies for the opportunity cost of these products.

[24]Data is obtained from Datastream, series codes: S93116, S06551, and S06553.

[25]Additionally, there are missing values for the 1 year swap spread for 9/15/1999–3/5/2000. As a result, for this rate, I only report estimates for the smaller subperiod 12/2000–7/2007 and the final period.

[26]For the 5 year mortgage in 1996–2007, the weak exogeneity is not rejected, but the P-value is 0.107. In addition, the hypothesis of weak exogeneity conditional on complete pass-through (not reported) is strongly

Table 9: Hypothesis test results for mortgage rates with swaps

			Unconditional				Conditional		Joint
Term	Time	$\mathscr{H}_{1,2}^{\delta}$	$\mathscr{H}^{\beta}$	$\mathscr{H}_1^{\alpha,\delta}$	$\mathscr{H}_2^{\alpha,\delta}$	$\mathscr{H}_2^{\alpha,\delta,\Gamma}$	$\bar{\mathscr{H}}_2^{\alpha,\delta,\Gamma}$	$\bar{\mathscr{H}}^{\beta}$	$\mathscr{H}_2^{\alpha,\delta,\Gamma} \cap \mathscr{H}^{\beta}$
MR 1	'00-'07	5.78	2.67	32.43***	0.03	0.03	0.58	3.21*	3.25
	'09-'15	7.86	0.50	5.81*	3.90	3.90	3.40*	0.00	3.90
MR 3	'96-'07	5.87	2.79	9.94*	2.37	2.98	0.85	0.65	3.63
	'00-'07	10.90**	1.41	32.22***	0.36	0.43	0.67	1.52	2.08
	'09-'15	15.05	0.36	17.19***	1.41	1.41	1.12	0.07	1.48
MR 5	'96-'07	3.19	2.71	6.06	1.58	1.80	0.30	1.16	2.96
	'00-'07	0.75	0.01	50.48***	0.03	0.03	0.03	0.00	0.03
	'09-'15	67.37***	–	85.60***	–	–	–	–	–

Notes: This table reports the likelihood ratio test statistics for each of the hypotheses of interest in the following order: (1) $\mathscr{H}_{1,2}^{\delta}$ tests for the presence of asymmetric adjustments in the error-correction; (2) $\mathscr{H}^{\beta}$ tests for complete pass-through; (3)–(4) $\mathscr{H}_i^{\alpha,\delta}$ for $i \in \{1,2\}$ tests for weak exogeneity of the market rate and retail rate, respectively; (5) $\mathscr{H}_2^{\alpha,\delta,\Gamma}$ tests for strong exogeneity of the market rate; (6) $\bar{\mathscr{H}}_2^{\alpha,\delta,\Gamma}$ tests for strong exogeneity conditional on complete pass-through; (7) $\bar{\mathscr{H}}^{\beta}$ tests for complete pass-through conditional on strong exogeneity of the market rate; and (8) $\mathscr{H}_2^{\alpha,\delta,\Gamma} \cap \mathscr{H}^{\beta}$ tests the joint hypothesis of complete pass-through and strong exogeneity of the market rate. Results are based on 4,999 bootstrap samples. Statistical significance at the 10%, 5%, and 1% level is denoted by *, **, and ***, respectively. If the roots of the characteristic polynomial are inside the unit circle for a given hypothesis, the LR statistic is not reported.

market rate is strongly exogenous for all rates and time periods with the exception of the 5 year mortgage rate in the last period. With the same exception, pass-through is also complete for all rates and time periods. Although *completeness* and strong exogeneity are rejected conditionally for the 1 year mortgage separately in two different periods, the unconditional and joint hypothesis test results suggest that these restrictions should be imposed. The most striking differences are for the results on the *symmetry* hypothesis. The 1 year mortgage adjusts symmetrically in both periods and the 3 year mortgage rate adjusts symmetrically in the last period but not in 2000–2007.

Table 10 contains the coefficient estimates for the restricted models and reveals the direction of the asymmetry. The 3 year mortgage rate exhibits upward rigidity in 2000–2007. As mentioned in Section 4.2, since this asymmetry is not present in all of the rates,

rejected.

Table 10: Coefficient estimates for mortgage rates with swaps

Rate	Time	β	ρ	α_1	α_2	δ_1	δ_2	ψ
MR 1y	'00-'07	−1.000	−1.977	−0.128	0.000			
	'09-'15	−1.000	−1.864	−0.012	0.000			
MR 3y	'96-'07	−1.000	−1.931	−0.041	0.000			
	'00-'07	−1.000	−2.285	−0.489	0.000	0.406	0.000	2339.855
	'09-'15	−1.000	−2.289	−0.057	0.000			
MR 5y	'96-'07	−1.000	−1.981	−0.033	0.000			
	'00-'07	−1.000	−2.186	−0.253	0.000			
	'09-'15	−1.407	−1.354	−0.007	0.001	−2.057	−0.278	165.865

Notes: This table reports the coefficient estimates from the final restricted models: β and ρ are the coefficients for pass-through and markup presented in (2); α_i and δ_i are the linear and nonlinear adjustment coefficients, respectively, presented in (3) — subscript 1 is for the retail rate and 2 is for the market rate — and ψ is the parameter determining the behaviour of the logistic function in (4).

it is likely driven by competitive pricing behaviour as opposed to aversion to riskier loans that become more prevalent when rates increase. In the last period, the 3 year mortgage rate adjusts symmetrically although the likelihood-ratio test statistic for this hypothesis is large and the unrestricted coefficient estimate is $\hat{\delta}_1 = -0.408$, suggesting downward rigidity. Nevertheless, although the evidence for downward rigidity in the 3 year mortgage rate in the last period is weaker when using the swap rate as the relevant market rate, there is evidence of a switch in asymmetry suggesting less competitive pricing behaviour.

Since the majority of the hypotheses for the 5 year mortgage in the last period are rejected because of explosive roots, the coefficient estimates are left unrestricted. Although *completeness* is rejected, the pass-through coefficient is greater than 1, suggesting that it is indeed complete. Moreover, the sign on the impact coefficient is negative, which implies that the mortgage rate responds more quickly to a rate rise than a rate fall.

Despite the different proxy for banks' cost of funding, the coefficient estimates are very similar to the ones in Table 7. The estimates of the mark-up are lower with the swap rates, which is due to the fact that the swap spreads are positive on average, but pass-through is complete for all rates and time periods. The downward rigidity found in the 5 year mortgage rate in Section 4.2 is robust to this different specification, but the conclusions on the adjustments of the 1 and 3 year mortgage rates are not. Upward rigidity for the 1 year rate mortgage in 2000–2007 and downward rigidity for the 3 yearrate mortgage in the last period are no longer significant. Meanwhile the 3 year mortgage rate adjusts more quickly for a swap rate decline than for a rate increase in 2000–2007.

6 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. Furthermore, the empirical model used for estimation and inference encompasses commonly used models in the IRPT literature. The nonlinear VECM estimates the long-run equilibrium pass-through equation while accounting for short-run dynamics and asymmetric adjustments. In addition, the model allows for explicit testing of commonly made assumptions of exogeneity and reveals that the conclusions based on tests conditional on these assumptions can differ from those based on unconditional tests.

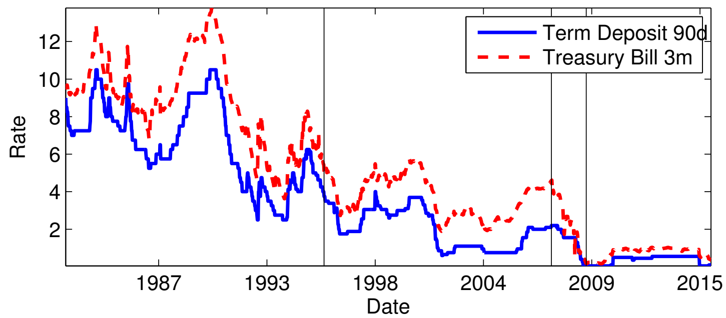
The results identify incomplete pass-through and asymmetric adjustment for various loan and deposit rates in different time periods. In the period 1983–1996, before the Bank of Canada set the Bank Rate to the upper bound of the corridor for managing the overnight rate, pass-through was incomplete only 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 and the 1 year mortgage (or the 3 year mortgage when swap rates are used). Finally, in the most recent period 2009–2015, pass-through has significantly declined for longer term deposits and asymmetric adjustment has reappeared for mortgage rates — although the presence of downward rigidity is only robust for the 5 year mortgage rate.

These results 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.

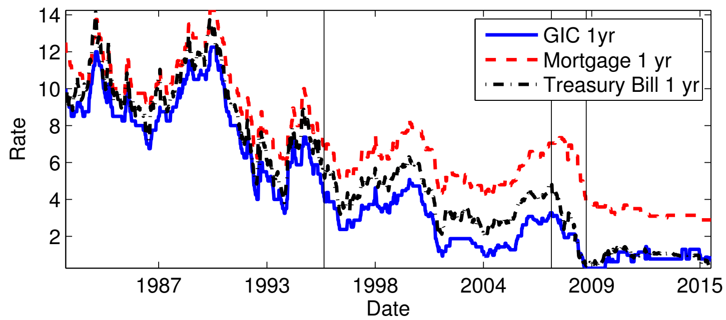
In contrast to the US and Europe, the pass-through from market to retail loan rates in Canada was resilient to the financial crisis. However, the presence of asymmetries and the decline in pass-through to deposit rates suggest that overall the transmission between money market rates and retail loan and deposit rates has weakened. The decline in pass-through is consistent with the effects of increased competitiveness in the face of funding uncertainty (Ritz and Walther, 2015) and could be exacerbated by regulatory pressures. Thus, disentangling these channels as well as extending the analysis to other countries are natural next steps for future research.

Figure 1: Interest rates 1983–2015

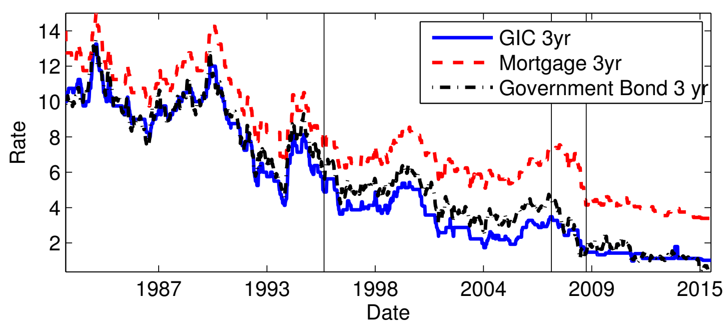
(a) 3 month maturity



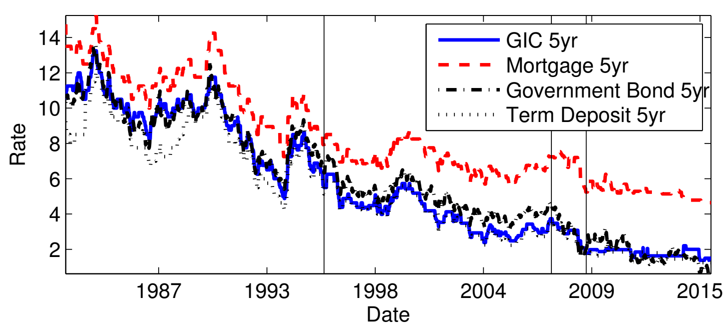
(b) 1 year maturity



(c) 3 year maturity

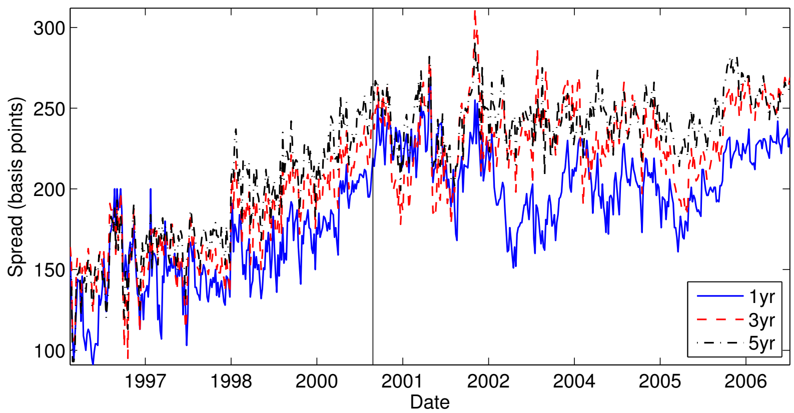


(d) 5 year maturity



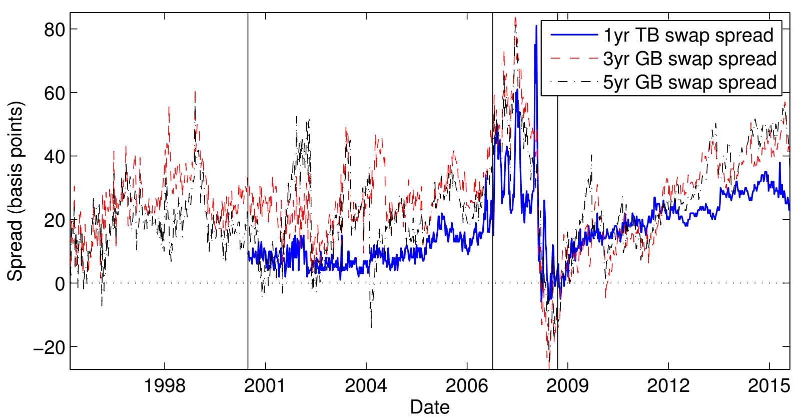
Notes: Vertical black lines indicate subsample breakpoints. Source: CANSIM Table 176-0078.

Figure 2: Mortgage rate spreads in 1996-2007



Note: Mortgage rate spread is the difference between the mortgage rate and the matching maturity government bond. The vertical black line indicates the subsample breakpoint. Source: CANSIM Table 176-0078.

Figure 3: Spreads of 3 month swaps over matching maturity market rates in 1996-2015



Note: Vertical black lines indicate subsample breakpoints. Source: Datastream.

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